Rudolf Avenhaus
Nicholas Kyriakopoulos
Michel Richard
Gotthard Stein
Editors

Verifying Treaty Compliance

Limiting Weapons of Mass Destruction and Monitoring Kyoto Protocol Provisions

Springer

Verifying Treaty Compliance

Rudolf Avenhaus
Nicholas Kyriakopoulos
Michel Richard
Gotthard Stein
(Editors)

Verifying Treaty Compliance

Limiting Weapons of Mass Destruction and Monitoring Kyoto Protocol Provisions

Springer

Professor Dr. Rudolf Avenhaus
Universität der Bundeswehr München
85577 Neubiberg
Germany
rudolf.avenhaus@unibw.de

Professor Dr. Nicholas Kyriakopoulos
The George Washington University
Washington, DC 20052
USA
kyriak@gwu.edu

Dr. Michel Richard
Commissariat à l'Energie Atomique
Direction des Applications Militaires
Direction Matières Surveillance, Environnement
Centre d'Île de France Bruyères, le Châtel, 91680
France
michel.richard@cea.fr

Dr. Gotthard Stein
Forschungszentrum Jülich
Programmgruppe Systemforschung
und Technologische Entwicklung (STE)
52425 Jülich
Germany
g.stein@fz-juelich.de

ISBN-10 3-540-33853-5 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-33853-6 Springer Berlin Heidelberg New York

Cataloging-in-Publication Data
Library of Congress Control Number: 2006925525

Springer is a part of Springer Science+Business Media

springeronline.com

Printed in Germany

Hardcover-Design: Erich Kirchner, Heidelberg

SPIN 11745808 64/3153-5 4 3 2 1 0 – Printed on acid-free paper

Preface

Verifying the compliance of states with treaties may sound dry and dreary. However, when it is about respect for pledges that states have given not to acquire lethal weapons or not to emit more than limited quantities of greenhouse gases the voltage in the circuit may be quite high.

The experiences I had at the United Nations of verification and inspection before the Iraq war (2003) and during sixteen years as the Director General of the International Atomic Energy Agency were anything but dreary. I lived some of the problems and possibilities, which are so well described and analyzed by the writers of this most welcome volume. For instance:

- the reluctance of states to accept inspection that is sufficiently far-reaching to give high level confidence;
- the impossibility of proving the negative and the inevitability of some residue of uncertainty;
- the effectiveness and cost of verification;
- the new techniques and equipment that continuously become available.

I concur wholeheartedly with many of the findings in this book, in particular that monitoring, verification and inspection must remain technical, professional and independent of individual governments. The experience of the Iraq war started in 2003 shows the danger of governments relying on and presenting faith based evidence. I said at that time of our UN inspection team: "We may not be the brightest in the world, but we are professional and we are in nobody's pocket." This is vital both for states accepting inspection and for the inspection results to be given credibility.

International verification does not preclude that government conduct their own verification, whether by electronic and satellite surveillance or other means. However, if they do so, they should weigh all the evidence they obtain, whether it comes from their own means or through the independent international inspection. They have some means of verification which international authorities do not have. On the other hand, international inspectors have direct and legal access to installations, documents and people, which governments are unlikely to have.

Governments would do well to assist international inspection authorities by transmitting to them information that may be helpful. Yet, such cooperation must remain largely a one way traffic. International inspection must never function as remote controlled instruments of national intelligence or else they will lose the respect and credibility they have.

If international factual verification of compliance with treaties is a rather new and difficult activity, the next step - reaching conclusions and determination of what is to be done - is even more difficult. In the field of trade, governments have handed considerable power to an impartial judicial institution within the World Trade Organization to examine the factual dossier of each case submitted to it and to judge on compliance with treaty obligations. It may even decide whether economic measures of retaliation are permitted in cases of non-compliance. While this marks a desirable step towards an effective rule based system the permission of retaliation is a primitive form of sanctions. It is evidently not a model for the enforcement of, say, restrictions in the emission of greenhouse gases.

The councils and boards to which verification reports in the sphere of arms control are submitted - for instance, the UN Security Council or the IAEA Board of Governors - are no judicial institutions. They consist of states, which judge in matters in which they, themselves, are interested parties and stakeholders. In the field of security governments will not easily step back from these prerogatives. This is all the more reason that they should have before themselves reports which are the results of independent professional verification.

This book rightly starts from the premise that multilateral treaties on arms control and global environmental issues will remain vital to lay down agreed standards and that effective verification of compliance will promote faithful implementation. The authors bring a wealth of experience and their analysis is rigorous. They show that the subject of verification is a central and dynamic discipline and they make very substantial contributions to its development.

Hans Blix

Foreword

The risks posed by the spread of sensitive technologies that can be used to produce weapons of mass destruction have increased dramatically in recent years. The 21^{st} century has ushered geopolitical transformation, socio-economic movements and environmental change on an global scale. The bipolar, East-West world of the last century exists no more; old political alliances are drifting; new coalitions are forming; and the global war on terrorism creates new divides. Political turmoil and conflict in the post September 11, 2001 era have led to a growing realization that nuclear, chemical and biological weapons may now be obtained clandestinely by non-state actors, sub-national groups or terrorists who, in a fluid and rapidly changing environment of globalisation, could use them to destroy people or blackmail their leaders. International efforts necessary to inhibit the spread of weapons of mass destruction, and to eliminate them as far as possible, face challenges of extraordinary complexity.

International treaties and conventions requiring binding commitments on the part of the member states and establishing appropriate compliance verification regimes constitute a primary assurance against such risks. For instance, the Treaty on the Non-proliferation of Nuclear Weapons (NPT) with its safeguards system, applied by the International Atomic Energy Agency (IAEA) on nuclear materials and facilities on the territories of the member states, represents the cornerstone in the nuclear field, gives assurance about the peaceful nature of the nuclear activities and aims to prevent nuclear proliferation. The NPT, with its long history and positive experience since 1968, has become a model, and its elements have influenced other fields where proliferation concerns exist, such as the biological and chemical industries. In the environmental field, the Kyoto Protocol represents the major international effort to reduce the emissions of greenhouse gases.

From a technical perspective, verification of compliance requires not only the use of a broad range of technologies, but also the development of new and creative methodologies for integrating them into comprehensive systems taking into account related factors such as delivery systems for weapons of mass destruction and black market networks. Another factor that needs to be considered is the impact of globalization on the development of verification methodologies. The global scale of commercial activities affects the amount and quality of information that needs to be processed and evaluated. The increased processing needs demand more complex information processing systems. At the same time, in the interest of efficiency and cost-effectiveness, synergies need to be found among verification technologies and methodologies that have been developed for different treaties as, for example, special on-site inspections, protection of sensitive information in connection with attribute measurements, satellite imagery, forensics, etc.

A wide range of issues dealing with technologies and methodologies have been addressed in depth by the Working Group on Verification Technologies and Methodologies of the European Safeguards Research and Development Association (ESARDA). This organization has been engaged since 1978 in further developing and improving the safeguards system for nuclear materials and facilities, especially in connection with the Treaty establishing the European Atomic Energy Community and implementing its safeguards system. Out of this unique experience of international scientific collaboration grew the realization that the knowledge gained in the study of nuclear safeguards issues is transferable to other fields and endeavors involving international agreements.

The experience gained by the IAEA from research and development in the nuclear verification arena gives rise to great optimism. In a growing number of different IAEA member states research networks are being established. This is due to the new dynamics caused by the expanded task of the IAEA to detect undeclared nuclear materials and activities. From this, many new initiatives have emerged.

Of extreme importance, however, is the need to generate interest in the academic community to perform structured and coordinated research in the field of compliance verification, with the emphasis on interdisciplinary cooperation. This approach of involving different disciplines, ranging from political science to mathematical game theory, is inherently imbedded in this book and can be followed throughout the various contributions. The philosophy, contents and organization of the book are described in detail in the introductory chapter. It is hoped that the approach taken in this book can lead toward the establishment of a specialized discipline in compliance verification. A major challenge in reaching that goal is the difficulty of finding the appropriate balance between generality and detail in the discussion and analysis of problems in areas of scientific controversy.

The Editors

Acknowledgement

The editors wish to express their appreciation to the European Safeguards Research and Development Association (ESARDA) for providing a forum where topics related to the main theme of this book were presented and discussed. Presentations by the contributors to this volume and many other knowledgeable experts took place during a number of meetings of the Working Group on Verification Technologies and Methodologies over a two-year period. These presentations gave rise to lively discussions within the working group, which helped crystallize the unifying theme of the book. The editors also wish to thank the German government for providing partial support for this project.

Contents

VIII Perspectives and Conclusions

Introduction

Rudolf Avenhaus, Nicholas Kyriakopoulos,
Michel Richard, Gotthard Stein

One could be forgiven for questioning the utility of yet another book on arms control treaties. During the past decade there has been a proliferation of problems in the field of arms control and disarmament. These include clandestine weapons programs - Iraq is a glaring example, delays in the destruction of chemical weapons stockpiles, increase in the number of nuclear-weapon States, questionable practices about obligations of States to comply with treaty obligations and efforts to break the moratorium on nuclear weapons testing. These problems have re-enforced the arguments of those who, as a matter of dogma, question the benefits of multilateral treaties. As a result, the negotiations in the Committee on Disarmament on the Biological Weapons Convention have stalled on the crucial topic of verification. The spillover effect of such skepticism on other multilateral treaties such as the Kyoto Protocol of the United Nations Framework on Climate Change is evident in the refusal of the United States to ratify it. At the same time, the benefits of multilateral treaties seem self-evident to the advocates of multilateralism. In the debates between the two camps, the latter group has an inherent disadvantage. While the skeptics can point to specific failures of the multilateral framework, the proponents cannot use a counterfactual argument to identify specific successes. Arguments along the line "things would be worse, if treaty X were not in place" would not be convincing to those who approach these issues with an open mind. Even if one were to point to specific cases of abandonment of weapons programs, such as the nuclear program in South Africa, it would be difficult to attribute these positive developments solely to the implementation of a treaty.

Trying to resolve these arguments from a political perspective would immediately lead to a conundrum. Considering the welfare of the citizen as the end objective, one side believes that it is best advanced by ensuring the supremacy of the nation State, while the other by advancing the welfare of the global citizen. These philosophical arguments, although interesting, lead to interminable and inconclusive debates particularly when they involve treaties on arms control and on the environment. Regardless where one's personal beliefs lie, the reality is that treaties exist, others are being negotiated and negotiations on new ones will inevitably start. Taking as a starting point the interest of both philosophical positions to advance the welfare of the citizen, the question is how to do it within the framework of multilateral treaties. To frame the question another way, what role should treaties, such as arms control and environmental, play in the framework of national policies by the States? At one extreme of the philosophical debate, that role should be minimal, while at the other it should be essential. A more realistic answer would place it somewhere between these two extremes. The problem then becomes one of finding the golden mean. To move past the philosophical debates, one needs, first, to identify the major issues over which the arguments revolve and then develop a mechanism for addressing them using as a reference point the only common ground between the two extremes, namely, the welfare of the citizen.

The arguments are advanced along two broad paths. One is that in the implementation of existing treaties the objectives have not been attained. A commonly advanced argument is that "States have cheated, or will cheat; they have not been caught, or, when caught, have not been punished." Ergo, "what good is a treaty that does not live up to its expectations?" This line of arguments is best exemplified by the "failure" of the safeguards system of the International Atomic Energy Agency to detect the clandestine nuclear weapons program in Iraq. Even worse, by the failure of the international community to react to the clear violation of the Geneva Protocol for the Prohibition of Use of Chemical Weapons, by Iraq against the Kurds and during the Iran-Iraq war. The second line invokes the futility argument. It can be framed as "past experience has shown that it is difficult, if not impossible to design a verification system that will detect cheating; therefore, what's the point of concluding treaties knowing that cheaters can violate them with impunity?" The difficulties in developing such a system have stalled progress in the Biological Weapons Convention negotiations.

One recognizes that treaties are products of negotiations and compromises and are reached through consensus. While this process is unavoidable, it also saws the seeds of serious difficulties during implementation, particularly for treaties requiring monitoring and verification for the purpose of ensuring compliance or detecting non-compliance. In the Chemical Weapons Convention one finds language such as "shall review compliance with [the] Convention." (Art. VIII, A, 20), "shall promote compliance with [the] Convention." (VIII, A. 31) and "obtain clarificationon any situation whichgives rise to a concern about its possible non-compliance with [the] Convention." (IX, 4). The Convention also establishes the Organization for the Prohibition of Chemical Weapons to ensure, inter alia, "international verification of compliance" (VIII, 1). The verification regime uses routine inspections to verify declarations by the States and challenge inspections to address concerns about compliance raised by one or more States. Questions about the effectiveness of the verification regime have already been raised and serious doubts exist whether the tool of challenge inspections would be used. The doubts are based on the rationale of quid pro quo. If one State requests a challenge inspection in another State, what is it to prevent the second State, or one of its allies, from doing same to the first State, particularly when the decisions on challenge inspections are taken by majority voting? In this case, the stability of entire treaty system would be at stake unless a mechanism could be found to prevent abuse. Careful reading of other arms control treaties would reveal similar potential problems. Of course, negotiators try to learn from past experience. Although one would hope that these lessons would improve the negotiated treaties, sometimes, they slow down progress as in the case of the Biological Weapons Convention. We believe that the experience gained over the past half century in negotiating and implementing multilateral arms control treaties if properly exploited can contribute toward the development of more effective treaties. Furthermore, the lessons learned from arms control treaties can also be applied to other equally, or perhaps more, important treaties such as environmental. This book is written with the modest goal of contributing to that pool of knowledge.

A new perspective

Traditionally, the scientific and engineering communities have played a supporting role in the negotiations for the various arms control treaties. The dominant forces during the negotiations are political, military and economic interests. In addition to the military and intelligence communities, the private sector is frequently involved in establishing negotiating boundaries. The Chemical Manufacturer's Association played a decisive role in formulating the inspection regime for the Chemical Weapons Convention. Similarly, the pharmaceutical industry has played an important role in the Biological Weapons Convention. As a result, the monitoring systems specified in treaties are based on compromises balancing the need to collect data for verifying compliance with the need to protect proprietary information be it national security or business. An additional important factor is cost. Even if there would be no other objections to collecting the necessary information, the cost of doing so might be so high, that States would be unwilling to bear it. It is left to the scientists and engineers to implement verification systems imperfect as they may be. It follows that verification regimes based on such compromises provide insufficient information upon which decisions about compliance are made. As a result, there is inherent uncertainty in the making of decisions about compliance.

Uncertainty notwithstanding people would argue that, at some point, a decision needs to be made whether a particular action or sequence of actions by a State constitute non-compliance. In reality, the decision would be the likelihood of non-compliance. One then is faced with the problem of establishing a threshold for detecting non-compliance. An additional complication is the fact that in most treaties the obligations of the States may not be of equal importance. Submission of complete and accurate declarations at specified times is an obligation as is the non-production of a chemical weapon. Violation of either obligation would legally be classified as non-compliance, but the two violations would have vastly unequal significance. Obviously, there are categories of non-compliance depending on the ranking of obligations according to their significance. Critical reading of the various treaties will reveal many issues that involve uncertainties and require trade-offs. Some of these are caused by the structure and contents of the treaties while others involve the instruments of implementation.

The question then arises what needs to be done to improve the performance of multilateral treaties that involve monitoring, verification and provide for penalties in cases of non-compliance. In order to gain a better understanding of the issues involved in establishing non-compliance, we have viewed the subject from the perspective that a treaty is a complex system that involves specified processes, inputs, outputs and feedback. This perspective allows one to apply scientific methods and perform systematic analysis, draw conclusions and formulate recommendations for optimizing the structure, contents and implementation of a treaty. Viewing treaties as systems has two major advantages. For existing treaties it provides an objective mechanism for evaluating their performance with respect to the articulated obligations of the States and can be used to identify improvements in their operation. For treaties under negotiation system models are useful for evaluating proposed positions, verification regimes, monitoring systems and for analyzing the impact and effectiveness of sanctions.

The experience gained from the operations of existing treaties provides a good starting point. What were the treaties expected to accomplish? How were they expected to do it? How have they been performing? What aspects of a treaty have created unforeseen problems? Are some of the goals unrealistic? Is the verification regime inadequate? Is the monitoring system insufficient? Can non-compliance be detected and measured? Do the penalties for non-compliance ensure compliance? What correction mechanisms, if any, could one employ to improve the performance of a treaty? Questions similar to these can also be asked for treaties under negotiation. The answers would help clarify issues, identify potential problems and lead to alternative courses of action. At this point a note of caution is in order. It is important to keep in mind that there is a chasm between the worlds of science and international diplomacy. The former operates on clear, universally accepted rules and requires precision, while the latter thrives on compromise, ambiguity and continuously shifting political alliances. It would be hubris to expect that the precision of the scientific approach could be transplanted into the world of international treaties. Nevertheless, only the systematic analysis of the scientific approach can define the parameters and establish the bounds within which a given treaty could be expected to operate in a reasonably effective manner. The establishment of an objective mechanism for evaluating performance is necessary in the absence of a supranational decision-making authority with enforcement powers.

To perform a credible job in applying the scientific method to a complex system such as a treaty one needs to involve a diverse collection of scientific disciplines. Some are specific to a treaty while others are applicable to most if not all treaties. A few examples of the former category are: chemical engineering and chemistry for the Chemical Weapons Convention; chemistry, physics and seismology for the Comprehensive Nuclear Test- Ban Treaty; atmospheric science, chemistry and physics for the Kyoto Protocol; biology and chemistry for the Biological Weapons Convention; chemistry, nuclear engineering and physics for the Nuclear Non-Proliferation Treaty. Treaties with provisions for monitoring and verification rely on a generic information infrastructure that collects, transports and processes data. The major components of the infrastructure are sensors, e.g., seismometers, satellite remote sensing systems, inspectors, etc.; communications, e.g., local area networks, the Internet, etc.; computations, e.g., workstations, mainframe computers, software, etc. The information infrastructure, in addition to the technological component, relies on a diverse set of mathematical tools for collecting, transporting and processing the data. Some of these are: probability theory and game theory for scheduling inspections and collecting samples; signal processing for collecting and analyzing signals; coding theory for providing efficient communications and ensuring the integrity of the information; decision theory for detecting events and discriminating between compliant and non-compliant activities. Although one can evaluate and improve the performance of each of the major elements of a treaty, in the end, there is only one important question that needs to be answered: Does the treaty do what it is supposed to do and how well does it do it? The only mechanism for providing a reasonably objective answer to that question would be integration of the various components of the treaty into a single system and analysis using mathematical modeling techniques including optimization theory and stability analysis.

The preceding discussion has demonstrated that to understand the operation and evaluate the performance of treaties requiring monitoring, verification and enforcement of compliance one needs to integrate knowledge from a broad and diverse collection of disciplines. So far, the major body of knowledge about this type of multilateral treaties is from the area of arms control. As concerns about the environment increase, environmental treaties are bound to assume equally prominent international roles. The experience gained from the operation of arms control treaties could be applied toward the operation of environmental treaties. Although there is highly specialized knowledge in each of the various disciplines associated with a treaty, there is no identifiable discipline that addresses issues common to all multilateral treaties requiring monitoring, verification and compliance. It is the nature of the scientific approach that progress in the various fields occurs though specialization. Recognizing the increasingly important role such multilateral treaties play in the global scene the need for a scientific discipline with focus on treaty analysis, evaluation and design has become apparent. Our aim in this book is to identify the major technical issues that have arisen or could arise in the operation of treaties and to develop a systematic mechanism for addressing them. In doing so we hope to lay the foundation for a distinct scientific discipline by establishing a framework for integrating knowledge from a wide range of scientific disciplines and using it to improve the operation of multilateral arms control and environmental treaties.

Organization of the material

The integrated approach advocated in this book is reflected in the selection of the subjects and their arrangement into coherent units. The topics are grouped into four parts each corresponding to a major component of the treaty process. To place the various contributions into perspective the first part describes a theoretical model of treaties as processes and establishes the conceptual framework for viewing the broad spectrum of contributions as a coherent collection of related and complementary subjects. Theoretical models are idealized versions of reality, in this case, the reality of existing treaties and the global environment in which they exist. To make the connection between theory and practice, the conceptual framework is followed by a set of contributions describing six treaties and their requirements. The chapters have been written for the most part by individuals who have or have had working knowledge of their respective topic. The contributors present not only an overview of each treaty but also problems that have arisen during implementation. The six treaties have been selected in order to emphasize the common ground shared by treaties that require monitoring, verification of compliance and provide for sanctions in cases of non-compliance. Five treaties are on arms control, Nuclear Non-Proliferation Treaty, Chemical Weapons Convention, Biological Weapons Convention, Comprehensive Nuclear Test-Ban Treaty, and the Treaty on Conventional Forces in Europe; the sixth contribution is an extensive discussion of the United Nations Framework Convention on Climate Change and its Kyoto Protocol in order to demonstrate the utility of theoretical modeling and broad applicability of the conceptual framework.

In the recent past, the security framework that arms control treaties have been designed to establish has been called into question by the discovery of secret weapons programs and A. Q. Khan network for clandestine traffic in nuclear technologies. The part on field experiences presents a comparative analysis of a number of confirmed violations of treaties as well as extensive discussion of the Iraq case by two authors who have had direct involvement in the investigations of the Iraqi program. Although the lessons learned from the case of Iraq cannot be applied to the routine operations of arms control and environmental treaties, they serve two purposes; they illustrate the inherent limitations of existing verification regimes, and they provide a basis for improvement.

The arrangement of the topics in the fourth part of the book has been designed to demonstrate the central role played by technologies and methodologies in monitoring and verification. The subjects covered in this part are indicative of the scope of the core activities of the ESARDA Working Group on Verification Technologies and Methodologies. A number of the contributions have been presented and discussed in meetings and seminars organized by the group. To present the diverse topics as a coherent unit, the topics have been grouped into four sections. In keeping with the philosophy of the book that a systematic approach to the development of effective verification regimes needs to have a theoretical underpinning, the first section gives examples of the applicability of formal models to the various phases of what we have referred to as treaty process.

The topic of technologies is perhaps the most difficult subject to cover in a comprehensive discussion of verification systems. Since the term is so general, it is practically meaningless as a useful tool in analyzing and evaluating verification systems, unless it is further qualified. Technology encompasses instruments, systems of instruments, algorithms and software. An exhaustive study of these four broad topics would require volumes to be covered. Instead, under the headings of systems and linkages, and emerging verification technologies, we have selected a few representative examples which serve to illustrate the wide range of technologies that are or can be used in verification systems. The examples range from individual sensors to satellite systems for remote imaging, algorithms for image analysis, and modelling of physical processes. Under the heading of methodologies, we have also included a chapter describing the new discipline of nuclear forensics. The impetus for this new discipline has been provided by the need to trace the movement of diverted or stolen nuclear materials through clandestine networks.

The focus of the fourth topic under the heading of methodologies, technologies and synergies is on the information systems upon which the verification regimes rely to make decisions about non-compliance. These decisions are based on the analysis of large quantities of data, which include data generated by inspectors and instruments, provided by the member States, and collected by the executive organizations established by each treaty. In this section of the book the lead chapter describes a generic infrastructure for an information processing system that is applicable to all treaties requiring monitoring and verification. The other three chapters are devoted to the characteristics of the data that are processed by the information infrastructure and to discussing issues arising in obtaining and using these data.

The majority, if not all, of the contributors to this volume come from the scientific and technical community and their contributions reflect that perspective. In addition, they have direct knowledge of their subject matter through their affiliation with the executive organizations of the treaties they discuss, their participation in treaty negotiations, or their affiliation with national or multinational organizations that interface directly with the treaty organizations. In this respect, they are primary sources of information. At the same time, multiple authors cover the same subject from different perspectives; they may even have contradictory points of view. What might seem repetitious, redundant or even contradictory serves a purpose. It is designed to demonstrate the complexities and ambiguities inherent in the treaties and to highlight the need for a systematic approach to a thorough examination of the issues.

As mentioned in the beginning of this chapter, treaties are legal instruments developed through the process of negotiations. Although their study and analysis requires a technical approach, in the final analysis, their effectiveness depends heavily on political considerations. The final section includes a contribution from the perspective of political science in order to provide a complete overview of the issues associated with verification regimes, and another contribution with examples from the nuclear field of research initiatives that need to be undertaken in order to improve the effectiveness of the nuclear non-proliferation regime.

Audience

The book is addressed to an audience as diverse as the material contained in it. The book is designed to benefit three major groups: policy-makers and treaty negotiators, international civil servants charged with implementing treaties and last, but not least, the scientific and technical community that is inevitably called upon to solve all the difficult problems that the negotiators bypass by labelling them "technical details". There are different objectives for each of the three categories of audience. We hope to make the policy-makers and negotiators aware of the interdependencies among all the elements of a treaty by providing a comprehensive overview of the many factors affecting its performance. Viewing a treaty as an integrated system during negotiations should help identify potential ambiguities, inconsistencies, and contradictions that might be caused by proposed or adopted positions. Systematic analysis of a treaty would enable negotiators to evaluate alternative negotiating options; it would also allow the policy-makers to make an objective assessment of the capabilities and limitations of a treaty.

The material in this book should also be useful to the large group of people who are involved in the various aspects of treaty implementation. These are not only the international civil servants but also those who are associated with the national support programs to the international organizations. As with any other organization charged with carrying out a specified mission, the functions within an international organization are compartmentalized and few people have a comprehensive understanding of the impact of localized technical decisions on the overall mission of the organization. In addition, few of the new recruits into the organization have had anything but a superficial knowledge about the operation of the organization. This book, by providing a comprehensive overview of all the issues that might arise during the operation of the treaty, should be a useful background material to help these people relate their particular function to the overall mission of the organization. The book can play a similar role for those engaged in various aspects of the national support programs. The needs of the international organizations always exceed the available resources from the member States. Using the comprehensive overview of the treaties in conjunction with the advocated systematic approach for evaluating performance, the national support programs should better be able to identify and prioritize projects in need of support.

In the scientific and technical community the focus of the activities related to arms control and environmental treaties is primarily on specialized technologies. For example, there is extensive seismological literature on detection and discrimination of seismic events in reference to the Comprehensive Nuclear Test-Ban Treaty. Similarly, extensive work is being done in developing technologies for international nuclear safeguards and physical protection, although a substantial part of this type of work is done in the context of the national support programs. For historical reasons, most of these activities are treaty-specific even though some of the specialized technologies could be applicable to multiple treaties. For example, remote sensing technologies are as applicable to environmental treaties as they are to the Chemical Weapons Convention, the Nuclear Non-Proliferation Treaty and the Comprehensive Nuclear Test-Ban Treaty to mention a few. One of the major difficulties in developing specialized instruments for monitoring arms control treaties has been the small market size for such specialized technologies. Some of the specialized instruments are designed and built solely for the technical organization supporting the operation of a specific treaty. Because of the small number of units involved, it not only becomes impossible to achieve economies of scale, but it also the producers of the instruments tend to be small companies that are likely to fail unless they are supported by the national support programs or the international organization. Addressing monitoring and verification as a generic issue would help develop a common technological base that would help decrease cost and increase the reliability of the supply by broadening the market.

The theoretical framework combined with experiences from the operation of a number of treaties can form the basis for research on global infrastructures. Research on infrastructures is a recent phenomenon stimulated primarily by the need to secure critical national infrastructures. Most of the research has been concentrated on national infrastructures for obvious reasons. Although there are references to infrastructures transcending national borders, such as transportation and communications systems, the research activities in this area are limited because of the difficulties involved in defining the boundaries of these systems. Arms control and environmental treaties, with provisions for monitoring and verification of compliance, are ideal examples of global critical infrastructures, because they are essential components of the framework for international security. As such, they need to operate reliably and cost-effectively and are expected to provide services at high levels of confidence. The topics and the organization of the book have been selected to stimulate research activities not only at the theoretical level, but also on the application of existing technologies to global systems in this area and to identify needs for new technologies. The book should also be useful as an educational tool for those who seek in depth understanding of how treaties operate, what are the major issues arising during their operation and how can the treaty performance be optimized.

I

Conceptual Framework

Verification of treaty compliance contains elements of a political and institutional as well as of a technological nature. Complex and multifaceted structures are inherently imbedded. Therefore a conceptual framework is developed which gives a holistic view and offers solution paths to specific questions.

Conceptual Framework

Rudolf Avenhaus and Nicholas Kyriakopoulos

1 Introduction

The trend in the negotiations for arms control treaties has been toward the specification of increasingly complex obligations, more stringent verification requirements and elaborate monitoring procedures. In the course of the last century, these treaties have evolved from simply describing obligations to requiring compliance and providing for sanctions in case of non-compliance. The Geneva Protocol for the Prohibition of the Use of Chemical Weapons [1] is an example of the former. The Chemical Weapons Convention (CWC) [2] and the Comprehensive Nuclear Test-Ban Treaty (CTBT) [3] are the most recent examples of the latter. These complex treaty structures linking obligations, verification of compliance and sanctions have been developed in order to increase confidence that the treaties will contribute to and become an integral part of the national security apparatus of each State.

Although, confidence in a given treaty is the desired goal during negotiations, the cause and driving force behind the development of elaborate formal mechanisms for monitoring and verification has been technology. Advances in electronics, communications, computers and transportation have made it realistic to contemplate monitoring, and verification. High speed and low power electronics have made possible the sensing of physical phenomena, including human activities, in situ or remotely. Communications technology allows the transport of large quantities of data anywhere on terra firma and nearby space in real time. Transportation technology has made possible the dispatch of inspectors practically anywhere on earth to collect data either visually or by instruments. Large amounts of data can be stored because of the rapid increase in memory capacity, while computational speed makes it possible to perform complicated computations and extract relevant information in near-real time.

The impact of the technological advances can be seen in the establishment and operation of Technical Secretariats charged with the task of monitoring the performance of each treaty. The activities of each Secretariat are prescribed by the respective treaty and are overseen by organizations such as the International Atomic Energy Agency (IAEA), the Organization for the Prohibition of Chemical Weapons (OPCW) and the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO). A similar structure and operation is envisioned in the negotiations for revising the BWC [4]. Although the total annual cost associated with the establishment and operation of these organizations is miniscule compared to the size of military budgets, the question of cost-effectiveness is always present. Typically, opponents of a particular treaty express little confidence in the operation of the treaty, while proponents argue that the world is better off with it than without it. At one level the arguments are centered on whether or not a particular organization is doing its job, namely, on how well it implements the provisions of the treaty. At another, the arguments revolve around the question of whether verification of a treaty is at all possible. Did the IAEA fail in the performance of its duty with respect to the clandestine nuclear weapons program of Iraq, or is the current system of safeguards not capable of detecting such activities? Could a BWC ever be verified? If one wishes to look beyond assertions or selective use of facts one needs to have an objective mechanism, a common reference point, for addressing such questions on a rational basis.

Quite a bit of work has been done on verification technologies and methodologies as well as on issues of compliance, verification and international security. The existing literature on arms control treaties, verification of compliance and sanctions may be grouped into two broad categories, political analysis and technological tools. The former have as starting point either the need for a treaty to control certain classes of weapons or take an existing treaty as given and proceed with the analysis of some aspect of the treaty [5,6,7,8]. On the other hand the focus of the literature on technological tools is on technologies and methodologies that could be applied to existing or future treaties [9,10,11,12,13][Section 5 this volume]. To our knowledge there exists no unifying framework that relates objectives, operation, monitoring, evaluation and improvement of the treaty operation.

The need for a rational approach will become more pronounced in the future. As the world has become concerned about the impact of man-made pollutants on the environment, States have recognized the need for controlling the emission of pollutants on a global basis and move toward the establishment of environmental treaties with great economic implications. The discussions about information warfare could sooner or later identify a need for international agreements governing the flow of information through the global communications network. Terrorist acts, namely, attacks against civilian targets in the absence of declared war, by non-State actors are also generating international agreements specifying obligations of the States in the presence of such acts [14]. The debates about the Kyoto Protocol to the United Nations Framework Convention on Climate Change [15] [MacFaul this volume] give a partial indication of the intensity of disagreements about such treaties.

This chapter lays the foundation for analyzing the operation of multilateral treaties and establishes a framework for evaluating their performance using objective criteria. By objective we mean measurable with respect to a reference system. Treaties requiring monitoring are no different from other physical processes making possible the development of a dispassionate approach for analyzing their performance. The results of such analyses can yield important information about what a given treaty can or cannot achieve and at what cost. These questions can be answered by viewing treaties as processes, or systems, the essential elements of which are goals, activities, measurements, errors, feedback and control [16].

2 Treaties as dynamic systems

Treaties that specify activities, goals, monitoring of the activities, verification of compliance obligations and provide for sanctions in case of non-compliance contain all the characteristics of feedback control systems and can be modeled as such. The goals are listed in the preamble of a treaty in the form of motivating factors and desirable objectives, and in the articles describing the obligations of the States Parties. These goals are the *reference inputs* to the *process*, namely, the activities covered by the treaty.

A verification regime is designed to detect discrepancies, *error*, between the on-going activities and the treaty goals. Discrepancies may indicate either non-compliance with the obligations, or imperfect operation of the verification regime. The simplest example of the latter is the use of insufficient or noisy data. Regardless of the nature of the discrepancies most treaties provide for a correction mechanism, *controller*, in the form of revisions, periodic reviews, or sanctions. The Treaty on Conventional Forces in Europe (CFE) [17] envisions that the Joint Consultative Group may agree on improvements to the viability and effectiveness of the treaty. Periodic reviews also provide a forum where treaty revisions may be considered. On the other hand, the CTBT provides for periodic reviews of the operations and effectiveness of the treaty "with a view toward assuring...that the objectives and purposes are being realized". Left unsaid is what would be done if they are not. In case of non-compliance, measures necessary for ensuring compliance are authorized to be taken. A notable example of the lack of a corrective mechanism is the Geneva Protocol. It obligates the States Parties not to use chemical weapons, but it is silent on what is to be done in case a State has used them making those obligations unenforceable. After the Second World War the trend in multilateral arms control treaties has been to include the provision of potential sanctions in case of non-compliance.

Verification of compliance relies on measurement systems which come under different labels for each treaty. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) [18] requires States "...to accept safeguards ...for the exclusive purpose of verification" (Art. III, §1). The verification regime of the CTBT consists of four elements: an International Monitoring System, consultation and clarification, on-site inspections, and confidence-building measures. (Art. IV, §A.1) Two of the four elements, International Monitoring System and on-site inspections, are clearly components of the measurement system. Confidence-building measures are also a component of the measurement system, because they consist of information supplied by the States, albeit voluntarily, within the scope of the verification regime. On the other hand, consultation and clarification is clearly part of the control function, because they involve actions triggered by discrepancies, real or perceived, between obligations and activities. "States Parties should...first make every effort to clarify and resolve...any matter which may cause concern about possible non-compliance..." (IV, §C.29). Although the CWC does not specify a concept analogous to the safeguards system for the nuclear fuel cycle, in the Annex on Implementation and Verification it includes an implicit measurement system consisting of declarations provided by the States Parties and international inspections. The measurement system for the CFE consists of "notification and exchange of information" (Art. XIII), inspections (Art. XIV), and "national or multinational technical means" (Art. XV).

Thus, regardless of the specific terms used in various treaties a generic model for analysis and evaluation can be constructed using control system concepts as shown in Figure 1. In the subsequent sections, the functions of each component are examined in detail from the perspective of their role in the operation of the treaty. As a result, the major components are decomposed into modules each having a separate and distinct role. This decomposition gives rise to the more complex model developed in subsequent sections. For existing treaties, the concept of *equilibrium states* can be used to evaluate the *stability* of the operation using quantitative measures. At any given time, a treaty may be in a *stable* or an *unstable* equilibrium state. In this chapter, we use the example of the NPT to illustrate how the stability of a treaty could be evaluated. The question of whether the verification regime specified in the treaty is capable of detecting proscribed activities can be addressed from the perspective of *observability.* Similarly, the discussions about the effectiveness of sanctions in ensuring compliance could become more substantive were they to be based on a thorough understanding of *controllability.* For future treaties, the generic model could be used to evaluate proposals under negotiation, before they become incorporated into the treaty text. As with any model, the utility of the model described in this chapter lies in the fact that it is a reference point with respect to which the practices of implementation can be analyzed and evaluated. Starting from a sound theoretical underpinning one can address the practical question of cost-effectiveness of every element within the scope of a treaty.

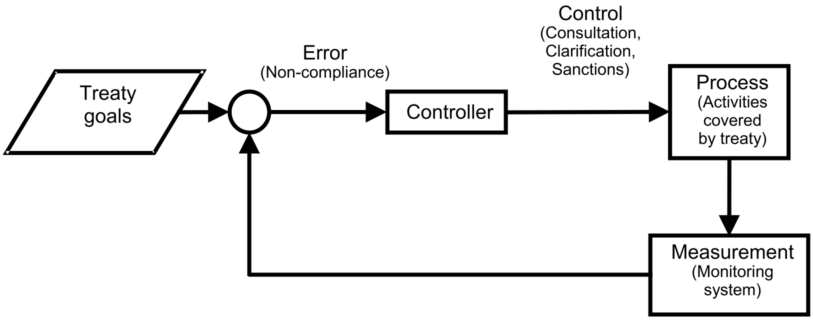


Fig. 1. A generalized model of multilateral treaties as a feedback control system

3 Treaty goals as reference inputs

Treaty goals refer to activities for which the States Parties undertake or exercise some form of control and for which a State would bear ultimate responsibility in ensuring adherence to the obligations. These activities may involve events, e.g., nuclear explosions (CTBT), items, e.g., battle tanks (CFE), or processes, e.g., production of scheduled chemicals (CWC), methane emissions in waste management and in the production, transport and distribution of energy (Kyoto). The domain may consist of specified locations such as declared facilities, the entire realm of each State, or even the globe and its surrounding space. Nuclear safeguards (NPT), counting of armaments (CFE), production of Schedule 1 chemicals (CWC) are examples of discrete elements in the domain *space*. The National Implementation Measures of the CWC apply to anyone "anywhere on [the] territory" of the State, while the obligation of each State under the CTBT not to carry out any nuclear test regardless of geography implicitly extends the spatial domain to the entire globe and its surrounding space. The domain of a treaty also has a temporal component. The destruction of chemical weapons and chemical weapons facilities need to be completed by specified times. Treaty limited items under the CFE are moved with specified schedules. Activities such as methane production in waste management under the Kyoto Protocol, production of scheduled chemicals under the CWC, reprocessing of spent nuclear fuel under the NPT, or other similar activities covered by a treaty take place continuously over *time*. Thus, the domain of a treaty extends in both space and time. For treaties with a three-dimensional space, such as the CTBT which covers sub-surface, surface and atmospheric testing, the coordinate system for the treaty domain has *four* dimensions.

The obligations of the States Parties to a given treaty fall into two categories, *qualitative* and *quantifiable*. The latter have *measurable* attributes, while the former, lacking precise definition of their meaning in the context of the treaty, cannot be assigned an objective measure and are subject to as many interpretations as the number of people making them. In Table 1 the goals of some representative treaties are listed and assigned to the appropriate class.

Table 1. Examples of treaty goals as reference inputs

Treaty Goals - Obligations of States Parties				
Attributes	NPT	CFE	CWC	CTBT
Quantifiable	• not manufacture • not transfer • not receive nuclear weapons	• maintain a secure, stable and balanced overall level of conventional armed forces in Europe • eliminate capability for launching surprise attack	• never develop, produce, otherwise acquire, stockpile, retain, transfer • never use • destroy facilities and weapons	• not carry out any nuclear weapon test explosion • prohibit and prevent any nuclear weapons test
Qualitative	• not in any way assist, encourage or induce other States to acquire nuclear weapons • not seek or receive any assistance from other States to acquire nuclear weapons • pursue negotiations on cessation of nuclear arms race and on complete nuclear disarmament	• refrain from the threat or use force against territorial integrity, or political independence of any State • prevent any military conflict in Europe • achieve greater stability and security in Europe	• not engage in any military preparation for chemical warfare • not assist, encourage or induce in any way anyone to engage in any activity prohibited by the manufacture of chemical weapons	• refrain from causing, encouraging, or in any way participating in the carrying out of any nuclear weapon test explosion or any other nuclear explosion

Quantifiable goals for the activities covered by the treaty can be assigned reference values. Some of the variables can be binary, e.g., "not carry out a nuclear test explosion", while others may be continuous, e.g., "never...develop...chemical weapons". Development involves many steps and it takes time. It is not an instantaneous event that either occurs or does not. It is also an example of a vector reference input, because development involves multiple activities. Some of the reference inputs may be deterministic, e.g., "never use", while others may be more appropriately described in terms of random variables, e.g., "maintain a secure, stable and balanced overall level of conventional armed forces in Europe". For the quantifiable objectives, discrepancies between the activities covered by a treaty and the goals lead to a measure of non-compliance.

Qualitative objectives present a major and possibly insurmountable problem in evaluating the performance of treaties dealing with potentially controversial subjects such as arms control or the environment. The obligation of States, under the NPT, to "...pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a Treaty on general and complete disarmament..." [Art. VI] is a perfect example of an unmeasurable and, consequently, unverifiable objective. A State can justify continuing possession of nuclear weapons, while claiming adherence to this particular goal by simply showing up at some negotiating forum. Good faith can neither be defined, nor measured. Conversely, a nuclear weapons State could be accused of violating the obligation not to "...induce other States to acquire nuclear weapons..." by reserving the right to use them, or, continuing to possess them. A non-nuclear-weapon State, feeling threatened by the nuclear weapons is induced to undertake development of its own nuclear weapons.

Similar examples can be found in other treaties. Under the CWC, a State could be accused of violating its obligation to not "assist, encourage or induce in any way, anyone to engage in any (prohibited) activity", by awarding a doctorate in chemical engineering to someone, who, subsequently, would direct a chemical weapons program in some other State. It could be argued that common sense would or should reject that interpretation. Unfortunately, "common sense" is not one of the criteria governments use to make decisions.

Problems can also arise with some of the quantifiable goals. Accuracy and cost play a significant role in the making of decisions based on measurements. If the state of the art for the required measurement tools (equipment, procedures, human resources) for some treaty goals is such that, the accuracy of the measurements is low, those goals would not be feasible in practice. Similarly, if the costs of measuring and achieving some goals are prohibitively high, the feasibility of those goals may also be questionable. The discussions concerning a verification regime for the BWC are a case in point. One could envision an inspection regime covering every potential BW facility, but at what cost? In the CWC, a toxic chemical used as chemical weapon in World War I was not placed in Schedule 1 along with the other toxic chemicals used as chemical weapons but in Schedule 3, with much less stringent verification procedures, because it is produced for non-prohibited purposes in very large quantities. Applying the verification provisions for Schedule 1 would entail unacceptable costs in terms of resources and intrusiveness. The objective of the CFE to eliminate the capability for launching a surprise attack can be feasible only if it concerns large scale offensive action. On the other hand, eliminating the capability for attacks similar to the one on the World Trade Center might not be a feasible objective for such a treaty. Regarding the CTBT, the objectives not to carry out and to prohibit weapons tests are feasible; however, preventing such tests may not be feasible, because the starting point of the action "prevent" cannot be defined.

One then is led to the conclusion that, in the modus operandi of a treaty, the obligations could be grouped into three distinct categories, quantifiable-feasible, quantifiable-non-feasible, and qualitative. Goals in the first category would be considered obligatory while the latter two could be viewed as desirable. Quantifiable-non-feasible goals could be used as guidelines for the future evolution of the treaties. In some instances, after a treaty has entered into force, the latter two categories of goals could be reviewed in light of the accumulated experience and could either be modified to become quantifiable-feasible, or omitted as treaty objectives [19]. Figure 2 shows such a possible decomposition.

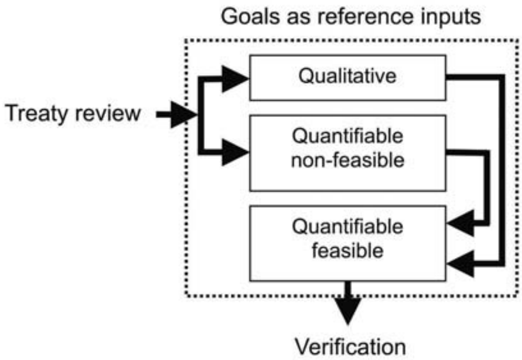


Fig. 2. Categories of treaty goals and their uses in the operation of a treaty

Even if the goals are quantifiable and feasible, not all are of equal significance, because they do not pose the same risk to the objectives of a given treaty. Ten kilograms of highly enriched uranium do not pose the same risk as a reprocessing plant. The CWC considers risk as a criterion for placing toxic chemicals in Schedules 1 (high risk), 2 (significant risk) and 3 (risk). Thus, for each of the quantifiable-feasible treaty goals a corresponding numerical weight needs to be assigned indicating its relative significance with respect to the other goals. Even if one were to attempt to do that, the question would still arise about the criteria to be used for quantifying relative significance. A revealing and instructive example is the assignment of chemicals to one of the three schedules in the CWC. Although a chemical has been used or might be used as a chemical weapon, one of the criteria for designating it as "high risk", "significant risk", or "risk" is its commercial usage. A chemical is put in Schedule 1 if it "has little or no use for purposes not prohibited" under the CWC. For Schedules 2 and 3, the corresponding criteria are "not produced in large commercial quantities" and "may be produced in large commercial quantities", respectively, for non-prohibited purposes. For example, Phosgene, a chemical that was used and could be used as a chemical weapon, has been placed in Schedule 3, because it is being produced in large commercial quantities and thus it is subject to less stringent monitoring than that of chemicals in Schedules 1 and 2. This type of rationalization, however legitimate it might be considered, makes the assignment of risk questionable if one uses the objectives of the treaty as a reference point. A possible tool for handling this type of issues is fuzzy logic [20,21,22].

The treaty model must also be able to account for an additional complication. The typical form of a treaty is to enunciate some general objectives and to specify the obligations of the States Parties to the treaty to achieve these objectives. Although the treaties are explicit in their prohibition of the States Parties helping non-signatories violate the treaty objectives, they are silent on how to deal with non-signatory States that violate those objectives. Even if the quantifiable-feasible goals are achieved within the domain of the treaty, what is the meaning of achievement, if the goals are not achieved outside the treaty domain? The development of nuclear weapons by States that are not signatories to the NPT is a case in point. The impetus for signing the treaty was the need to conclude "an agreement on the prevention of wider dissemination of nuclear weapons" (NPT Preamble). Although the nuclear-weapon States Parties are obligated not to help non-nuclear-weapon States develop weapons and the non-nuclear-weapon States Parties are obligated not to develop such weapons, the NPT is silent on the obligations of the States Parties toward non-signatory States that develop nuclear weapons. This omission raises serious questions whether the non-proliferation goal of the NPT is achievable.

The foregoing discussion leads to the development of a reference system for listing and classifying treaty goals. It comprises the following seven classes of treaty goals: *discrete, continuous, quantifiable-feasible, quantifiable-non-feasible, qualitative, among States Parties, regarding States not-Parties*. The implication of the independence of these goals is that an objective evaluation of compliance can only be done in terms of each of these classes independently and not as a single variable.

4 Verification regimes

In arms control treaties, the term *verification* is used in a broad context such as " ensuring verification of compliance with the provisions" (CFE) and "international verification of compliance" (CTBT), or, in conjunction with specific goals and procedures such as "systematic verification of the declaration", "systematic verification of destruction" and "systematic verification through on-site inspection" (CWC). In the NPT, States Parties accept safeguards "for the exclusive purpose of verification of the fulfillment of its obligations with a view to preventing diversion". A more extensive and comprehensive discussion of these definitions is found in a handbook published by the United Nations Institute for Disarmament Research (UNIDIR) jointly with The Verification

Research and Training Centre (VERTIC) [23]. A legal perspective is found in the writings of the Austrian lawyer and diplomat Winfried Lang [24,25].

Although the discussions on verification have been concentrated, so far, on arms control treaties, they may, in the near future, be extended to other international agreements. Environmental issues raise global concerns and generate acrimonious debates not only about goals but also about compliance and verification. Concerns about information warfare conducted through the global information infrastructure could generate a need for international agreements that would specify obligations and may involve monitoring and verification.

Regardless how it is used, the word verification generates considerable controversy when used in debating whether a particular treaty is "verifiable". There are many public and, generally, inconclusive debates about the merits and importance, or the lack of such qualities, between proponents and opponents of these treaties. As is frequently the case with issues evoking strong emotions, the discussions are based on broad assertions, preconceived notions and ulterior motives. The blame for this state of affairs lies with the use of the term *verification.* Noble as the goal of finding the truth (*veritas*) is, the reality of the terms of many treaties is that either truth has many faces or it is elusive. To develop a rational basis for discussing the merits of a treaty one needs to have a precise definition of the meaning of the term verification. The terms used in the CFE, CTBT and the NPT provide a starting point. The expressions "verification of compliance with the provisions" and "verification of the fulfillment of its obligations" establish the connection between goals and the activities within the domain of a treaty. It requires comparison of the obligations with activities. Any objective comparison requires clearly defined and measurable goals. Therefore, goals that are quantifiable-non-feasible and qualitative cannot be used in evaluating compliance. For example, verification that a State did not in any way cause a nuclear explosion is meaningless, as is verification that a State did not induce in any way anyone to engage in any activity prohibited under the CWC.

Another condition for verifying compliance is that the activities defining the treaty domain be consistent with the goals. The main motivation for concluding the NPT was the desire to prevent wider dissemination of nuclear weapons. Yet the activities covered by the treaty pertain only to the member States. Nuclear activities of States not-parties to the convention are not covered. The treaty has no mechanism for achieving the goals of preventing wider dissemination of nuclear weapons. Even within the domain of a treaty the range of specified activities may be insufficient to provide the necessary information for verifying compliance. One of the goals of the CWC is the prevention of diversion of scheduled chemicals from permitted uses to prohibited ones. To detect diversion at any point within the life cycle of these chemicals all activities within the life cycle of these chemicals would have to be monitored. Yet, the verification provisions do not require such monitoring making verification of compliance with respect to non-diversion impossible under the current verification regime [26]. Thus, a second necessary condition for verifying compliance is for the domain of the treaty to comprise all activities that are related to the obligations.

Assuming that all activities related to the goals have been included in the treaty domain, one can define non-compliance as the discrepancy between the goals, or reference inputs, and the reality of the activities. The reality is described by the measurements performed by the monitoring system. As with any measurements there are inherent errors in the measurement system. In addition, the measured variables might not be sufficient to identify all variables of the monitored processes. International safeguards have been designed to account for all nuclear material in declared facilities and have been continuously reducing the already small fraction of unaccounted material. However, detecting prohibited activities in undeclared facilities has, so far, been an unsolvable problem. The introduction of enhanced safeguards is supposed to address this issue, but, so far, there has not been any objective evaluation of the effectiveness of such a system [27]. Thus the discrepancies between goals and activities covered by a treaty are affected not only by the accuracy of the measurements, but also by the completeness of the set of measured variables. These observations lead to the conclusion that compliance is not a deterministic binary variable, as the term is commonly used, but a probabilistic concept.

Given that the verification regime of any treaty will always generate discrepancies leads to the question of how significant these discrepancies might be. If the maximum number of treaty limited items in the CFE runs in the thousands, what is the meaning of non-compliance when the maximum number is exceeded by one, two, three, one hundred, one thousand, items? Or, for the NPT, what is the significance of not accounting for one gram, ten grams, one hundred grams, one kilogram, of plutonium per year? Is one tank as significant as one thousand tanks? Is one gram per year as significant as one kilogram per year? These questions lead to the need for introducing weighting factors in the various measurements and the element of risk in the process of evaluating compliance. The use of the risk criterion in the CWC has already been previously discussed. A similar criterion needs to be applied in evaluating the significance of measured discrepancies. Thus, it is not only necessary to measure discrepancies but also to order them on the basis of risk.

In addressing the issue of compliance for existing treaties, one needs not only to make a distinction between feasible and non-feasible goals, but, also, to establish the relations between the feasible goals and the activities covered by the verification regime. In the case of incomplete connections between goals and activities, it will not be possible to determine whether the discrepancies indicate non-compliance or are due to insufficient information. A clear understanding of the meaning of the feasibility of goals and the sufficiency of the relations between goals and verification activities should help negotiators improve the robustness of future treaties.

Having identified the feasible goals, one needs to go one step further by separating these goals into two categories. One contains goals which may be considered as short term actions such as explode a weapon, destroy a weapon, etc. This category includes also goals involving counting or itemization such as number of treaty-limited entries. The second category consists of goals specified as processes, i.e., sequences of activities occurring over time. Examples of such goals are the obligation not to manufacture nuclear weapons, of the obligation not to develop, produce, or otherwise acquire chemical weapons etc. In a purist interpretation a short-term action is an instantaneous value of a process. Consequently, it could be argued that the first category is a subset of the second. Nevertheless, since the treaties identify short-term actions and itemization as explicit goals, we will adhere to this classification for the purpose of consistency and clarity.

For goals specified as instantaneous events, compliance can be measured by establishing whether an event has or has not taken place. A nuclear test, or the launching of a projectile filled with toxic chemicals denote non-compliance regardless when the actions occur. In the case of the CFE, increasing treaty-limited items above the specified levels also denotes non-compliance. For this category of goals, non-compliance is a binary variable and the objective of the verification process is to design and implement a binary detector using a set of measurements that are appropriate for each type of event. Since measurements are noisy, non-compliance is a probabilistic rather than a deterministic concept. Consequently, one can talk accurately only about improving the probability of detecting non-compliance, by using better sampling techniques, more sensitive instruments, better algorithms for evaluating data etc.

For the goals, which are processes, a different perspective is necessary in order to understand the meaning of verification of compliance. For the purpose of this discussion, we assume that a process has a beginning, duration and end. For example, one way to manufacture a nuclear weapon is to start with the raw material, natural uranium, go through the intermediate steps of enrichment, and end with the production of a nuclear bomb. A similar process can be identified for the production of a chemical weapon. Since the entire process can be identified for the production of a prohibited weapon, the verification process needs to collect sufficient data for detecting the existence of the process. In the verification regimes described in the treaties under discussion, monitoring is limited to processes at specified declared sites. The verification regimes for those treaties are silent about monitoring systems for processes, which do not involve declared sites. It is not clear how one would monitor such processes.

An alternative manufacturing path for producing a prohibited weapon is to substitute production steps from processes that are not prohibited by a treaty. In such a case, the beginning of the weapons manufacturing process may be defined as either the stage where the diverted material enters the weapons manufacturing process or the beginning stage of manufacturing the diverted material. If one accepts the former model, the domain of the verification process covers only the manufacture of the weapon without regard to the source of the diverted material. However, the NPT and the CWC, by seeking to detect diversion from non-prohibited processes, implicitly incorporate them into the weapons manufacturing process. Thus, the verification domain is extended into activities not prohibited by the treaties.

For a manufacturing process, the meaning of non-compliance needs clarification. If at the end of the process, a weapon is produced, its existence falls under the first category of instantaneous events and detection of non-compliance is a binary decision. Similarly, it could be argued that diversion of material away from non-prohibited uses is by itself a non-compliant process. However, diversion is not a well-defined term. Consider for example the case of the NPT. The application of safeguards generates an output which is a measure of the material within the safeguarded nuclear fuel cycle and not of diverted material. Instead, discrepancies are labeled as material unaccounted for. The reason of course is well known. It is not easy or, with current knowledge, not even possible, to measure *diversion*, even in the case of the nuclear fuel cycle where safeguards in combination with containment and surveillance are applied to the entire fuel cycle. Although discrepancies between two sets of values can be measured, diversion is itself a process that requires precise definition before it can be identified as such through measurements.

If the problem of defining precisely the treaty goals, which are processes, were solved, the verification regime would need to perform sufficient measurements in order to be able to correctly identify it. There are known theoretical foundations for determining the number of variables and frequency at which they must be measured for any well-defined process. We will illustrate this with a simple example. A chemical process requires one day to begin producing a particular chemical and the production cycle lasts for ten days. To find out what quantity has been produced over the entire production cycle, measurements would have to be taken at least twice a day, otherwise the amount of material diverted during any given day would not be detected. However, in treaties such as the CWC, inspection schedules for facilities where production processes need to be monitored in order to detect diversion, are not based on the characteristics of the given process. Instead, they have been determined by such criteria as equitable distribution of inspections among States, maximum number of inspections per facility and year, etc. Thus, although it is not difficult to determine the amount of sufficient and necessary information for evaluating compliance, the verification regimes are not always based on such requirements.

An important parameter in the design of detection systems for events and processes is the time elapsed between the instant an event has taken place, or diversion has begun. Ideally, such detection should occur instantaneously. In reality, there will always be a time delay. The question then becomes what would the impact of detection delay be on the objectives of the treaty. If a State intends to use a prohibited chemical agent for an imminent surprise attack, a detection delay bigger than the time interval between diversion and use would, obviously, be too long. One can then conclude that *timeliness* of detection becomes a significant design parameter. There are costs associated with timeliness. Minimizing delay maximizes detection cost. On the other hand, minimizing detection cost maximizes the cost to the objectives of the treaty. Thus, a cost-benefit analysis needs to be done to reach an acceptable balance.

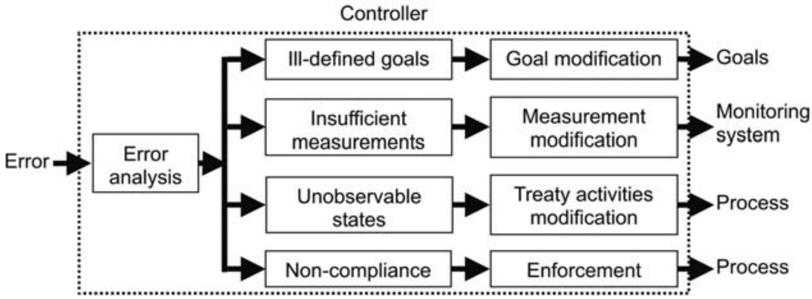


Fig. 3. Architecture of the correction mechanism for stabilizing the operation of a treaty

The previous discussion has identified four distinct categories of potential discrepancies or errors between treaty goals and the activities comprising the treaty domain. Errors can be caused by ill-defined goals, unobservable activities, insufficient measurements and non-compliance. Each class of errors requires different correction activities (control functions). Errors caused by ill-defined goals can be corrected by reformulating the goals into quantifiable-feasible objectives, while those caused by unobservable activities can be corrected by expanding the scope of the treaty. Errors due to insufficient measurements on observable activities can be corrected by improving the design of the measurement system to increase the number of points at which measurements are taken and the frequency of measurements. Discrepancies not attributable to defects with the definition of goals, incomplete specification of the activities falling under the purview of the treaty, or improper design of the measurement system, could then be reasonably assumed to be caused by non-compliance. Thus, if the treaty is properly designed to correct discrepancies other than those caused by intentional deviation from the goals, non-compliance can be detected with increased confidence. Existing treaties use consultation, clarification and sanctions as the principal control functions for driving the treaty process into stable equilibrium. Figure 3 shows the decomposition of the controller and the feedback loops for controlling the operation of a treaty. On the basis of the preceding discussion, the model shown in Figure 1 can be modified to yield the more detailed model shown in Figure 4.

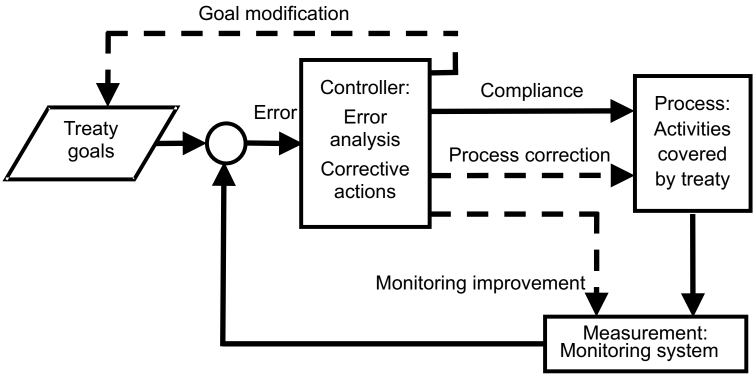


Fig. 4. A refinement of the generalized treaty model differentiating between non-compliance and errors caused by treaty imperfections

5 Monitoring

Monitoring for the purpose of verification is described differently in the various treaties. The NPT does not use the term at all. Instead it requires the States to accept safeguards for the purpose of verifying non-diversion of nuclear materials. The CFE and the CWC do not specify an overall system analogous to nuclear safeguards, but they list specific mechanisms such as, counting, information exchange, information transmission, notifications, technical means of verification, inspections, declarations, data monitoring, and monitoring with on-site instruments. A somewhat analogous concept to the international safeguards is the International Monitoring System of the CTBT, in combination with on-site inspections and confidence-building measures. These three elements compose the monitoring system for verifying compliance. For the purpose of illustration the types of measurements for each of these four treaties are listed in Table 2.

Similarly, although there is no specific name associated with it, the Kyoto protocol is calling for the establishment of a national system and methodologies for estimating anthropogenic emissions [15]. It also calls for information exchange and the generation of verifiable reports.

Regardless of the specific terminology used in each treaty, one can identify three categories of measurements, reports generated by the State, reports generated by inspectors and all measurements generated autonomously by instruments, i.e., without the direct and continuous intervention of human operators.

The first category comprises reports, submissions, declarations, notifications or other similar words that denote measurements generated by each State and sent, at specified instances, to the other States, an international authority or both. These measurements may be in digital form as data files, or in analog form as images, graphs, drawings, etc. The measurements obtained with

Table 2. Monitoring Elements

Treaty	Monitoring Elements
NPT	• data reporting required • quantitative measurement of flows and inventories of nuclear material • containment and surveillance measures • special inspections, e.g. for search of undeclared facilities (INFCIRC 540)
CFE	• data reporting regimes • on-site inspections of declared military sites • special inspections • national technical means
CWC	• data reporting requirements • on-site inspections of declared facilities • special inspections
CTBT	• seismic • hydroacoustic • infrasound • radionuclide measurements • on-site inspections

inspections generate information in analog form using human sensing, visual and otherwise, and in digital form through physical measurements, extraction of data from files, including the collection of samples for analysis at a place other than the point of inspection, or instrument readings. The third covers all instrument readings regardless how the measurements are done, in situ or remotely. Although the first two categories are characterized by the direct human intervention they differ in a fundamental way. The State and the inspectors have, if not an adversarial relation, at least, a divergence of interests. These divergent interests require that the information contained in the two categories of reports be treated differently. The accuracy of the information contained in the reports submitted by the States needs to be verified, while that of the inspector is accepted at face value. In addition, all data, regardless of their source, be it human or machine, are subject to two categories of errors, one caused by the data-generating process, such as transmission errors, and the other by the measurement system. Thus, the information generated by a monitoring system to evaluate discrepancies between treaty goals and the activities covered by a treaty needs to be treated in the stochastic sense.

The measurements for monitoring of activities, such as those required for detecting diversion, could be periodic or random. In either case, the measurement times are a function of the process characteristics (continuous, discrete event), the material to be diverted, the diversion mechanism, and the detection threshold requirements. A good example of a measurement system applied to a process for the purpose of detecting diversion is the safeguards system applied to the nuclear fuel cycle. It combines process monitoring with inventory control to account for all special nuclear material anywhere in the nuclear fuel cycle with a high degree of accuracy. Treaties specifying obligations involving this type of activities are modeled as dynamic systems.

Activities that can be considered as short-term actions such as explode a weapon, destroy a weapon, etc., can be viewed as instantaneous events, although the preparations leading up to the event are processes. For treaty goals specified as instantaneous events, the monitoring system need only be designed to detect single events rather than sequences of events. On the other hand, if the goal is not only to prohibit an event but also to prohibit preparations for it, the monitoring system must also perform measurements of the associated activities. The monitoring system for the CTBT is designed to detect nuclear explosions but not the preparations for such events. Furthermore, it does not perform any measurements to verify compliance with the goal of "constraining the development and qualitative improvement" and "ending the developments of advanced new types of nuclear weapons". It could be argued that these goals, because they are listed in the Preamble, are not as important as those specified in the basic obligations. On the other hand, the CWC prohibits the development of chemical weapons as a basic obligation, yet it neither defines weapons development processes nor does it specify a monitoring system for measuring variables associated with such processes. The approach to the design of measurement systems for single event detection is also applicable for goals involving counting or itemization. The number of samples needed to estimate the size of a population is a function of the desired confidence level for the estimate. Similarly, the number and distribution of sensors needed to locate a seismic event of a specified minimum magnitude within a specified maximum distance from the actual event location is also a function of the confidence level for the estimate. Treaties specifying obligations regarding distinct events or inventory items are static systems in the sense that the obligations do not involve sequences of actions over time. In practice, a treaty may have both components. Prohibition of use of chemical weapons is the static component of the CWC, while the prohibition of the development and production of chemical weapons implies the existence of a dynamic system.

Measurement systems for monitoring multilateral treaties with global coverage may be grouped into two categories, one for measuring process variables for dynamic systems and the other for monitoring static systems. For static systems, the primary consideration for the design of monitoring systems is the number of measurement points be they by instruments, inspectors or file transfers. The measurement points could be locations for sensors, places where inspections can take place, or places where data records can be generated. For dynamic systems an additional important consideration is the frequency with which the measurements are performed. It determines the sampling frequency of sensed physical variables, the frequency of measurements for instruments measuring in-line process variables, the frequency of inspections and schedules for submitting reports.

The problem of designing monitoring systems for performing measurements anywhere on the globe may be subdivided into four separate problems: point measurements, facility measurements, area measurements and global measurements. Point measurements are defined as those performed by a single measurement tool in a specified location. The class of measurement tools includes sensors ranging from simple sensing elements such as temperature sensors, to complex instruments such as mass spectrometers, to inspections at a storage facility, to files from a single data storage device. The terms facility and area are somewhat arbitrary. Facility implies a location with a well-defined area, such a nuclear power plant, a military base, a seismic sensor array, a collection of computers connected through a local area network. By contrast, an area has no defined boundaries, but for treaty monitoring purposes it is defined as being smaller than a State or a region of a State.

For point measurements the design considerations are capabilities of instrumentation technologies, inspection procedures, auditing techniques and assurance of integrity of the raw data. At the facility level, the major design problem is how to interconnect the point measurement devices into an integrated facility monitoring system. The simplest example of such a problem is the design of a seismic array in a particular location to optimize direction finding. A more complex system is the one designed for real time monitoring of a fuel enrichment facility. For facility monitoring systems the main technical issues are the design of the network interconnecting the point measurement devices, the allocation of processing capabilities among the network nodes and the preservation of the integrity of the data flowing through the network. The integration of point measurement devices into a network brings up the issue of allocation of processing functions among the nodes of the network. One design approach may have all raw data from each sensing element transmitted to one or more central nodes for additional processing. Another may perform some amount (ranging from small to substantial) of processing at each sensing node and transmit only the results. Each of the options has an impact on the designs of both the network and the measurement devices.

For treaties requiring monitoring of extended areas, measurement may be done by instruments in situ or through remote sensing. In some cases such as monitoring emissions in the vicinity of plants unattended instruments could provide the required measurements and transmit them through a remote monitoring system. In areas where it is difficult to deploy ground-based sensors remote sensing either using airborne instruments or orbiting satellites might be the only option. For remotely monitored measurement devices the major questions that need to be addressed are the reliability of the device, and the integrity of the measurements and of the transmitted information. For remote sensing the primary technical issue is the capability of the remote measuring device to perform the measurements needed by the treaty verification regime. Finally, the global monitoring system is essentially a global communications infrastructure linking the point, site and area monitoring systems. At this level, the technical issues are similar to those of any other communications system that offers multiple classes of services such as file transfers and continuous data streams.

In summary, treaty monitoring involves the collection, processing and storage of information. The design of monitoring systems requires the solution of technological and methodological problems. The technological issues concern capabilities and limitations of sensing, transmission and storage of information. The methodological issues focus on deployment of sensing devices, architecture of monitoring networks, intrusiveness of devices and networks, integrity, reliability and cost-effectiveness of the entire monitoring system. Some treaties such as the CTBT and the CWC specify the monitoring system in great detail in the treaty itself making it very difficult if not impossible to improve it using accumulated experience. For example, the number and location of the primary monitoring stations for the CTBT are specified in the treaty. If operational experience were to suggest that the accuracy of locating an event would be improved by adding one or more primary stations, it would be difficult if not impossible to implement the change, because it would require re-negotiating the treaty. One could argue that using data from the auxiliary seismic stations to refine the calculations from the primary stations is equivalent to adding more stations. Even so, the number and locations of all stations are fixed and it is questionable whether those numbers could be changed. Similarly, it has been shown that the accuracy of locating nuclear explosions can be improved by combining seismic detection with satellite imagery. Although the treaty provides for the incorporation of additional monitoring technologies, the task would be difficult if not impossible. These problems exist because in the CTBT and CWC the monitoring systems were specified through negotiations and are included in the treaty text. Any change would require agreement among all States Parties. On the other hand, the NPT requires the States to accept safeguards applied by the IAEA. The IAEA introduces new technologies and methodologies as they become available and applicable. The Kyoto Protocol obligates the member States to "cooperate in scientific and technical research and promote the maintenance of systematic observation systems and development of data archives to reduce uncertainties related to climate system, verification, reporting and accountability". While the goals of a treaty are formulated on the basis of political considerations, objective verification of compliance can only be done, if the design of the monitoring system is based only on technical considerations.

6 Evaluation of treaty compliance

The most contentious subject in the operation of a treaty is the meaning of compliance. To quote again Winfried Lang [24]: "An especially difficult situation may arise when procedures of compliance control-verification lead to assessments reflecting various degrees of compliance and do not give a clear *black and white* indication of non-compliance. (see also Butler [28]) The notion of military significance of a violation shows that compliance with disarmament regulations is not something absolute. Thus, the following question has to be replied to: At which point of a scale of violations does a breach of international obligations occur that engenders the international responsibility of the state concerned with all the consequences linked to?"

In that context, the design of the monitoring system must include proper analysis of measurement errors and component failures. Due to these errors and failures, the inspectorate may make two kinds of wrong decisions which, of course, should be avoided as much as possible. First, the inspectorate may conclude from the data that there was an illegal action if in fact there was none - error of the first kind or false alarm. Second, the inspectorate may conclude that there was no illegal action if in fact there was - error of the second kind or no detection of an illegal action. In Table 3 examples for errors, failures and illegal behavior are listed for monitoring systems of the four treaties NPT, CFE, CWC, and CTBT.

Table 3. Examples of error, human failure and illegal behavior

Treaty	Error, Failure and Illegal behavior
NPT	• statistical error of nuclear material measurement • systematic error and/or failure of measurement instruments and Containment/Surveillance (CS)-systems • falsification of reported data • diversion of nuclear material from declared facilities • undeclared facilities
CFE	• counting error • random sampling error • falsification of reported data • increase and deployment of Treaty Limited Entries (TLE) and personnel beyond agreed threshold • TLE at undeclared military sites
CWC	• statistical error of material measurement • systematic error and/or failure of measurement instruments and C/S-systems • falsification of reported data • production of chemical weapons in declared facilities • undeclared facilities
CTBT	• statistical error of measurement instruments • systematic error and/or failure of measurement systems • earth quakes • weapons tests

To develop techniques for avoiding the afore-mentioned errors of the first and second kind, the instantaneous events or short term actions and the processes must be considered separately. In the case of short term actions, the accuracy and reliability of the measurement methods being part of the monitoring system have to be evaluated for each class of events. If this is done, then statistical decision theory provides the appropriate tools for the solution of the inspectorate's decision problem.

Take the case of the CTBT: Let us assume that the measurement error distributions and failure rates of the monitoring systems are known and furthermore, that the characteristics of an earthquake on one hand and that of an underground nuclear explosion on the other are known. Then, if a seismic event is registered, the procedures for discriminating between the two possible causes of the event - earthquake or nuclear explosion - although straightforward for data analysts, generate answers that have inherent ambiguities.

For processes, however, two new elements enter the stage. First, non-compliance strategies have to be taken into account. Take the example of the NPT, which has been analyzed the longest and in detail. The design of a monitoring system, including data reporting, depends on the assumed diversion strategies. One strategy could be to remove fissile material in quantities in the same order of magnitude as that of the accuracy of measurements. Another could be to remove quantities larger than the measurement accuracy and to falsify the reported data in order to conceal the diversion. Conversely, the diversion strategies depend on the implemented monitoring system.

Second, and most significant, to detect diversion from a process one needs to formulate a detection principle commensurate with the process. In the case of diversion of fissile material from a production process the *principle of mass conservation* is applicable. If there were no measurement errors, and no material were missing then the so-called book inventory at the end of some reference time - initial inventory plus receipts minus shipments - should be identical to the real or physical inventory at that time. Since measurement errors cannot be avoided, however, there will always be a difference between these two inventories and the data analysts have to find out, if this difference can be explained by measurement errors or not, i.e., if material has been diverted.

In sum this means that in addition to the statistical decision analysis, based on some detection principle, e.g., mass conservation in case of fissile material, game theoretical analyses must also be performed. Such analyses not only produce equilibrium strategies of inspectors and plant operators, including corresponding detection probabilities, but also describe the efficiency of the safeguards system [29], see also Avenhaus and Canty this volume. It should be mentioned in passing that this way conditions can be found under which the equilibrium strategy of a state is legal behavior, in other words under which conditions a state is *deterred from behaving illegally.*

Let us conclude with two other aspects of the evaluation problem: First, there is the probability of false alarms which have been mentioned already. Because of the measurement errors they can never be completely avoided as for example in the case of variable sampling procedures used for the measurement of bulk material. For a given monitoring system one can try to keep the false alarm rate as low as possible, but this goes at the expense of the probability of detecting illegal behavior. This general system property - any fire alarm system demonstrates this - has to be taken into consideration; formally the problem can only be solved by comparing the possible losses caused by these two errors, namely, false accusation of the innocent, and missing the guilty one.

Second, it turns out that if one determines - as mentioned with the help of decision and game-theoretical methods - optimal inspection strategies, then the size of the illegal action has to be taken into account. This does not mean that the inspection authority has to know it, but rather that the system has to be adjusted to some quantity of diversion of valuable material or illegal action in general which is considered militarily relevant. Thus, we see that the question raised at the beginning of this section, namely, which size of a violation means a break of international obligations, has to be answered in order that a rational verification system can be established.

7 Analysis of Treaty Performance

In this chapter we have sought to lay the foundations of a systematic approach for modeling and analyzing multilateral arms control and disarmament as well as environmental treaties. By considering a treaty as a system of interconnected components we have shown that the concept of verification of compliance is unambiguous only for those treaty goals that are quantifiable and therefore, measurable. For qualitative or ambiguous goals, there is no objective mechanism for defining and measuring compliance. For this category of goals, it becomes a costly and meaningless exercise to talk about "verification of compliance". Instead, terms such as "confidence building measures" might be more appropriate.

In fact, one of the main reasons for the arguments about verifiability is that treaties impose verification regimes on feasible as well as non-feasible goals. The verification regimes of the treaties examined in this chapter are imposed without regard to their applicability on all of the treaty objectives. Therefore irresolvable arguments arise. Let us mention in passing that, based on the preceding discussion, the objectives and implementation of the integrated safeguards regime for the NPT [27] needs a careful re-evaluation.

Even if the treaty goals are quantifiable, the question still needs to be asked, whether some or all of the goals reflect the objectives of the treaty as a whole. Assuming they do, it would be possible to design a monitoring system for collecting sufficient information in order to detect non-compliance. Even so, the question still remains how does one determine whether or not the cost of constructing such a system is acceptable? "How much is Enough" asked Alan Krass many years ago [6]. To answer that question one has to define in quantitative terms what is meant by "acceptable costs". In so trying one has to take into account further parameters of the verification system, such as the size of the militarily or environmentally significant quantity of an illegal action, the false alarm rate and the probability of detecting an illegal action. In addition to these parameters, which were already discussed in the previous section, the expected time between the beginning of an illegal action and its detection characterizes the verification system as well.

Thus, there are at least these five parameters of the verification system, which have to be specified. It then becomes a matter of choice which of those may be considered as boundary conditions and which ones as objective functions. In a practical approach one probably would try to keep the values of all of these parameters within "reasonable" limits.

From a conceptual point of view, the idea of deterring a State from engaging in illegal behavior provides an intellectually more satisfying approach for determining sufficiency of costs of verification systems. A State is induced to legal behavior or deterred from illegal behavior if the expected gain in the latter case is smaller than that in the former one. This idea has already been introduced into the official NPT language a long time ago. In the Verification agreement INFCIRC/153 [30] it is written "and the deterrence of such diversion by the risk of early detection". In order to use this deterrence idea for a quantitative determination of the monitoring effort in a concrete case, the *utilities* of a State have to be estimated for both detected and undetected non-compliance.

Let us summarize our ideas of an appropriate analysis of the performance of a specific arms control and disarmament or environmental treaty by posing the following questions which have to be answered in the course of such an analysis:

- Are the objectives of a treaty feasible? What does feasible mean?
- Given that these objectives are feasible, how can compliance with these objectives be measured or evaluated?
- Given an appropriate verification system is established, do the objectives characterizing this system reflect the objectives of the treaty itself?
- What is the minimum information necessary for evaluating compliance? Can the monitoring regime specified by a treaty provide sufficient information to evaluate compliance?
- Given that the objective of the verification regime could be reached in principle, and the minimum information necessary for evaluating compliance could be provided, would the resources required to achieve these objectives be realistic in terms of cost, manpower etc?

It is this kind of analysis which oscillates between technically sophisticated and high-level political considerations that has not been yet performed on a larger scale. The systematic approach described in this chapter forms the basis of a new scientific discipline. Adopting such an approach would improve the operation of existing treaties, optimize the design of future treaties and help minimize the arguments about compliance.

References

1. Geneva Protocol, (1925): *Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare*, Arms Control and Disarmament Agreements (1996 Edition), U. S. Arms Control and Disarmament Agency, Washington, DC, USA.
2. Chemical Weapons Convention (CWC), (1993): *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction,* http://www.opcw.org/html/db/cwc/eng/cwc_frameset.html.
3. Comprehensive Nuclear-Test-Ban Treaty (CTBT), (1996): http://www.ctbto.org/treaty/treaty_text.pdf.
4. Biological Weapons Convention (BWC), 1972: *Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction*, Arms Control and Disarmament Agreements (1996 Edition), U. S. Arms Control and Disarmament Agency, Washington, DC, USA.
5. Curnow, R., M. Kaldor, M. McLean, J. Robinson, P. Sheperd, (1976): General and Complete Disarmament - A Systems Analysis Approach, *Futures*, Kidlington, Oct. 1976, vol. 8, Issue 5, pp. 384-396.
6. Krepon, M. (1984): Arms Contro*l Verification and Compliance,* Foreign Policy Association Headline Series, No. 270, September/October 1984.
7. Krass, A. (1985): *Verification: How Much is Enough?* Taylor and Francis, London, UK, and Philadelphia, PA, USA.
8. Mærli, M. B. and R. Johnston, (2002): Safeguarding This and Verifying That: fuzzy concepts, confusing terminology, and their detrimental effects on nuclear husbandry. *The Nonproliferation Review*, vol.9, no.1, pp. 54-82.
9. Tsipis, K., D. W. Hafemeister, P. Janeway (eds), (1986): *Arms Control Verification: The Technologies That Make It Possible*, Pergamon-Brassey's International Defense Publishers, McLean, Virginia, USA.
10. Arnett, E. H. (ed), (1989)*: New Technologies for Security and Arms Control: Threats and Promise*, Washington, DC, American Association for the Advancement of Science, Washington, DC, USA.
11. National Research Council (NRC), (1990): *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, National Academy Press, Washington, DC, USA.
12. Schroeer, D. and D. Hafemeister (eds), (1998): *Nuclear Arms Technologies in the 1990s*, American Institute of Physics, New York, USA.
13. National Research Council (NRC), (2002): *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty*, National Academy Press, Washington, DC, USA.
14. Suppression of Terrorist Bombings (STB), (2001): *International convention for the suppression of terrorist bombings*, http://www.state.gov/documents/organization/38408.pdf
15. Kyoto Protocol, (1997): *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, http://unfccc.int/resource/docs/convkp/kpeng.html
16. Avenhaus, R. and N. Kyriakopoulos, (2000): A Systematic Approach for Closing the Gap between Expectations and Reality in Arms Control, *Proceedings of the*

22nd ESARDA Seminar: Strengthening of Safeguards: Integrating the New and the Old", Dresden, Germany, 8-10 May 2000
17. Conventional Forces in Europe (CFE), (1990): *Treaty On Conventional Armed Forces In Europe*, http://www.fas.org/nuke/control/cfe/text/cfe_t.htm
18. Non-Proliferation Treaty (NPT), (1968): *Treaty on the Non-Proliferation of Nuclear Weapons*, Arms Control and Disarmament Agreements (1996 Edition), U. S. Arms Control and Disarmament Agency, Washington, DC, USA.
19. Richards, P. G. (1988): Stages Toward a New Test Ban, in Krepon, M. and M. Umberger (eds), (1988): *Verification and Compliance: a Problem-Solving Approach*, Ballinger, Cambridge, MA, USA, pp. 73-91.
20. Kyriakopoulos, N. (1998): The Fuzzification of Monitoring, *Proceedings of the Seminar on Modern Verification Systems: Similarities, Synergies and Challenges*, Helsinki, Finland, 12-14 May 1998, pp. 279-288.
21. Zadeh, L. A. (1965): *Fuzzy Sets, Information and Control*, vol 8, pp. 338-353
22. Zadeh, L. (1994): The Role of Fuzzy Logic in Modeling, Identification and Control, *Modeling Identification and Control*, vol. 15 No.3, pp. 191-203.
23. United Nations Institute for Disarmament Research (UNIDIR), The Verification, Research, Training and Information Centre (VERTIC) (2003): *Coming to Terms with Security: A Handbook on Verification and Compliance*, United Nations publication, Sales No. GV.E/A.03.0.12.
24. Lang, W. (1995): Compliance with Disarmament Obligations. ZaoRV 55, pp. 69 - 88.
25. Lang, W. (1996): Compliance Control in International Environmental Law: Institutional Necessities. ZaoRV 56, pp. 685 - 695.
26. Lundin, S. J. (Ed), (1991): *Verification of Dual-use Chemicals under the Chemical Weapons Convention: The Case of Thiodiglycol*, (SIPRI Chemical and Biological Warfare Studies, no. 13), Oxford University Press, New York, N. Y., USA.
27. International Atomic Energy Agency (IAEA), (1997): *Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards.* INFCIRC/540 (corrected), IAEA, Vienna, Austria.
28. Butler, W. E., (ed), (1991): *Control over Compliance with International Law*, Dordrecht and Boston and Norwell, MA, U.S.A.: M. Nijhoff Publishers.
29. Avenhaus, R. and M. Canty, (1996): *Compliance Quantified - An Introduction to Verification Theory.* Cambridge University Press, Cambridge, UK.
30. International Atomic Energy Agency (IAEA), (1972): *The Structure and Content of Agreements Between the Agency and States Required in connection with the Treaty on the Non-proliferation of Nuclear Weapons.* INFCIRC/153 (corrected), IAEA, Vienna, Austria.

II

Treaties and their Requirements

International treaties are indispensable for global governance. In particular treaties for arms control and non-proliferation as well as environmental issues are of prominent concern. Examples of different treaties and their requirements are discussed here. Special emphasis is given to verification mechanisms and their institutional bases.

Arms Control and Non-Proliferation Treaties: An Ontology of Concepts and Characteristics

André Poucet

1 Introduction

To reduce the risk and proliferation of arms, particularly weapons of mass destruction, a number of international treaties and other agreements and export control regimes have been concluded. Their purpose is to reduce or eliminate certain weapons or weapon systems, to curb the proliferation of weapons and of sensitive, dual-use technologies, or to increase security and build confidence in other ways. Some of these treaties are multilateral and intended to cover all States, such as the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Conventions on Biological (BWC) and Chemical Weapons (CWC), the Comprehensive Nuclear Test Ban Treaty (CTBT). Others are applicable to a particular region, such as the Conventional Forces in Europe Treaty (CFE), the Open Skies Treaty, the Antarctic Treaty, the Treaty of Tlatelolco, covering Latin America, and other nuclear weapon-free zone treaties. Some others are bilateral at origin, such as the Intermediate Nuclear Forces Treaty (INF) and the Strategic Arms Reduction Treaty (START).

In [1] an extensive overview of arms control treaties is presented and their characteristics analysed. Much of the analysis in that paper served as a basis for this chapter. In the following sections, the most important non-proliferation treaties, NPT, CWC, BWC and CTBT are presented in detail. Also the CFE, an arms control treaty, and the Kyoto protocol (an example of verification to protect the environment) are presented in detail.

Most of the treaties include technical and institutional measures of verification in order to prevent or detect possible violations. Some of these verification measures are extensive, with technical monitoring systems and specialized agencies to implement the monitoring of the treaty. Many include on-site inspection provisions and several have elaborate technical systems to collect, analyze, distribute and exchange technical information. While the verification procedures were designed for specific treaties, they have elements in common on a generic level. It is at this generic level that we may gain insightful guidance for the blueprints of future international agreements. In the following sections, we are comparing the legal and technical aspects of the Treaties and Agreements and make an attempt to classify the verification provisions with respect to their objectives, scope and technical means.

The current world situation, with new and increased security threats, including proliferation of weapons of mass destruction, disruption of critical infrastructure, terrorism or trafficking, will require new international or multilateral instruments e.g. on security in the supply chain (container security), to counter proliferation of explosives, small arms and man-pads, to deal with cyber-crime etc. The lessons learned from existing Treaties and Agreements can help to draft such new instruments.

2 Overview of the main arms control related treaties and agreements

A description of the most important arms control related treaties and agreements is presented in the following sections of this chapter. Here we limit the discussion to a brief introduction to these treaties and conventions allowing the reader to understand the comparison of their general characteristics, as summarized in Table 1.

Table 1. General treaty characteristics

	Legally Binding	Politically Binding	Data Exchange	Verification instruments	OSI Routine or Challenge	Governing body	Verif. Org.	Final action on violation	Worldwide Regional or Bilateral
NPT	X		X	X	R+C		I	SC	W
CWC	X		X	X	R+C	X	I	GA/SC	W
BWC	X		X					SC	W
CTBT	X		X	X	C	X	I	UN	W
Ottawa	X		X		C	X		OP	W
INF	X		X	X	R	X	N	OP	B+
START	X		X	X	R+C	X	N	OP	B+
TTBT/PNET	X		X	X	R	X	N	OP	B
CFE	X		X		R+C	X	N	OP	R
Open Skies	X			X	R	X	N	OP	R
Export controls		X	X			X		OP	

The table provides information on the following characteristics:

- Whether or not the treaty or agreement is legally binding (stronger) or politically binding (weaker). This is discussed in more detail in section 3.2;
- If there is a provision for exchange of data (e.g. declarations). In fact this is almost always the case with the exception of the Open Skies Treaty and the Treaty on Conventional Armed Forces in Europe;
- If there are verification instruments such as measurement or monitoring equipment;
- If use is made of on site inspections, either routine (R) or challenge (C) on-site inspections or both;

- The presence or not of a governing body and the presence and type of a verification organization either international (I) or national (N). Then latter is typical for bilateral agreements where the Parties verify each other. Also in CFE, although the Treaty is Regional (hence multilateral) , the verification process is bilateral and done by national organizations;
- Who is taking action when a violation is detected: as indicated in the table, the United Nations (UN) have played a significant role in many international treaties. In 1980 the United Nations General Assembly (GA) established a verification mechanism for the 1925 Geneva Protocol banning the use of chemical and biological weapons. A number of multilateral treaties contain provisions for questions regarding compliance to be addressed by the United Nations, usually the Security Council (SC). The Secretary-General also receives annual reports on compliance and organizes fact-finding missions for the Landmine Convention, collates reports for the United Nations Register on Conventional Arms, and produces the annual reports on confidence-building measures for the 1972 BWC. In bilateral treaties but also in export control regimes, CFE and Open Skies, (one of) the Parties are often taking action (OP: Other Parties);
- If the Treaty or Agreement has the ambition to be worldwide (W), regional (R) or bi-lateral (B);

The following Treaties and Agreements have been analyzed:

The **Non-Proliferation Treaty** includes three pillars: nuclear non-proliferation, disarmament and development of peaceful uses of nuclear energy. The Treaty is legally binding and almost universal as it was ratified by 189 State parties with only five States out (India, Pakistan, Israel, Cook Islands and Niue). Recently one Party, North Korea, withdrew. The verification rests on the International Atomic Energy Agency (IAEA) in Vienna and is based on declarations by State Parties of inventories and movements of fissile materials and (under the Additional Protocol) of declarations of nuclear activities. Use is made of analysis of data obtained from remote or on-site inspections (routine inspections, and, as part of the Additional Protocol, short notice challenged inspections), sampling (in facilities or, under the Additional Protocol, in wider areas) as well as other open source data (e.g. satellite imagery) to check the declarations systematically.

The **Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction** is legally binding and is also almost universal as it has 153 Parties with 16 countries (mainly from the Middle East) missing. The verification regime is based on declarations by State Parties on stockpiles and their destruction, production facilities and their dismantling, research labs and chemical plants producing specific chemicals. The declarations are checked (sometimes partially depending on the issue) mostly by routine inspections.

The Organisation for the Prohibition of Chemical Weapons in The Hague implements the Treaty. It consists of a technical secretariat guided by a governing body (the Executive Council of 41 States) and a yearly Conference of State Parties.

The **Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction** is also conceived as a legally binding and universal Treaty with currently 151 State Parties with a further 16 that have signed but not yet ratified. At this moment, the Treaty has no verification or monitoring arrangements, but just periodic review conferences.

The **Comprehensive Nuclear Test Ban Treaty** has the objective to eliminate all nuclear weapon tests thereby preventing proliferation of nuclear weapons and supporting nuclear disarmament. To fulfill the objective, the Treaty needs to be universal and effectively verifiable. Currently 168 States have signed the Treaty and of those 105 have ratified. However, to become effective, it needs ratification of 44 Member States (explicitly mentioned in the Treaty itself) of which currently only 32 have ratified. The Comprehensive Test Ban Treaty Organisation (CTBTO) will be established as soon as the Treaty enter in force. CTBTO will have a Conference of State Parties, an Executive Council and a Technical Secretariat. The verification regime consists of an International Monitoring System (IMS), Consultation and Clarification between Members, On-Site Inspections and Confidence Building Measures. IMS is a network of facilities for seismological monitoring, radionuclide monitoring, hydro-acoustic sensors, infrasound sensors and respective communication. The International Data Center (IDC) receives and processes the data and makes these available on-line to the State Parties. Each State Party has the right to request an on-site inspection on the territory of any other State Party. It is an example of intrusive, challenge inspection regime.

The **Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction (Ottawa Convention)** has the overall objective to eliminate all anti-personnel mines worldwide and has been signed by 133 Parties (not by US, China, India, Pakistan and Iran). The treaty asks for a detailed declaration, to be updated yearly and indicating the location of land minded areas, their clearance, the mines destruction of stockpiles etc. There is no real verification mechanism, but a possibility to send fact-finding missions. A yearly conference of Parties is held and Non Governmental Organisations (NGO's) play a significant role in these meetings and are fully accepted by the State Parties. NGO's play an important role in mine clearance and assistance to victims.

The **INF and START Treaties** have the objective to eliminate ground launched ballistic and cruise missels with ranges between 500 and 5500km (INF) and to reduce Intercontinental Ballistic Missiles (ICBM), Submarine Launched Ballistic Missiles (SLBM) and heavy bombers (START). Originally these treaties were signed between the United States (US) and the Soviet Union. Since the breakup of the Soviet Union, the signatories include Russia, Kazakhstan, Ukraine and Belarus. The verification regime provides for the use of national technical means, notifications, cooperative measures, perimeter and portal continuous monitoring (with X-ray machines and in certain conditions neutron detectors) and on-site inspections. Interestingly the inspections were sometimes outside the territory of the Parties but in "host states" (Belgium, Italy, the Netherlands, Germany, United Kingdom (UK)) facilitated by separate agreements with these states.

The **Threshold Test Ban Treaty (TTBT)** was signed in 1974 between the US and the USSR (later Russian Federation) to limit nuclear weapon test explosions to a maximum yield of 150 kt. The original treaty was to be verified by using national technical means helped by provisions of geological and geophysical data on test sites. In 1990, additional protocols were signed to add intrusive and complicated on-site inspection procedures. Verification is helped by tele-seismic measurements. During certain tests, each Party was allowed to operate independently three seismic stations on the territory of the testing Party.

The **Treaty on Conventional Armed Forces in Europe** has the objective to achieve a stable balance of conventional armed forces in Europe and to eliminate the capability of launching surprise attack and large-scale offensive action. It is by nature a regional Treaty, signed by 30- states in Europe, CIS and the US. The verification regime is monitoring deployment and reduction in air and ground forces and heavy military equipment. For that reason, the State Parties notify location and numbers of heavy military equipment, movement or reduction of such equipment. On-site inspections on declared sites to verify the correctness of the notifications are carried out, as well as challenge inspections in certain areas. The inspection regime is based on the principle that one State Party inspects another State Party, so there is no multilateral verification agency. The governing body for the Treaty is a Joint Consultative Group, open to all Parties.

The **Treaty on Open Skies** establishes an aerial observation regime with the objective to strengthen peace and security in Europe. So it is basically a confidence building scheme between 30 States in Europe, Central Asia, Canada and the US. The inspection regime allows overflights of all of the territories of the State Parties which are organized in co-operation between observing and observed States. The verification procedures include annual quotas, maximum flight distances, notification protocols (e.g. 72 hour notification), provisions for certification of aircraft and for allowed instrumentation. There is a Central Data Bank, operated by the OSCE secretariat where all notifications of flights are stored (but not the observation data).

Export Control Regimes like the Nuclear Suppliers Group (NSG), the Australia Group (AG), the Wassenaar Arrangement (WA), the Missile Technology Control Regime (MTCR) and The Hague Code of Conduct against Missile Proliferation (HCOC) all have the objective to reduce the proliferation of direct and dual use materials and equipment in nuclear (NSG), biological and chemical (AG), conventional weapons (WA) and missile technology (HCOC, MTCR). There are no verification regimes but under NSG, AG, WA and MTCR the export denials are communicated to other parties. Participating States have national legislation to enforce the import/export guidelines.

3 Legal concepts and mechanisms of the verification process

In broad terms, verification is an agreed process covering the entire set of measures enabling the parties to establish that the conduct of the other parties is compatible with the commitments they have assumed under that agreement. The objective of the verification process is to provide assurance that States execute and respect agreed commitments, thereby building confidence between them on a global scale or within the actual region.

3.1 Elements of the verification process

The verification process includes several elements. Four associated and successive themes may be distinguished:
a) The existence of a basic commitment, whether a legal norm or a loose political agreement, in relation to which the parties' behaviour will be defined, observed, evaluated and qualified.
b) The acquisition of factual data regarding legal instruments, practice and behaviour related to a basic commitment. For disarmament or arms control agreements, it includes knowing the measures taken by the States to implement their commitments. States must also be able to observe the conduct of each other to assess that none of them drifts away from the agreed commitments. The factual data may be provided by the concerned parties themselves in a transparent process as confidence-building measures or may be obtained through an international verification regime.
c) The analysis of these data, their interpretation and evaluation from a technical, legal and also political point of view. The norms at stake often present a certain degree of flexibility, so that they can be applied and respected in

different ways. The analysis should address how States are fulfilling their basic commitments, taking into account international legal traditions and rights. States can conduct the analysis individually or through a specific international body.
d) An assessment of a States legal qualification takes an ensemble of the aforementioned elements into account. The purpose is to assess if a particular State or States respect the basic commitments or if they are in breach of their obligations or international law. Thus, far from being an objective and automatic process, this may result in consultations among concerned States. In the end there might even be grounds for disagreement that could provoke the implementation of other procedures provided for in the agreement.

3.2 Legal experience and practices

There are basically two types of instruments that are designed to regulate the conduct of States in international society: legally binding and non-legally binding documents. A legally binding document, i.e. an international treaty, carries the maximum obtainable binding force, and thus the sanctions that may be imposed in cases of a breach could also be expected to be strict. It would also more easily be implemented in a domestic juridical system than a non-legal document, particularly in those countries that have adopted the so-called incorporation system, in which a treaty, once concluded, may have direct domestic legal effect without the legislature enacting a domestic law implementing the treaty.

It sometimes takes time to conclude and implement an international treaty. This is particularly true of those treaties that require approval of respective States' parliament and subsequent ratification. For instance, the 1982 UN Convention on the Law of the Sea took 12 years to enter into force in 1994; more than four years passed before the CWC took effect in 1997. The CTBT has yet to enter into force seven years after its opening for signature. Such a problem would not arise in the case of non-legally binding documents. They come into force as soon as they are signed or adopted, unless otherwise specified.

It is true that not all treaties are subject to national parliamentary process. The so-called executive agreements can be concluded between executive bodies without parliamentary involvement. Nevertheless, they may go through a strict legal scrutiny within the respective Executive Branches, depending on each State's national treaty-making system. Moreover, if they contain provisions that affect private rights of the citizens they are, in most countries, required to have parliamentary consent before being concluded. But this would not be the case with non-legally binding documents even if they contain similar provisions.

In terms of amendment, most treaties provide for a procedure comparable to, and as strict as, their conclusion. In addition, an amendment may well lead to two different regimes; between those States that stick to the original one and those that prefer the amended one. In the case of non-legal documents, the procedure of revision is as simple as their adoption, usually a general agreement among the participants. This gives more flexibility to the documents and has less risk of producing double regimes.

The most important merit of treaties in comparison with non-legal instruments lies in their binding force. A non-legal document's authority is not necessarily less than that of treaties. For instance, documents adopted within the framework of the CSCE/OSCE have been well respected and implemented by all participating States as if they were treaties.

In the security and arms control field non-legally binding instruments are frequently used. Among the most salient examples are the Helsinki Final Act, the Stockholm Document, and the Vienna Documents on Confidence- and Security-Building Measures agreed upon and implemented within the framework of the CSCE/OSCE. In addition, agreements establishing export control regimes are all non-legally binding: the Nuclear Suppliers Group, Australia Group, MTCR and Wassenaar Arrangement. These regimes have generally been well implemented through national legal processes by transforming the rules into domestic laws. Worth mentioning in this respect is the International Code of Conduct against Ballistic Missile Proliferation, which had been negotiated in the framework of MTCR and adopted in The Hague in November 2002. Although non-legally binding, it requires subscribing States to take transparency measures and provides for regular meetings to review and develop further working of the Code.

However, one should not overlook the fact that the arms control areas in which non-legal instruments have frequently been used thus far are limited to those of harmonization of export control legislation and confidence-building measures. This fact may suggest that drastic measures involving limitations, reductions or eliminations of weapons or weapons systems require something more than just a political instrument, given the nature of the measures to be taken. There is a conspicuous exception to this general trend: the Agreed Framework signed in October 1994 between the United States and the Democratic People's Republic of Korea (DPRK). Though only politically binding, it contains such rigorous measures as the freeze and ultimate dismantlement of specified nuclear facilities in North Korea. This may be due to certain external factors, including the possible implications of US recognition of the North Korean "State,"should it have been concluded as a legal document.

Apart from a multilateral agreement or arrangement, it is also possible to form a legal frame as a UN Security Council resolution adopted under Chapter VII. Such a resolution is legally binding and can take effect immediately. There are already precedents in which a document usually formulated in an international agreement took the form of a Security Council resolution, including Resolution 827(1993), which adopted the Statute of the International Tribunal for the Former Yugoslavia. In relation to terrorism, the Security Council adopted Resolution 1373(2001), which encompasses a large set of measures to prevent and suppress terrorism.

4 Technical concepts and mechanisms of the verification process

4.1 Characteristic attributes of the verification process

Without making an attempt to develop a complete taxonomy, verification activities can be distinguished on the basis of a number of attributes. When a technical verification system is developed, such attributes are to be considered in the implementation and may have an impact on the technologies and methodologies that can be deployed in such a system. Five important attributes are discussed below.

The object of verification

The object of verification can be any of a combination of the following:

- the presence (or the absence of) events (event based);
- the correctness of a declaration;
- the completeness of a declaration;
- the adherence to a procedure;
- information provision as a confidence building measure.

Verification in the context of CTBT could be qualified as event based: it verifies the absence of any evidence of nuclear test explosions through a sophisticated network of real time monitoring stations. NPT safeguards verification has been traditionally verifying correctness of State declarations. With the introduction of the Additional Protocol, besides the expanded contents of the State declaration, the verification now not only includes the correctness but also the completeness of the State declaration. Verification under the Open Skies treaty can be qualified as confidence building: it is a provision of information and not a verification of adherence of a procedure or of the correctness/completeness of a declaration.

A distinction can be made between positive verification and negative verification. Positive verification is a demonstration that the commitments made have been respected. In practice this can be achieved only in few cases, such as inspection of the destruction of an agreed number of weapon or weapon systems. Verification in most cases secures a negative demonstration - no breach of the commitments made can be assessed and it is then assumed that they have been respected. States are always presumed to respect their commitments de bona fide, and it is necessary to demonstrate an alleged violation.

It can be noted that the negative verification i.e. the absence of events (as opposed to presence) or of the completeness of a declaration (as oppose to correctness) can be a difficult and wide scoping process since the real situation against which the verification must be made can be open ended.

The directness of the verification

A distinction can be made between direct verification and indirect verification. Direct verification is used in arms reduction treaties (START, INF), where the Parties directly verify the adherence to agreed procedures on reduction of deployable weapons or weapon dismantling. The NPT relies on verification of a declaration and is therefore qualified as indirect. CTBT makes use of indirect verification of (the absence of) evidence of tests.

Another distinction can be made between unilateral verification, when one or several States individually assess the behaviour of another State, and the verification imposed on a State from either a cooperative process among concerned States, or an agreed institutional mechanism. The former belongs to international general law, while the latter belongs to specifically organized international processes.

The control strategies

Mitchell [2] distinguishes between six strategies of control:

1. Deterrent strategies: involving sanctions, threats or implying a cost;
2. Remunerative: to make the desirable behaviour more attractive;
3. Preventive: trying to eliminate the choice of non-compliance;
4. Generative: generating alternative opportunities such as in the closed cities initiative or the International Science and Technology Centre (ISTC);
5. Cognitive: e.g. trying to clarify financial, technical and safety risks of weapon development;
6. Normative: trying to change behaviour by altering moral values.

In general, all treaties invovle confidence building measures facilitating the agreements' conclusion and implementation. Some functions are preventive, or dissuasive, because verification raises the cost of a violation and makes non-compliance or "cheating" more unlikely. Verification also fills an early warning function as it enables States to uncover breaches to an agreement at an early stage. Last, it enables the parties to an agreement to react effectively against these violations, once the penalties are established.

Deterrent strategies are difficult to implement and do not always result in effectively changing the conduct of a state. In fact, a weak point or difficulty with arms control regimes has been what to do when ambiguities or violations are discovered by the verification mechanisms. Very few penalties have actually been implemented, and sometimes ambiguities remain unclarified. Sanctions are difficult to agree upon, difficult to implement and not always effective in changing the conduct of a country even when they are applied. For many reasons, States are loathe to expel others from an arms control treaty for violations. Thus one way around this problem is to tighten national implementation measures by developing and enhancing legislation to cover actions of each nation's citizens in any location under its jurisdiction. State Parties to the BWC, for example, are in the process of working on enhanced national implementation measures.

The type of reporting

The reporting can be done by the Party to the Treaty itself as in the NPT, it can be by another other Party, or it can "problem" based reporting. Problem reporting implies a (continuous or not e.g. sampling based) independent monitoring function. CTBT is a typical example of a problem reporting verification system which because of the nature of the events monitored needs to be continuous (24h per day, 7 days per week). In NPT safeguards, the Party is self reporting and the verification organization is checking correctness and completeness. Problems are identified when there is a mismatch between declaration and evidence found during inspections etc. (see below). Continuous monitoring is not always feasible and the concept of timeliness (of detection) is used.

The information used in the verification

In this context, Brown [3] identifies five general categories of verification measures:

1. Cooperative measures; e.g. exchange of military information, of design information (as in safeguards);
2. National technical means, for instance non-intrusive observation from radar, optical, and satellite surveillance;
3. Technical monitoring or measurement devices placed at or near sites;
4. On Site Inspections (OSIs);
5. Intelligence channels, collecting information from agents, immigrants or defectors, communication intercepts, and information leaks.

In recent verification activities, an increasing use is made of open source data (on the internet, on-line news services, data bases etc.) and commercial satellite imagery. The information collected is similar to that collected with national technical means or intelligence channels but it is available also to agencies that do not dispose of internal intelligence resources.

Some verification systems may not fall unequivocally into a certain attribute category. This is particularly true for the information collection attribute where many verification systems use a combination of information collection. In other cases, the verification system may have different attribute values depending on the particular phase in the verification process. As an example, when an anomaly is detected in the verification of Additional Protocol (AP) declarations (indirect verification), a direct verification by means of an on-site inspection may occur.

5 Verification tools

Most of the treaties and agreements contain technical, institutional and administrative procedures to verify that States Parties comply with the treaty provisions. The verification procedures are designed specifically for the particular treaty, but on a more generic level they have a great deal in common. Many include on-site inspection/observation provisions and some have extensive technical systems to collect, analyze and distribute technical information.

While most arms control agreements have more or less extensive verification provisions, a few have no verification or monitoring arrangements at all, but just periodic review conferences (e.g. BWC). Where verification provisions are included, they are designed to provide confidence that States Parties are adhering to the requirements of the agreement. In general, verification provisions are designed to deter non-compliance, or to detect non-compliance if it does occur. The following paragraphs discuss some of the main tools in the verification process.

5.1 On-site inspections

On-site inspections, which can be either routine or challenge, are included in the verification provisions of many arms control agreements. The NPT and CWC provide for both routine inspections of declared facilities and challenge inspections. The conversion or elimination of nuclear weapon systems under the START and INF Treaties, and of conventional weapon systems under the CFE Treaty, are subject to intrusive on-site inspections, as are some nuclear test explosions under the TTBT or under the CTBT. Some inspections, such as those that monitor conversion or elimination activities, are scheduled well in advance. Others are conducted on very short notice, to minimize the possibility of hiding illegal activities. Some agreements require the regular exchange of data. This facilitates verification by providing a database that can then be monitored by inspections and National Technical Means (NTM). Many agreements limit the number of inspections by means of a quota system (INF, START, CFE, Open Skies). Some inspections are conducted on a bilateral basis (TTBT, START Treaty before the breakup of the USSR). Others are conducted by groups of States Parties (CFE, Open Skies). Still others are conducted by international organizations (NPT, CWC, CTBT).

Since the purpose of all verification arrangements, and in particular of OSI provisions, is to preserve and enhance confidence, it is essential that OSI rules and procedures be designed and implemented in such a way that they protect the legitimate rights and concerns of both the inspecting and inspected parties. Thus the inspecting party needs to have sufficient access to provide confidence that the agreement's obligations are being fulfilled. At the same time, the inspected party should be protected from unreasonable interference with its normal activities or unwarranted intelligence activities. Arms control agreements have generally been successful in finding this balance. It has proven possible to implement very intrusive measures on a global scale involving not only government facilities, but also private property and industry. Routine inspections, including those of industrial facilities, have worked well and enhanced confidence. Although there is less experience with challenge inspections, when carried out properly, they can be very effective in building confidence. If, however, challenge inspections are seldom used, there is the danger that their application will be seen as an accusation, rather than an attempt to clarify an ambiguous event.

5.2 Technical Monitoring systems

In addition to OSI provisions, some treaties have provisions for technical verification systems. The CTBT has the most extensive global monitoring system that provides States Parties with information that no single State can obtain on its own.

The International Monitoring System of the CTBT provides for over 1,500 autonomous sensors (seismic, hydroacoustic, infrasound and radionuclide particulates and gases) located in 321 stations in 92 countries around the globe. The stations are in many cases operating in remote areas and under hostile conditions. The sensors are designed specifically to detect nuclear explosions, but the data on radionuclide particulates and gases could be useful also for other nuclear monitoring purposes. The stations are operated as a unified system and provide standardized information to an International Data Center in Vienna. Data and information are sent "in the clear" (un-encrypted), but with a digital signature to assure the integrity of the data, both in transit and in the data bases at the central receiving facility. A centralized administrative body, the Provisional Technical Secretariat during preparatory phase prior to entry into force of the Treaty, establishes norms, formats, specifications of equipment and oversees the ongoing build-up, testing and evaluation of the monitoring system.

Extremely large volumes of data (gigabytes per day) are collected and automatically processed to result in two million events to be examined per year. Automated screening procedures are used to identify the small overall fraction of data that is related to events that might require further examination. All participating national authorities are assured of complete access to all data. The assessment of the information regarding the nature of observed events is the responsibility of States Parties.

The Open Skies Treaty provides for the use of observational aircraft equipped with cameras, videos, infrared and radar equipment with closely specified capabilities. The information collected during overflights is available to all parties to the treaty.

It has proven possible and important to use modern technology, e.g. large data bases, sensor technologies, information and communication technologies, in such verification systems. Experience has shown that the design of a successful verification system requires an overall systems approach. This ensures that the end users will receive the intended verification product in a timely way. National authorities, industry and research institutes have an essential role in designing and implementing verification arrangements. The establishment and operation of technical verification systems also contribute significantly to building confidence.

5.3 Verification tools in safeguards

The classical nuclear safeguards system implemented by the IAEA is based on the verification that no diversion of material declared under safeguards has occurred. In the verification process data from accountancy declarations are compared with results of inspection activities. This is therefore a process of verifying the correctness of declarations. For a nuclear facility, or group of facilities, material balance areas and key measurement points are defined to create a material accountancy system in which both the declarant and the inspector have to take their measures. Extensive use is made of highly sophisticated instruments to perform these measures. Discrepancies observed lead to so-called Material Unaccounted For (MUF).

In practically all fuel fabrication and reprocessing facilities, non-destructive measurement equipment is installed. This may be gamma spectrometry, passive or active neutron counting. Such instrumentation is intended to measure entire items without the need for taking a sample. Modern instrumentation should allow unattended measurements of the items of interest. Where non-destructive analysis is not applicable, samples are taken and shipped to a specialized laboratory for analysis. The installation of On-Site Laboratories at large reprocessing plants has significantly contributed to provide timely results.

To guarantee that nothing unacceptable happens in between inspections (in jargon "to guarantee continuity of knowledge"), use is made of surveillance systems and of seals. Digital surveillance cameras are now common for surveillance purposes. The amount of images may become very large and review of surveillance images requires a significant effort. Inspectors are greatly supported in their analysis work by sophisticated computer programs. Computer algorithms allow the automatic extraction of features in images and the detection of changes in such features from one image to the next. A range of sealing systems with different degrees of hardening against tampering exists.

The introduction of the Additional Protocol has led to a profound change in the safeguards verification approach. In addition to verifying correctness of declarations, the IAEA has also to verify the completeness of a state declaration. Moreover, the verification is extending from accountancy based verification, i.e. based on quantitative information on inventories and movements, towards qualitative verification. Among other things, the IAEA is using open source information as an independent means for verification of the completeness and correctness of declarations submitted under AP. The open source information includes satellite images and other information, much of which is of a qualitative nature.

The analysis of "environmental" samples is another of the technical means for detecting undeclared nuclear activities, e.g. separation of plutonium or production of highly enriched uranium. In particular particle analysis has demonstrated to be a powerful technique in this respect. Swipe samples may be collected inside or outside a facility. On such a swipe, uranium or plutonium particles need to be identified and their isotopic composition is subsequently measured.

5.4 Preparatory technical work

Experience from the Open Skies Treaty, the CTBT and the CWC shows that technical expert work prior to and during negotiations on verification methods, technologies and equipment is essential for the design of the verification provisions of a treaty and for its implementation. During the CWC negotiations a number of test inspections were made and similarly a number of test flights were conducted prior to the entry into force of the Open Skies treaty. A Group of Scientific Experts worked for more than fifteen years at the Conference on Disarmament to develop and test a verification system for the Nuclear Test Ban Treaty. During this preparatory technical work, a prototype International Data Center was developed and many of the seismic stations of the global network were established. To pave the way for the TTBT, calibrating the yield estimation methods and joint verification experiments were conducted at US and USSR test sites. These examples demonstrate the importance, if not the necessity, of co-operative preparatory work. Similar technical expert work could be undertaken in advance of negotiations on new treaties and agreements. Japan has for, example, suggested that such expert work commence on how to verify the cessation of the production of fissile materials for weapons purposes (so-called "Cut-off").

6 The cost

It is difficult to analyze the cost benefits associated with arms control, as there are no quantifiable pricetags to place on lives and limbs lost or lives saved. Yet war produces a direct economic impact on infrastructure, output, fixed and human capital, medical facilities and care, and employment, to name a few. Funding the obligations contained in arms control agreements has proved problematic in both the United States and the Russian Federation, as well as many other countries.

At the height of the cold war, in 1987, global military expenditures reached U.S. $1,500 billion, much of which was spent on nuclear arsenals (there were an estimated 75,000 strategic nuclear warheads). From 1989 to 1998 global military expenditures declined 34 percent, to $760 billion [4]. World military expenditures began to increase in the late 1990s after a 10-year period of post-cold war reductions. This was largely due to the increase of US expenditures. World military expenditure amounted to almost $800 billion in 2000, according to SIPRI.

At the same time, the cost associated with verification and compliance with treaties has risen in no small part because of the larger costs of nuclear weapons production and the cleanup costs for nuclear weapons disposal. The United States General Accounting Office estimated in 1995 that costs involved with cleaning up nuclear weapons facilities would be "at least $300 billion (and perhaps as much as $1 trillion) and take more than 30 years to complete" [5]. The Russian Federation stipulated the right to withdraw from the START II Treaty "if extraordinary events of economic and technical origin, which make it impossible for the Russian Federation to fulfill its obligations under START II Treaty or jeopardize the environmental security of the Russian Federation." In both countries the official cost for destroying chemical agents have been continuously rising, while public fears mount over the storage, transport and incineration.

The increased cost of implementing arms control treaties also contributes to the delay in their implementation. For example, the Chemical Weapons Convention requires its member States to destroy all chemical munitions and chemical weapons plants by the year 2007. However, the Organization for the Prohibition of Chemical Weapons has granted a five-year extension to the Russian Federation, which holds more than 40,000 tons of chemical weapons/agents. The United States, which holds 31,280 tons of agents, has incinerated or chemically neutralized about a quarter of the stockpile for $24 billion, but this effort has been delayed by local questions, safety concerns, etc, and thus it may also have to request an extension of the deadline.

Economic constraints not only limit the START and CWC implementation process, but they prevent the realization of safety and security standards in the nuclear, chemical and biological sites, as well as missile and submarine bases. This in turn leads to well-founded concerns about the threat of proliferation and/or terrorists removing fissile materials, chemical agents, and tactical nuclear warheads. In that connection, the 2002 G-8 initiative on the Global Partnership involves a pledge to raise $20 billion from G-8 and other countries over the next 10 years to support specific cooperation projects in Russia and possibly in other countries as well. By way of comparison, the cost of maintaining the US nuclear complex for a year has been estimated at over US$25 billion, including $4.5 billion annually for the Stockpile Stewardship programme [see 6].

7 Generic lessons learned

From the analysis of the experience of existing Treaties and Conventions, a number of lessons can be learned that can be useful for the development of future arms control, non-proliferation (e.g. the Fissile Material Cut-off Treaty (FMCT) or, more general, security related treaties.

The following main insights can be derived:

- The regimes are generally successful - In general existing arms control and disarmament regimes are operating successfully. The treaties have helped make the world more secure and enhanced confidence and co-operation among treaty parties. They have also established widely respected norms. In this perspective, arms control in some enlarged sense has always reflected and will continue to reflect the need of each State to have an efficient (foreign or homeland) security policy in a variety of bilateral or multilateral international contexts. The recent withdrawal of the DPRK from the NPT and potential similar action from other states raises concerns however and demonstrate the difficulty to engage in sanctions.
- Agreements can be successfully concluded within a variety of different legal frames. The maximum binding force is obtained trough a legally binding international treaty. Also non-legally binding instruments including agreed codes of conduct, executive agreements and Security Council resolutions could be useful frames for security agreements.
- It has proven possible to agree on and to implement extensive and intrusive on- site inspection measures also involving sensitive facilities and private industry. On-site inspections that are regularly carried out are a valuable confidence building measure.
- Highly technical verification systems also with global reach have been successfully developed, agreed upon and implemented.
- Existing treaties and agreements have shown that the governing and implementing organizations can be of different kinds, sizes and have different responsibilities. Some treaties are essentially lacking a central authority, whereas others have a large implementing organization to operate verification systems, conduct on-site inspections and analyze and in some cases also assess the information collected.
- The costs of establishing and operating international arms control and disarmament treaties, including implementing verification organizations and technical systems are negligible compared to what we spend globally on other elements of our security, especially on the armed forces.
- Experience have shown that technical expert work on verification methods, technologies and equipment prior to and during negotiations is essential for the design of the verification provisions of a treaty and for their implementation. Such expert work might include the establishment of provisional technical systems to demonstrate feasibility and capabilities.

8 Conclusions

Existing arms control and disarmament regimes and other security related agreements have helped make the world more secure and enhanced confidence and co-operation among treaty parties. They have also established universally or widely respected, norms. The NPT, BWC and CWC have established global norms with respect to weapons of mass destruction against which the behavior of individual states can be measured. The NPT has established a global framework to prevent the proliferation of nuclear materials and technologies for weapons purposes. The Nuclear Suppliers Group is overseeing the implementation of guidelines for the control of nuclear material and equipment. The Australian Group and the Missile Technology Control Regime are two other well-established international instruments to implement export control in order to limit proliferation of critical weapons material and technology. Within the frame of the CWC the destruction has begun of the large stockpiles of chemical weapons in Russia and the US. The CTBT, another non-proliferation instrument still to enter into force, has led to a worldwide cessation of nuclear test explosions.

The bilateral US - USSR START and INF treaties have rid the world of many thousands of operational strategic nuclear weapons. START has irreversibly reduced by approximately 50% the ICBM, SLBM and heavy nuclear bomber forces of the U.S and USSR. INF has eliminated a whole class of ground-launched ballistic and cruise missiles nuclear systems with a range of 500 to 5500 km. Within the CFE more than 60 000 heavy pieces of military equipment have been destroyed in Europe. The inspection regime of the CFE and the overflight regime of the Open Skies Treaty has increased transparency and promoted confidence in Europe. The Ottawa treaty banning anti-personnel landmines, negotiated outside established frames and still lacking global adherence, has established an important norm against the possession and use of landmines.

The security perspective of today and tomorrow is broader than that of yesterday. On the global scale we need confidence building and control instruments, and we are trying to move from armed conflicts to crisis prevention and management. Conflicts today mainly occur within rather than between states and non-state actors are playing an increased role. New categories of threats from sub-state national or transnational entities have been developing over the last decade. In many parts of the world the greatest threats to human security are still famine and disease. We are also facing a growing number of threats to our complex modern societies of an economic and technical origin. Deliberate attacks on our information systems to manipulate the very nerves of our societies can be launched from any point on earth and by small groups of people.

Highly technical verification systems with a global reach have been successfully developed, agreed upon and implemented. Many systems are using modern sensors, computer and communication technology and benefit from sophisticated computer programs able to handle and analyse large volumes of data.

The governing and implementing organizations are of different kinds and sizes and have different responsibilities. Some treaties are essentially lacking a central authority, whereas others have a large implementing organization to operate verification systems, conduct on-site inspections, analyze and in some cases also assess the information collected.

Experience from several arms control treaties has shown that technical expert work on verification methods, technologies and equipment prior to and during negotiations is useful and efficient for the design of the verification provisions of a treaty and for its implementation. Such expert work might include the establishment of provisional technical systems to demonstrate feasibilities and capabilities.

The costs of establishing and operating international arms control and disarmament treaties, including implementing verification organizations and technical systems, are negligible compared to what we spend globally on other elements of our security, especially on the armed forces. The total budget for the three largest international arms control organizations is just over $400 million or about 0.05% of the annual world military expenditure of $800 billion.

The experiences from existing treaties can and should be applied to new security problems. The fact that existing treaties in general have promoted security and confidence among the States Parties should encourage further efforts to establish treaties or agreements on outstanding security issues. The CD has facilitated the creation of several treaties, but its rigid procedures and consensus decision-making have presently put it at a deadlock. The Ottawa convention on land mines has shown that it is possible to create a treaty among the willing through ad hoc negotiations outside of a formal, pre-existing body. The time has come to explore different options to initiate work on urgently needed treaties, agreements and control regimes to enhance our security.

References

1. Dahlman O., R. Alewine, M. Asada, E. Ifft, J. Mackby, B. Massinon, A. Meerburg, A. Poucet, B. Sitt, S. Sur (2004): Generic Aspects of Arms Control Treaties: Does One Size Fit All? *EURATOM report EUR 21077 EN*, European Commission Joint Research Centre.
2. Mitchell, Ronald B. (1997): International Control of Nuclear Proliferation :Beyond Carrots and Sticks, *The Non-proliferation Review*, Fall.
3. Brown, James, William K. Cheek, John G. Tower (1992): Verification. *The Key to Arms Control in the 1990s*. Washington: Ed.. Brassey,s (US), Inc.
4. Willett, Susan (2002): Costs of Disarmament-Rethinking the Price Tag, *Geneva: UNIDIR*, United Nations, p. 46.
5. General Accounting Office (1995): *Nuclear Weapons Complex Establishing A National Risk Based Strategy for Clean Up*, GAO/T-RCED-95-120, Washington, D.C.

6. Cirincione, Joseph (2000): The Assault on Arms Control, *The Bulletin of the Atomic Scientists*, Vol. 56, No. 1, pp. 32-37.

International Atomic Energy Agency Safeguards under the Treaty on the Non-Proliferation of Nuclear Weapons: Challenges in Implementation

Jill N. Cooley

1 Introduction

The overall challenge currently facing the safeguards system of the International Atomic Energy Agency (IAEA or Agency) is how most effectively and efficiently to provide soundly based safeguards conclusions in the face of an increasing workload and in light of recent discoveries of a range of undeclared nuclear activities in several States with comprehensive safeguards agreements. Since the discovery of Iraq's clandestine nuclear weapons programme in 1991, the IAEA safeguards system has been radically modified, especially to strengthen its ability to detect undeclared nuclear material and activities. Most significantly, additional protocols, based on the Model Additional Protocol (AP) to safeguards agreements approved in 1997, provide the legal authority necessary for the Agency to obtain more information than ever before about a State's nuclear activities and more access to nuclear fuel cycle-related sites and locations in the State. Fundamental to strengthened safeguards is a shift in focus from drawing safeguards conclusions based on safeguards implementation at the facility level to drawing conclusions based on implementation and evaluation of information for the State as a whole. This marked change of emphasis gives rise to new techniques and technology, to many new sources of information and to new methods of work. Outmoded database systems, major new nuclear facilities expected to come on line and under safeguards, current and future equipment needs, and pending mass retirements of experienced safeguards inspectors further strain the system. IAEA Member States have finally acknowledged the critical resource situation and have agreed to a budgetary increase for safeguards following more than 15 years of zero growth. The task now is to optimise the use of these resources to strengthen further the effectiveness and increase the efficiency of safeguards implementation. In the near to mid-term, a fundamental related challenge is to widen adherence to additional protocols in order to maximise the potential of the strengthened safeguards system. This paper focuses on that system and on the operational and technical challenges now confronting it.

2 Background

The Statute of the IAEA empowers the Agency to implement nuclear verification measures, or safeguards, to verify States' compliance with their nuclear non-proliferation commitments. With the 1970 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Agency became the designated verification authority for the implementation of safeguards in States party to the NPT. All non-nuclear-weapon States party to the NPT are required to conclude comprehensive safeguards agreements (CSAs) with the Agency. (The structure and content of CSAs concluded pursuant to the NPT are described in document INFCIRC/153 (Corr.) [1].) In accordance with the terms of such agreements, a State undertakes to accept safeguards on all nuclear material in all peaceful nuclear activities, within its territory, under its jurisdiction or carried out under its control anywhere for the purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices. Under these agreements, the Agency has the right and obligation to ensure that safeguards are applied on all such nuclear material.

IAEA safeguards in the two decades following adoption of the NPT focused on verifying the correctness of nuclear material holdings declared by States. Verification activities were conducted exclusively at nuclear facilities and other locations with declared nuclear material; safeguards conclusions reported annually to the international community were limited to the absence of diversion of this declared nuclear material. The discovery of Iraq's clandestine nuclear weapons programme highlighted the shortcomings of safeguards implementation focused essentially on declared nuclear material and safeguards conclusions drawn at the facility level. This set the stage and provided the catalyst for far-reaching efforts to strengthen the system, in particular its ability to detect undeclared nuclear material and activities. The crowning achievement in that regard was the adoption of the Model Additional Protocol by the IAEA Board of Governors in 1997 [2]. The legal authority conferred by and the technical measures provided for in additional protocols (APs) based on the Model make a vital contribution towards an assessment of the 'completeness' of a State's nuclear material declarations.

With an AP, the Agency is able to obtain more information than ever before about a State's nuclear programme and plans, and more access to nuclear fuel cycle-related sites and locations in the State. An assessment of 'completeness'[1] is a *conditio sine qua non* of safeguards conclusions that all of a State's nuclear material has been placed under safeguards and remains in peaceful

[1] In other words, an assessment that a State's nuclear material declarations include everything that **should** have been declared to the Agency.

nuclear activities or has otherwise been accounted for. Such conclusions can be given only for States with both a CSA and an AP in force and being implemented. Notwithstanding, the focus of safeguards implementation for **all** States with safeguards agreements in force has shifted from safeguards implementation and conclusions drawn at the facility level towards conclusions based on implementation and evaluation of information for a State as a whole.

3 The State evaluation process

The shift of emphasis towards 'completeness' has involved a significant change in the way in which safeguards are implemented; follow-up activities are planned and conducted; and safeguards conclusions are drawn, documented and acted upon. The framework for the overall process, the Safeguards State evaluation, seeks to integrate and assess the totality of information available to the Agency about a State's nuclear activities and plans, whether provided by States themselves under safeguards agreements, additional protocols and voluntarily; deriving from the implementation of in-field verification activities; or obtained from open and other sources of safeguards-relevant information. From all of the information available, the Agency seeks to form a comprehensive 'picture' of a State's nuclear programme and nuclear ambitions and identify any potential indications of diversion of nuclear material or of undeclared nuclear material or activities.

The State evaluation process finds tangible expression in the State evaluation groups established to carry out evaluations and in the State evaluation reports (SERs) that result from them. Periodically, an SER documenting the results of a State evaluation is prepared and submitted to a senior management committee for review. Each report includes background information on the State's nuclear programme, a consistency analysis of the elements of the programme, and conclusions and recommendations. When reviewing a SER, the committee considers the significance of each finding and the extent to which it may weaken the basis upon which the safeguards conclusions are drawn; and makes recommendations for future follow-up actions accordingly. Ultimately, in light of this assessment, the Agency draws safeguards conclusions for the State as a whole. Considerable time, effort and care are required to produce and update SERs, which underpin safeguards conclusions and form the basis for planning safeguards activities. The process has matured considerably since its inception. In 1997, five SERs were produced and reviewed. By mid 2005, some 330 SERs had been prepared and reviewed covering 105 States, 64 of which had significant nuclear activities. Current projections are for 96 SERs to be produced in 2006 - over double the 2001 total of 41.

The results of the on-going evaluations for each State determine the State-level safeguards approach, i.e., the level and focus of safeguards activities implemented for that State. The State-level safeguards approach is based on a State-specific set of objectives that need to be addressed in order to determine the relative level and focus of safeguards activities required for the Agency to draw soundly-based safeguards conclusions. It is formulated in light of the State's nuclear capabilities and the factors identified in the State evaluation. The overarching objectives include (i) verifying that no nuclear material placed under safeguards has been diverted and (ii) seeking indications of undeclared nuclear material or activities. In addition, the State-level approach calls for pursuing the resolution of questions or inconsistencies that may arise in the course of safeguards implementation.

For the first objective, the State-level safeguards approach specifies the activities considered to be sufficient to detect with a reasonable probability the diversion of nuclear material placed under safeguards. For States for which the Agency has not yet drawn the broader safeguards conclusion, the inspection activities have traditionally been prescribed by the Agency's safeguards criteria. In addition, facility-specific plans for design information verification prescribe the activities that should be conducted during the life cycle of the facility to assure that the facility-level safeguards approaches remain valid and that facilities are being operated as declared.

The second objective, seeking indications of undeclared nuclear material and activities (at either declared or undeclared locations), is often made up of several sub-objectives relating to particular components of a nuclear fuel cycle, for example associated with reprocessing or enrichment. The State-level approach indicates the relative level and focus of activities, for example environmental sampling, complementary access, unannounced inspections, or analysis of satellite imagery or other information, that should be conducted to meet those sub-objectives. Safeguards measures to meet this second objective are specified in the State evaluation reports and reviewed during that process.

In 2001, the Agency developed internal guidelines for the development of State-level safeguards approaches as part of the conceptual framework for the implementation of integrated safeguards[2] [3]. State-level safeguards approaches lend flexibility to safeguards implementation. For States under integrated safeguards, there is even greater room for flexibility because of the Agency's additional rights to information and access provided under an AP and due to the added assurances regarding the absence of undeclared nuclear material and activities. Therefore, to ensure comparability between State-level approaches each new State-level integrated safeguards approach is reviewed by a technical review committee to assess its consistency with the conceptual framework for integrated safeguards. As part of the State evaluation process, each State-level safeguards approach is to be reviewed periodically by the se-

[2] 'Integrated safeguards' refers to the optimum combination of all safeguards measures available to the Agency under comprehensive safeguards agreements and additional protocols which achieves maximum effectiveness and efficiency within the available resources in exercising the Agency's right and obligation in paragraph 2 of INFCIRC/153 (Corrected). The 'conceptual framework' comprises the set of safeguards concepts, approaches, guidelines and criteria that govern the design, implementation and evaluation of integrated safeguards.

nior management of the Department of Safeguards to assure that it remains appropriate in light of the State's nuclear programme, the evaluation of the consistency of information regarding the State's nuclear activities and the results of previous verification activities.

A major challenge for the State evaluation process has been how best to structure the final stages of information evaluation to provide a sound and consistent basis for safeguards conclusions. A related challenge is how best to customise and optimise State-level approaches for individual States while ensuring consistency in implementation effectiveness for all States. Guidelines have been developed, training updated, and internal review processes put in place. All such endeavours will need to be kept under review as experience is gained.

4 Information sources

4.1 State-declared information

The magnitude of the information management, analysis and evaluation challenges emerges from a variety of operational examples, all of which can impact significantly on safeguards conclusions. For instance, the processing of State-declared information can be more complicated and protracted than it might seem. In some areas, such as nuclear material accounting (NMA), States have a margin of flexibility in the way in which they can report. This means that staff involved in processing NMA data need to be familiar with the particular reporting modalities of the States for which they are responsible. There are also numerous data processing and software applications with which staff need to be familiar, not only because of the number and variety of such applications but - critically - because the interpretation of results can depend on the State's reporting practice. Another challenge is the growing demand for in-depth analysis of NMA data that software cannot really be designed to cater for. It follows that extensive, in-depth staff knowledge is key to the provision of accurate results, including for State evaluations and for the Safeguards Implementation Report (SIR). This is complicated by the long lead-time required to transfer knowledge from experienced to inexperienced staff and exacerbated by the absence of any formal in-house training on software querying languages essential for extracting data.

Some of the greatest difficulties in processing State-declared information stem from AP implementation. The timely, complete and accurate submission of information requested from States about their nuclear programmes and activities under an AP is vital to the process of information evaluation and thus to drawing the broader safeguards conclusions. A State's declarations under Articles 2 and 3 of an AP supplement largely numerical NMA data submitted under safeguards agreements with site descriptions and with information about activities not involving nuclear material; waste processing;

non-nuclear use of material; source material transfers and holdings; nuclear material activities; future plans and equipment transfers. The review of declarations involves a number of steps, each of which is important to a clear and accurate understanding of a State's nuclear activities and to verification activities in the field.

Challenges centre on such factors as the timing, content and format of the declarations received. Experience to date shows that some declarations have either not been received at all, have required elucidation, through consultation or correspondence with the relevant State authorities, or have been received too late to be reflected fully in the SER and the appropriate SIR. The Agency Secretariat promulgated guidelines in August 1997 to help States to complete, format and submit their AP declarations and to achieve consistency. For the same purpose, the Agency has developed a software programme called the 'Protocol Reporter', available to all States upon request. The programme can be tailored to a customized structure by a State and can support a decentralized process for the preparation of a submission. The programme enables the merging of information from various sources within the State and the preparation of computerized declarations for submission. Many States continue to submit their AP declarations in hard copy only. All of this results in the large amount of extra work required to process and validate information for loading into the Secretariat's electronic AP System. To rectify this situation and further to help States to submit their declarations in an accurate, timely and suitably formatted manner, the 1997 Guidelines were updated and reissued in 2004 [4].

4.2 Open source information

One of the questions that the State evaluation process seeks to answer is whether a State's declarations about its nuclear programme and plans are consistent with information obtained from 'open' sources, that is, sources **other** than the findings of in-field verification activities or obtainable from other, internal Agency databases. The open source collection is extensive, relying on scientific and technical literature, news media (including news service data bases), country-specific websites and commercial satellite imagery. Open source information can shed light on a number of safeguards-related concerns such as research into sensitive technologies; details about source and nuclear material production; location data which is particularly useful for complementary access under APs and for satellite imagery acquisition; imports and exports of dual-use or single-use technologies applicable to the nuclear fuel cycle or to a nuclear weapons programme; and statements indicating some interest in acquiring nuclear weapons. In a general sense, open source information is qualitatively different from State-declared and inspection-related information in that it is amorphous, of varying quality and reliability, and with no strictly defined collection procedure. Finding and evaluating this information requires new hardware and software, new skills and analytical ability, and new procedures. All of this has been a major work in progress since 1996.

The overall challenge confronting open source information collection and analysis is to extract safeguards relevant *knowledge* from an ever-increasing volume of material gleaned from specialist and regional sources. All of it must first be located, and then selected and processed, analysed, evaluated and cross checked for credibility. The magnitude of the task can be illustrated by the fact that at the end of 2004, the Agency had access to over 5000 scientific journals and information on thousands of commercial entities dating back to 1945. Selection mechanisms have had to be identified, tested and implemented. The Agency continues to expand its subscription databases and extend its capabilities for retrieving information in languages other than English. The introduction of new skills and tools has been and continues to be essential for the exploitation of open source material. A related challenge is always to be on the look-out for new sources of potentially valuable information. The downside is that the ever-increasing volume of information available imposes limitations on the Secretariat's analytical capability.

Challenges also confront the acquisition and use of commercial satellite imagery, a further open source of information that can be valuable in the areas of verification, evaluation, investigation and operational support. Contracts are in place with a number of commercial providers of imagery and cartographic information and a Satellite Imagery Analysis Laboratory has been established for the interpretation of commercial satellite images and the production of reports on analysed imagery. Satellite images are expensive, however, and there is limited, regular budgetary funding available for purchasing them. Rigorous priority setting is thus essential. There are other problems to overcome, such as the in-built limitations to some of the technology used for image collection and problems associated with the timeliness of imagery acquisition. Sometimes, political restrictions are imposed on the images that may or may not be procured.

4.3 Other information

The Agency has begun to develop its own capabilities for in-depth analysis and evaluation of nuclear trade activities on a global scale. These new capabilities involve techniques to enhance the collection and analysis of information about nuclear supply and procurement activities and the investigation of covert nuclear trade networks with a view to assessing whether these networks are supporting undeclared nuclear activities. These efforts complement other Agency safeguards activities such as its analysis of open source information. The Agency's effectiveness and efficiency can be further enhanced with Member States' support, for example through their making available relevant information on denials of exports and on attempts to procure sensitive nuclear technology. Access to the relevant information in a timely manner will be critical for these analyses.

5 Advanced techniques and technology

Agency access to new techniques and advanced technology relevant to safeguards application is extremely important if not essential in maintaining the credibility of safeguards conclusions. The remarkable improvements in the effectiveness and efficiency of material accountancy safeguards that occurred across the 1980s and into the 1990s were largely a result of the introduction of new and improved technical measures. New non-destructive assay techniques and new containment and surveillance systems along with the capability to transmit data from unattended safeguards systems in the field to Agency offices for review (remote monitoring) paved the way for improvements in verification coverage, continuity and in methodologies for the analysis of inspection data. The approval of environmental sampling as a new safeguards technical measure in 1995 ushered in a new era in the Agency's capability to address the problem of undeclared nuclear material and activities at declared facilities as well as undeclared locations.

5.1 Environmental sampling

Environmental sampling (ES) was introduced in 1996 as a safeguards strengthening measure under existing safeguards agreements. Its use was broadened considerably with the provisions of the AP which give the Agency authority to collect environmental samples at a wider range of nuclear-related locations as well as at undeclared sites. Thousands of samples have been collected during routine inspections and design information visits and during complementary access under APs.

In order to make use of this advanced technique, a whole new infrastructure has had to be designed, established and put into operation. Sampling kits have been created and protocols developed for the collection and handling of samples. Sample integrity, data confidentiality and appropriate staff training have also been given careful attention. Tools have been developed to aid in the evaluation of the analytical results, such as computer modelling of enrichment, irradiation and decay. A dedicated database has been established for recording the collection, processing, analysis and evaluation of the samples taken and to ensure that such information can be retrieved as required.

The IAEA Clean Laboratory is an important support component of the ES programme and is responsible for processing, screening, distributing, analysing and archiving samples. Analytical capability has been considerably increased by expanding the number of qualified ES laboratories in the Agency's Network of Analytical Laboratories (NWAL), which now includes 17 such laboratories in 7 Member States and the European Union. Improvements have been made in the application of secondary ion mass spectrometry and fission track thermal ionisation mass spectrometry analytical techniques and in the quality and variety of environmental sampling reference materials.

A challenge now is how best to manage the total number of samples being taken given finite NWAL capacity impacted in the last few years by a number of high priority samples supporting on-going investigations of undeclared activities in several States. Work is in progress with other Member States to qualify additional laboratories as part of the NWAL to improve the overall capability, throughput and response time of the system. Because of the stringent analytical requirements, few laboratories have the resources (equipment, human, and financial) to meet the qualifications. Sampling strategies might well have to be reassessed and rationalized. A further challenge is to reduce the ES cycle time to improve the timeliness of the resulting evaluations. An upgrade of the IAEA Clean Laboratory's particle analysis capability is being pursued to reduce sample turnaround.

Current technical challenges includes improving uranium detection capability by reducing background levels of natural uranium in the swipes; expanding quality control measures; improving methods of particle recovery; and investigating age dating techniques for uranium particles and more sensitive plutonium detection using accelerator mass spectrometry. The laboratories of the NWAL meet regularly with the Agency to review performance, to share progress on previous recommendations, and to identify new development work.

5.2 Equipment

The implementation of safeguards requires the availability of appropriately prepared, calibrated, tested and well-maintained equipment. The IAEA has accumulated considerable experience in the management of safeguards equipment. That experience is highlighted by the large equipment inventory (more than 25,000 items), by the long list of equipment authorized for inspection use (more than 100 different types) and by the annual equipment expenditure (approximately $12 million).

The Department of Safeguards has put considerable effort into modifying and extending the lifetime of equipment and has in many cases been successful. For the future however, more extensive use of digital equipment, which is expensive and has a shorter lifetime, will increase already high replacement costs.

Challenges are consistently faced because of the unique boundary conditions under which the development of safeguards equipment is carried out and the rapidly changing technological environment. For example, the commercial manufacturing base for dedicated safeguards equipment is small; in-field equipment needs to operate in harsh environments with sufficient reliability; instrumentation must be acceptable to State authorities and facility operators; data authentication and tamper-indicating measures need to be incorporated; and the confidentiality of the information obtained has to be protected. Taking into account the high cost of equipment development and implementation, and the substantial inventory of existing safeguards equipment, the efficient adaptation of the equipment inventory is required to function effectively within budget constraints and to satisfy new requirements stemming from the evolution to safeguards strengthening measures. Those new requirements include: suitability for joint use with State Systems for the Accounting and Control of Nuclear Material (SSACs) without compromising data security; operation in unattended mode for even greater periods between inspection visits; remote data transmission capability for remote monitoring or monitoring of equipment state of health; greater sensitivity for the detection of undeclared nuclear material production and transfers; and greater portability to complement new inspection regimes. All of the newly required features must be developed and implemented in an environment of rapidly evolving technology and externally developed and manufactured products, requiring substantial efforts to extend equipment lifetime and achieve cost-effectiveness.

There is also the constant need to respond to changing operational requirements. This in itself can give rise to difficulties. For example, while unattended monitoring systems are being used increasingly in facilities to reduce inspection effort, the introduction of remote monitoring has not met with unqualified success. Early on, the Agency experienced technical problems, variable installation and transmission costs, and delays in obtaining approval from State authorities. While most of the technical issues have been solved, and new cost-effective data transmission networks are becoming increasingly available in many countries, delays are still being experienced in gaining State approval for the implementation of remote monitoring, or the monitoring of equipment state of health.

New facilities, such as enrichment and conversion plants, will generate new and additional equipment requirements. This is also the case for spent fuel conditioning and material transfers to dry storage. The Agency relies heavily on Member States for assistance and extra-budgetary support for equipment development and procurement.

Safeguards equipment and instrumentation involves wide market assessment, extensive equipment testing, documentation and training. Managing the Agency's safeguards equipment within available resources will continue to be a major challenge for the Department of Safeguards, notwithstanding improved work practices, including implementation and the introduction of a strengthened and efficient equipment management system and the systematic application of a cost-benefit analysis prior to equipment development.

6 New infrastructure

The strengthened safeguards system needs extensive new infrastructure to support and improve implementation. It must be capable of adjusting to changing needs. Some of this infrastructure has been touched on in preceding paragraphs but there are many other examples. The process of developing appropriate new infrastructure and putting it in place will continue to be a challenge. As progress is made in some areas, priorities and resources must necessarily shift to other needs.

6.1 Approaches, guidelines and procedures

To date, a number of safeguards approaches have been revised and new ones developed as part of the strengthening process. The guidelines for planning, carrying out and reporting on design information examination and verification activities have been revised and a model design information verification plan developed to guide such activities during facility lifetime. Efforts continue to develop a more cost-efficient approach to safeguarding transfers of spent fuel. Although the Model Additional Protocol describes new techniques and technical measures that can be used for safeguards activities, it was never intended to specify in detail how those measures are to be implemented. For this a whole new infrastructure has had to be established, has grown and continues to mature. Guidance is required both for States and for the Secretariat - many of the challenges of the strengthened safeguards are new to both. In the first context, mention has already been made of the 1997 Reporting Guidelines for States and subsequent refinement thereto. In the second context, safeguards strengthening measures, in particular those provided for in APs, have resulted in a wide range of new or revised procedures and documentation. Guidelines for unannounced and short notice inspections, hitherto limited by practical constraints although within the bounds of existing legal authority, come into this category. So do the guidelines to describe and guide the conditions and activities, including complementary access, for drawing safeguards conclusions regarding the absence of undeclared nuclear material and activities at the State level. Guidelines have also been produced for complementary access at each category of location that Article 5 of the Model Additional Protocol identifies.

Work continues on State level and on facility-type-specific safeguards approaches to be implemented under integrated safeguards. Elements of the conceptual framework for integrated safeguards will continue to be developed or refined in the light of experience gained in implementation, further evaluation and available technology. In that regard, the introduction of State level integrated safeguards approaches for States with significant nuclear activities will impact considerably on time and resources as more additional protocols enter into force and are implemented and the prerequisite safeguards conclusions can be drawn. By September 2005 integrated safeguards were being implemented in eight States, including Japan, and State-specific integrated safeguards approaches were under development for a number of States.

6.2 Information technology

Clearly, any information system, especially one of the size and complexity of the IAEA Nuclear Verification Programme requires an underpinning infrastructure of specialist software and hardware. Accordingly, one of the objectives of the Programme is to provide an adequate information technology (IT) infrastructure and support mechanisms for the reliable and secure network, telecommunications and database services that verification activities require. In this general context, major efforts are being devoted to a re-engineering of the IAEA Safeguards Information System (ISIS) to provide immediate, on-line access to the information which safeguards inspectors need, whether at Headquarters or in the field; the capability to enable the Secretariat to analyse all of the information available to it to support strengthened and integrated safeguards; and a flexible and adaptable infrastructure to enable it to meet the challenges and needs of the future. The re-engineering is essential: the "legacy" datasets of the Department of Safeguards were configured in a modular way and were based on a now outdated IT infrastructure which is operating beyond designed tolerances. It is also incapable of being networked to meet the needs of today's business processes and other key requirements, not least of which is to accommodate the loading on human resources. The work of the Department has changed dramatically since 1991 and a feasibility study commissioned by the Secretariat in 2001 concluded that the current ISIS can no longer effectively support its activities. Acting upon that, the Secretariat commissioned an overall plan for re-engineering ISIS and in June 2005 a commercial contractor was selected for the 3.5-year project. It is expected that most of the funding for the project, as with safeguards equipment, will be funded from extra-budgetary sources.

6.3 Training

Specialist training is available to safeguards inspectors at all stages of their career and both the core and the specialized training curricula need continually to be adapted to meet changing needs at entry and advanced levels. Basic training has been updated progressively since 1997 to reflect both safeguards strengthening measures and changes in technology. The State evaluation process requires new skills in multi-disciplinary evaluation teams. These need to be developed through training and through targeted recruitment. Much has already been accomplished to equip staff with the new knowledge and skills they are called upon to possess. Courses have been developed in such areas as the strengthened safeguards system; a knowledge base of proliferation indicators; practical exercises in performing State evaluations; a course at nuclear facilities where country officers practice observing and detecting staged proliferation indicators; and a course on the roles and responsibilities expected from inspectors performing complementary access under APs. Additionally, the introduction of complementary access requires inspectors to carry with them appropriate 'implementation' skills that are covered in two courses: enhanced observational skills and communications skills. The Training Programme provides for that and for other specialized courses on such topics as environmental sampling and satellite imagery. This list is not exhaustive and can be expected to grow.

Adaptation and adjustment also applies to the assistance provided through training activities to Member States. Particularly important in this context is training in the establishment and expertise required by effective SSACs. These are essential to improvements in the effectiveness and efficiency of safeguards implementation. Whether internally or externally focused, training makes a valuable contribution to effectiveness and efficiency, to capacity building for the future and to succession planning.

6.4 Resources

For the last 15 years, the IAEA regular budget has been constrained by zero real growth, resulting, inter alia, in chronic under-funding of the Nuclear Verification Programme and a corrosive effect on its elements. By June 2001, safeguards activities were under-funded by some \$20 million and the safeguards system was undesirably reliant on extra-budgetary funds. It was against that background that the Department intensified its efforts to secure an increase in the Safeguards regular budget. These efforts were not based on any 'wish list' but on a full and thorough appraisal of current, new and projected activities. After protracted discussions with Member States and complex negotiations in the framework of the Programme and Budget Committee, the IAEA General Conference agreed in September 2003 to increase the regular budget of the Agency from \$249 million in 2003, to \$268 million in 2004. This includes a 12.4% increase for Safeguards from \$89 million in 2003 to \$102 million in 2004. The General Conference also recommended further increases to be phased in until 2007, when the safeguards budget is expected to reach an increase of \$19.4 million over 2003 (plus the yearly adjustment for inflation). The main components of the increased regular budget relate to staff costs, equipment and contracts.

The increase is welcome and long overdue. Safeguards activities are a statutory obligation and cannot be compromised. More resources will help the Department of Safeguards to continue to improve the effectiveness of the safeguards system, thereby fostering increased confidence in safeguards conclusions. The number of professional posts (368 as of the end of 2004) has already increased from the 351 post level of 2002 and the Department will be able to fund a larger part of its equipment needs. This nevertheless needs to be weighed against assumptions, as yet untested, that certain cost savings and further efficiency measures can be implemented. Added to that, it is important to bear in mind that although a high proportion of additional workload stems from AP implementation, there is an on-going need to implement traditional, nuclear material accountancy safeguards and to prepare to introduce sound and cost efficient safeguards measures in major new facilities such as a large scale reprocessing plant and a projected, large scale mixed oxide fuel fabrication plant in Japan. Appropriate provision must also be made for the conditioning and transfer, over a 10-year period of some 23000 irradiated fuel assemblies and 3000 irradiated absorbers at the Chernobyl nuclear power plant.

7 Towards the future: maximising the potential of the strengthened safeguards system

In the near to mid-term, a fundamental challenge will be to continue to encourage the conclusion and entry into force of CSAs and APs. The number of States with safeguards agreements and APs signed or in force continues to grow. Although the number of States with safeguards agreements had increased to 156 by the end of September 2005, there were still 36 States party to the Treaty on the Non-Proliferation of Nuclear Weapons which had still not brought CSAs with the Agency into force as that Treaty prescribes. As for APs, as of the end of September 2005 - more than eight years after the Board of Governors approved the Model Additional Protocol - 104 States had signed APs and 69, less than half of those States with safeguards agreements, had brought them into force. Extensive efforts have been and are being made to encourage wider adherence to safeguards agreements and APs. Guided by relevant resolutions of the IAEA General Conference, Board instructions and the Agency's Medium Term Strategy, outreach activities have included the convening of national, regional and sub-regional seminars and the formulation of an updated action plan for outreach activities determined by specific categories of States (i.e., those with significant nuclear activities, those with no nuclear material under safeguards and non-Member States). For each category, the main obstacles to concluding CSAs and APs have been identified and differing strategies devised to address and overcome them. The challenge now is to do so. The full potential of the fully strengthened safeguards system can be realized only for States with both a CSA and an AP in force for it is in respect of such States **only** that the Agency has, at its disposal, the full range of measures for implementing safeguards in the most effective and cost efficient way.

8 Conclusion

The implementation of safeguards is constantly evolving. It does so in keeping with technological developments and in pursuit of the optimum effectiveness and efficiency required under safeguards agreements. Adaptation to and managing change is therefore nothing new and the IAEA Department of Safeguards has a wealth of accumulated experience in these areas. What now confronts it, however, is of a different order and magnitude than anything that it has faced before - a revolution, rather than simply an evolution, in the way in which safeguards conclusions are drawn, documented and acted upon.

The main catalyst for this sea of change was the discovery, in 1991, of Iraq's clandestine nuclear weapons programme. This stark realisation that threats to the nuclear non-proliferation regime can come from within as well as from outside its ranks has prompted major initiatives to strengthen the safeguards system. There was a perceived need, in particular, for the Agency to have at its disposal more information than ever before about a State's nuclear activities and plans and more rights of access to places where nuclear material was or could be present.

Measures put progressively in place since 1992 are successive 'building blocks' towards these ends. They aim to assess the totality of safeguards-relevant information about any given State, so as to reach as full, or 'complete' a picture as possible. The mechanism within which this evaluation takes place, safeguards State evaluation, is complex and dynamic. The result, in general terms, is that for States with both a CSA and an AP in force, the Agency now has sufficient legal authority and technical ability to acquire all of the pertinent information required for more broadly based safeguards conclusions than were hitherto possible. This in turn, increases confidence in those conclusions as a contribution to global non-proliferation objectives.

Strengthening safeguards presents many opportunities but also many challenges. The vastly increased range and volume of safeguards-relevant information now available to the Agency requires new methods of collection, analysis, evaluation, storage and retrieval. Separate 'islands' of knowledge and technical capability need effectively and efficiently to be integrated. New hardware and software tools, new skills and ability, and new techniques and technology are variously required. Each plays a vital part. Much has been achieved since 1997 when the IAEA Board of Governors approved the Model Additional Protocol, which embodies the legal authority and technical measures needed for assessments of 'completeness'. Much has been achieved since then to build up the infrastructure and develop the guidance, procedures and training necessary for effective and cost efficient safeguards in today's world. A great deal of hard work, each aspect with its own challenges remains. The Secretariat of the IAEA will continue to work towards a more robust nuclear non-proliferation regime but can only accomplish so much alone. In order fully to reach the potential of strengthened safeguards system, States need to work towards concluding those safeguards conclusions that have yet to be brought into force and also towards universal subscription to APs based on the Model text.

References

1. IAEA (1972): The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected).
2. IAEA (1997): Model Protocol Additional to the Agreement(s) between the State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected).

3. Cooley, J.N. (2002): The Conceptual Framework for Integrated Safeguards, *Proceedings of the 43rd Annual Meeting of the Institute of Nuclear Materials Management*.
4. IAEA (2004): Guidelines and Format for Preparation and Submission of Declarations Pursuant to Articles 2 and 3 of the Model Protocol Additional to Safeguards Agreements, IAEA-SVS-11, Vienna.

Verification under the Chemical Weapons Convention

Mohamed Daoudi and Ralf Trapp

1 Introduction

This paper provides an overview on the verification system of the Chemical Weapons Convention (CWC), starting with a correlation of its different verification tools with the basic obligations undertaken by its States Parties. It firstly addresses the verification of declarations of chemical weapons (CW) and CW production facilities, as well as of their destruction. Then follows a discussion of the verification systems put in place to verify the non-production of chemicals weapons at facilities involved with legitimate activities, in particular in the chemical industry. Finally this paper looks at the challenge inspection regime.

As for the routine verification of chemical weapons stockpiles and production facilities and their disarmament (destruction/conversion), one can conclude that this is a relatively simple task in verification terms involving well-established and tested methodologies. These include a combination of quantitative (accounting controls, physical measurements, tracking), qualitative (labelling, observation, sampling and analysis) and physical security (containment, recording and observation) techniques. The main emphasis of the Organization for the Prohibition of Chemical Weapons (OPCW) is at further optimising the system to reduce manpower dependency without compromising verification standards.

Verification of chemical industry facilities is based less on quantitative or systematic methodologies, although accountancy controls and audits do play a significant role in these inspections. Given the large number of declared facilities (some of which have a considerable potential for conversion for CW purposes while many others have practically none), there is much reliance on qualitative tests and statistical selection processes to provide an acceptable degree of assurance. Individual inspections, whilst deserving attention from a methodological point of view (they have to be sufficiently robust and credible so a violation can be detected), are only part of the problem. Verification needs to be assessed as a system. Given the number and relative risk distribution among the declared facilities, methodologies for selecting facilities for inspection and decisions on desirable inspection frequencies are equally crucial to assess verification credibility. This has a strong political dimension.

Challenge inspection, by some analysts perceived as the "ultimate deterrence against cheating" whilst others would like to see it as almost a routine tool of compliance assurance, has many dimensions; this paper only looks at some: its main parameters, how to make it operational, and the fact that it has not been used. The paper concludes that, like with any other deterrence tool, what matters is the conviction that it could in fact be invoked (politically, legally) and executed with success (practically, procedurally). For that it needs the proper attention by the OPCW's Executive Council and advance planning, training and other necessary practical measures by the Technical Secretariat (TS) to maintain readiness for its execution. That provided, the frequency of use of challenge inspection has little relevance for its deterrence effect.

The CWC entered into force on 29 April 1997; at the time of writing 167 States had become a party of it and another 16 States had signed it but had not completed ratification. The number of States Parties continues to raise, partly a result of an Action Plan which the First CWC Review Conference requested and which is being implemented since its adoption in October 2003.

The CWC prohibits the development, production, stockpiling and use of chemical weapons and requires the destruction of CW stockpiles and former CW production facilities within prescribed timeframes, subject to international verification. To delineate these requirements, the CWC uses a definition of chemical weapons that is based on the properties of a given chemical (toxicity or precursor to a toxic chemical), purpose of use, and consistency of types and quantities of chemicals with such purposes[1]. In the practical verification conduct, the CWC uses control lists of treaty-regulated chemicals (the "Schedules").

This paper explains the verification regime established by the CWC and reflects on some of the practical experiences gained so far with its application.

2 Overview

In order to verify compliance with the different prohibitions and basic undertakings contained in it, the CWC uses a combination of routine and "special" verification means, see Table 1.

Routine verification measures are based on State Party declarations of certain types of facilities and activities, and involve both data monitoring and on-site inspections. This includes also the routine (systematic) verification of the destruction of CW stockpiles and production facilities.

"Special" inspections (in the CWC context challenge inspection and investigations of alleged use) are triggered by State Party requests, and aim at

[1] This is often referred to as the "General Purpose Criterion".

Table 1. Correlation between basic prohibitions and undertakings of States Parties under the CWC and applicable verification regimes

Reference in Art. I	Prohibition/undertaking	Means of verification provided for by the CWC
1(a)	Never under any circumstances to:	
	develop	S-1[2] inspections, CI[3]
	produce	S-1/2/3 inspections, CI
	otherwise acquire	S-1/2/3 transfer data monitoring, CI
	stockpile	CI
	retain	CI
	transfer (directly or indirectly) CW to anyone	S-1/2/3 transfer data monitoring, CI
1 (b)	Never under any circumstances to use CW	IAU[4]
1 (c)	Never under any circumstances to engage in military preparations for CW use	CI, declaration of protective programmes under Art. X
1 (d)	Never under any circumstances to assist, encourage or induce, in any way, anyone to engage in any activity prohibited to a State Party	CI
2	Destroy CW	routine inspec. (permanent presence)
3	Destroy all CW it abandoned on another State Partys territory	routine inspections
4	Destroy CWPFs (includes conversion for purposes not prohibited)	routine inspections (including inspection of converted facilities)
5	Not to use riot control agents as a method of warfare	IAU

[2] S-1 = Schedule 1 (and similarly for S-2 and S-3), relating to verification measures applied to the chemicals listed on the respective Schedule and the facilities that produce (process, consume - as applicable) these chemicals above the applicable annual threshold.[3] CI = challenge inspection. Note that under Article IX, States Parties also may engage in bilateral or multilateral clarification procedures, which may lead into OPCW verification measures under certain circumstances.[4] IAU = investigation of alleged use of chemical weapons.

verifying non-compliance concerns or allegations of CW use[2]. Whilst routine inspections are focused on declared facilities only, challenge inspection (and in a slightly different way investigations of alleged use) can be requested at undeclared locations or facilities as well.

If one takes the key prohibitions under Article I one by one and analyses how the CWC provides for verification of compliance with them, the following picture emerges:

[2] An investigation of alleged use by a State Party is effectively a challenge inspection because it pre-supposes non-compliance by the party in case. The CWC recognises explicitly the possibility that an investigation of alleged use can either be called for in the form of an assistance request (Article X), or as part of an Article IX procedure (including challenge inspection). See VA-XI.1 of the CWC.

At the top level, CWC verification can thus be portrayed as any of the following:

- a combination of routine (declaration-based) and request-triggered on-site inspections
- a mix of systematic and randomly applied verification (including with weighing factors) based on risk assessment
- a combinations of data monitoring and on-site inspection
- a complementary system of clarification procedures between States Parties (which could include the use of national technical verification means) and international verification measures applied by the OPCW.

In order to illustrate the size of this complex verification system, Table 2 and Figure 1 are given.

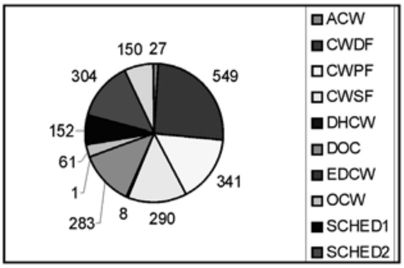
Table 2. Overview of key verification parameters of the CWC - status as of June 2005

Facility type	Number of States Parties that have declared facilities	Number of declared facilities/locations	Number of States Parties that have inspectable facilities	Number of facilities liable to inspection	Number of inspections conducted by the OPCW since EIF	Number of inspector days
CWPFs[1]	12	64	6	27	341	6,963
CWSFs[2]	6	35	6	31	279	8,728
CWDFs[3]	6	43	4	8	540	82,334
EDCW[4]					1	10
DHCW[5]					8	357
Old CWs	11	45	8	23	61	1240
Abandoned CWs	3	16	3	16	27	788
Schedule 1	21	27	21	27	149	2,580
Schedule 2	36	439	21	146	300	7,721
Schedule 3	34	498	33	421	150	2,757
OCPFs (DOC/PSF)[6]	73	4836	71	4648	281	4,761
TOTAL					2,137	118,239

[1] CW production facilities
[2] CW storage facilities
[3] CW destruction facilities (figure is based on destruction plans submitted by States Parties)
[4] Emergency destruction of chemical weapons
[5] Destruction of … CW
[6] Discrete organic /Phosporus, sulfus, fluorine chemicals

3 Routine (systematic) verification of chemical weapons stockpiles and production facilities and of their destruction or conversion

The basic provisions governing these verification measures are set out in Articles III, IV and V, and in Parts III through V of the Verification Annex. Also applicable are the general verification provisions of Parts I and II of the Verification Annex, the provisions of the Confidentiality Annex, certain



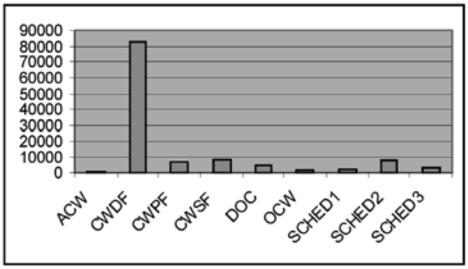


Fig. 1. Inspection distribution since entry into force (chart 1: inspections conducted; chart 2: inspector days spent)

provisions of the Annex on Chemicals[3] and provisions of other Articles, for example Article VIII dealing with the powers and functions of the statutory organs of the OPCW including the TS as its verification agency.

Article IV regulates the regime of routine verification to be applied to chemical weapons declared under Article III, paragraphs 1(a)(ii) and 1(a)(iii), and at chemical weapons destruction facilities. This verification will be on-site, systematic and international, involving inspection as well as monitoring by on-site instruments. All locations where chemical weapons are stored or destroyed are subjected to systematic verification through on-site inspection and monitoring with on-site instruments. Although these terms are not further defined in the Convention, their meaning can be deduced from the access provisions under Article IV and from the verification provisions in the Verification Annex.

'Systematic' is used as opposed to 'random'. However, it does not mean permanent except that CW destruction facilities will, when in operation, be subject to permanent monitoring. The term implies that verification activities are designed so as to ensure that no prohibited activities, for example, the removal of chemical weapons from a stockpile would go undetected. Verification may include inspection and monitoring by a system of instruments, both being supplementary methods[4].

CW storage facilities are subject to initial inspection by the OPCW. The procedural aspects of how to conduct these initial inspections for the purpose of verifying the declaration are dealt with in paragraphs 39 and 40 of Part IV(A) of the Verification Annex. However, the purpose of the initial inspection at chemical weapons storage facilities is not restricted to verifying the declaration under Article III. Under paragraph 1 of Part III of the Verification Annex, the purpose is also to 'obtain any additional information needed for planning future verification activities ... and to work on the facility agreement', to be

[3] For example, the composition of the Schedules impacts on the categorisation of chemical weapons into categories I, II and III, which have different destruction timelines.

[4] See, for example, Part IV(A) 42.

concluded not later than 180 days after the Convention has entered into force for the State Party or after the facility has been declared for the first time (paragraph 4 of Part III).

In essence, these initial inspections verify the baseline provided by CW possessors on the size and composition of their stockpile. In practice, this is essentially a quantitative inventory measure, where the numbers of declared CW items (shells, bombs, containers etc.) are verified. Whilst the CWC also foresees that the identity of the agent fill is to be verified, the practice is that this task will only be undertaken when the weapons have been moved to a destruction facility where they are opened for subsequent destruction. The main reason is safety - opening the weapons for verification or any other purposes at storage locations would violate standing safety regulations and pose unacceptable risks to inspectors and facility personnel alike. To maintain control of a stockpile until the items stored there are moved for destruction to a destruction facility, a regime of applying and managing seals is used to ensure that the OPCW can clearly link an item that is transported to and/or sampled at a destruction facility for analysis of agent content to an item that was inventoried at the original stockpile location.

Article IV does not require CW stockpile verification through on-site inspection and monitoring with on-site instruments, but speaks of systematic on-site verification in general. On the other hand, paragraph 42 of Part IV(A) of the Verification Annex re-introduces the concept of monitoring with on-site instruments. However, compared to other provisions of Part IV(A) and to the provisions under Part V, there is little emphasis on using such systems at storage facilities. Although verification 'shall ... combine on-site inspection and monitoring with on-site instruments' (paragraph 42, Part IV(A)), verification is clearly based on inspections on short notice rather than instruments installed on-site[5]. This is also the implementation practice.

The details of the verification of chemical weapons destruction operations are set forth in paragraphs 50 to 70 of Part IV(A) of the Verification Annex. There, it is stipulated that the aim of verification is to 'confirm the identity and quantity of the chemical weapons stocks to be destroyed; and ... to confirm that these stocks have been destroyed' (paragraph 50). Verification is based on facility agreements. For CW destruction operations which began before the Convention entered into force for the State Party in question, there is a requirement for transitional facility agreements after the entry into force until such time when final agreements are adopted and in place. Inspection activities

[5] This concept was changed at the end of the negotiations if compared to earlier versions of the draft Convention, marking a shift in security perceptions: with the end of Cold-War, the need to keep declared stocks under permanent surveillance had disappeared. For verification purposes, it sufficed to have a thorough initial inspection and inventory controls in respect to all weapons leaving the storage facility for a destruction facility, as well as of the destruction operations themselves. See the Explanatory Note of the Chairman of the Ad-Hoc Committee, CD/CW/WP.409.

include inventorying of CW received from storage facilities, monitoring of the destruction process to verify its integrity and confirm that destruction is actually taking place, sampling and analysis to verify the identity of the agent being destroyed and, as necessary, confirm completeness of destruction, and other measures necessary to confirm amounts and identity of CW destroyed as well as the completeness of their destruction. Verification techniques include in particular visual observation, the use of video cameras and recording devices, review of data generated by the facility process control system, sampling and analysis, and the application of certain access control measures at key points in the facility.

Old and abandoned chemical weapons (OCW, ACW), which are exempted from the provisions of Article IV through paragraph 1 of that Article, are covered under Part IV(B) of the Verification Annex. The declaration requirements mirror those of chemical weapons but recognise that information on the quantity and nature of these non-stockpile items may be less reliable/accurate under the circumstances.

There is a requirement for initial and "further" inspections of declared OCW. What is not clear from the wording of Part IV(B), and remains therefore open to conflicting interpretations, is whether the requirement of paragraph 7 of Part IV(B), which obliges States Parties to destroy these OCW "in accordance with Article IV and Part IV(A)", invokes only the State Party's responsibility to destroy, or also the requirement for the Secretariat to apply verification measures to the destruction operations.

Be that as it may, the purpose of inspection of these OCW is to verify the declaration (including whether they meet the respective definition of OCW, either pre-1925 or unusable CW produced between 1925 and 1946). This requires, inter alia, guidelines to determine the usability - an issue that remains unresolved between States Parties. As a practical fix, the OPCW uses internal guidelines that allow inspectors to record and assess the state of degradation of these weapons as the factual basis for assessing their (un-)usability.

In respect to abandoned CW (ACW) there is the additional requirement to establish facts that could lead to the identification of the abandoning State Party. The verification and other procedures applicable to ACW are set in a more complex framework, involving not only the State Party that has abandoned the CW in the past but also the State Party where these ACW are now located.

In respect to chemical weapons production facilities (CWPFs), which are subject to closure and inactivation at entry into force, Article V stipulates that all CWPFs are to be subjected to systematic verification through on-site inspection and monitoring with on-site instruments. Further detail is contained in the provisions of Part V of the Verification Annex.

The purpose of the initial inspection will be to verify the declaration[6]. That declaration format is specified in VA-Part V. The purpose of the initial

[6] Paragraph 6 of Article V.

inspection at chemical weapons storage facilities is, however, not restricted to verifying the declaration under Article III. Under paragraph 1 of Part III of the Verification Annex, the purpose is also to 'obtain any additional information needed for planning future verification activities ... and to work on the facility agreement', to be concluded not later than 180 days after the Convention has entered into force for the State Party[7].

Furthermore, paragraph 44 of Part V of the Verification Annex specifies in more detail the purpose of this initial inspection. This includes:

- confirmation that CW production has ceased and the CWPF is inactivated
- familiarisation with the measures taken to that end
- installation of temporary seals
- inventory confirmation (buildings and specialised equipment)[8]
- obtain information for planning future verification activities
- conduct preliminary discussion of a detailed agreement on inspection procedures (i.e., the facility agreement).

Subsequently to this initial inspection, systematic verification of the facility is being applied by the OPCW until its ultimate destruction[9]. As this verification was to be based on facility agreements and these will have to be finalized by 180 days after the Convention has entered into force for the State Party, there was a rather narrow time window for the conduct of the initial inspections (between day 90 and 180 after the Convention has entered into force for a State Party). In practice, it was possible for the OPCW to comply with that requirement for the conduct of initial inspections (using the approach of sequential inspections), but the conclusion of facility agreements experienced considerable delay.

Verification of closure will have to ascertain that the measures taken are such that the facility is 'rendered inactive'[10]. Paragraph 13 of Part V of the Verification Annex sets forth such measures. It speaks of 'agreed measures' thus implying that these measures will be agreed upon between the State Party and the TS. On the other hand, paragraph 13 lists those measures which, 'with due regard to the specific characteristics of the facility', shall be taken at each facility (i.e., obligatory measures).

Systematic verification through on-site inspection and monitoring with on-site instruments is to continue at each CWPF after closure has been verified, until the facility is eventually destroyed. Detailed procedures for this verification are set forth in paragraphs 48 to 54 of Part V of the Verification Annex. The aim of this verification is to 'ensure that any resumption

[7] Part III 4.

[8] Note that the destruction obligation extends to all equipment, whether specialised or not, and hence also standard equipment needs to be considered during the initial inspection.

[9] In the case of conversion, verification continues also after the completion of that conversion, for a minimum of 10 years.

[10] Part V 12.

of production of chemical weapons or removal of declared items will be detected'[11]. Verification is based on a facility agreement[12]. Facilities could see up to four inspections per year[13], normally to be announced 48 hours before the arrival of the inspection team at the site[14]. Inspectors will have unimpeded access in accordance with the facility agreement[15]. In practice, this is implemented through the conduct of regular re-inspection of these facilities, the re-inspection frequency being based on risk factors and decisions taken in the OPCW's annual programme and budget.

Paragraph 7(b) of Article V also provides for the systematic verification of the destruction of CWPFs, based on a detailed plan for the destruction of each facility and a review of that detailed plan, in accordance with paragraphs 36 to 42 of Part V of the Verification Annex, by the Executive Council. The aim of verification is to confirm that 'the facility is destroyed in accordance with the provisions of [the] Convention and that each item on the declared inventory is destroyed in accordance with the agreed detailed plan for destruction'[16]. After destruction has been completed, systematic verification by the TS will cease[17].

Paragraph 12 stipulates that for a CWPF temporarily converted into a facility for the destruction of chemical weapons, verification and other provisions set out in paragraphs 18 to 25 of Part V of the Verification Annex will apply[18]. Paragraph 18 sets forth the general principle that 'the regime for the temporarily converted facility is at least as stringent as the regime for chemical weapons production facilities that have not been converted'. In other words, all requirements for verification of such CWPFs until their destruction will apply, irrespective of other verification procedures that would flow from the facility being also temporarily used as a chemical weapons destruction facility.

Paragraph 15 of Article V stipulates that converted CWPFs shall be subject to systematic verification after conversion, in accordance with Section D of Part V. That includes an initial inspection of the facility to be converted in order to 'determine the accuracy of the information provided in the request, to obtain information on the technical characteristics of the proposed converted facility, and to assess the conditions under which use for purposes not prohibited under this Convention may be permitted'. If conversion is approved,

[11] Part V 48.
[12] Part V 49.
[13] Part V 49. Part V 54 passes the task of elaborating guidelines for the determination of the frequency of such inspections on to the Preparatory Commission.
[14] Part V 52.
[15] Part V 53.
[16] Part V 55. See also Part V 26 and 27.
[17] Part V 56.
[18] The second part of the paragraph also stipulates that, within the order of destruction, the facility will eventually have to be destroyed as a CWPF. Procedures as above discussed will then apply.

a facility agreement will be agreed upon within 90 days thereafter for the converted facility. This agreement will include verification conditions[19]. The State Party will be obliged to submit a detailed plan for conversion which will have to include proposed measures for verification[20], subject to approval by the Executive Council[21]. During the first ten years after conversion, inspectors will have far-reaching inspection rights at the converted facility and, if applicable, the surrounding chemical plant site[22]. The regime for continued verification after these ten years will be decided upon by the Executive Council[23].

Both Article IV and V contain provisions that relate to a situation where bilateral or multilateral agreements on the verification of chemical weapons or CW production facilities and their destruction are in force between two or more States Parties[24]. In such cases, in order to avoid unnecessary duplication of verification efforts and hence unnecessary cost, the Executive Council may decide to limit the verification activities of the TS to complementary measures if it considers that certain conditions are met[25]. If there was such agreement the character of verification by the OPCW shifts from the verification of CW/CWPFs and their destruction/conversion to the auditing of verification activities of the parties to such agreements.

To sum up this part of the paper, verification of CW stockpiles and production facilities is essentially a process of verifying, safeguarding and tracking declared items (chemical weapons including bulk containers, specialised and standard equipment at CWPFs), confirming their identity (in particular, the agent fill of CW), and monitoring and confirming their destruction in accordance with agreed standards ("end point of destruction"). The methodology used is close to what in nuclear safeguarding is known as "material balance verification", with well-defined accountancy areas and times, and the application of techniques to verify the closure of material balances. The process is highly systematised and relies on a combination of observation, object identification and tracking, containment measures as applicable, accounting, qualitative tests (sampling and analysis), quantitative tests (weighing, flow measurements) and instrumental monitoring (in particular video monitoring and recording). From a verification methodology point of view, it is as a relatively simple, robust and straight-forward process with a high level of assurance.

Figure 2 and Tables 3 and 4 illustrate the progress of the destruction and conversion of CWs.

---

[19] Part V 76.

[20] Part V 77 and 78.

[21] Part V 79 to 84.

[22] Part V 85.

[23] Part V 85.

[24] These provisions were introduced with a United States-Russian bilateral agreement in mind (which, however, never materialised). The main purpose was to reduce verification cost.

[25] A formal decision by the Executive Council is required.

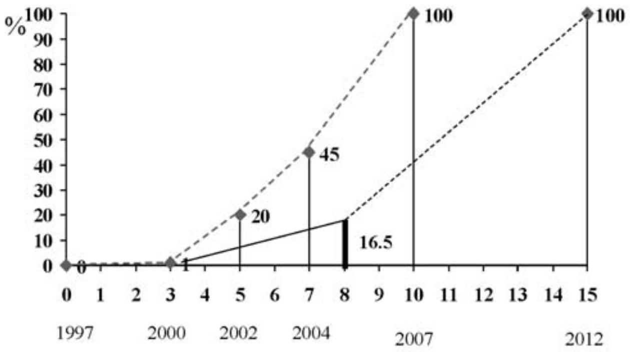


Fig. 2. CW destruction time lines and actual pace of CW destruction as at June 2005

Table 3. CW destruction progress, June 2005. CWPFs have been declared by 12 States Parties. Converted CWPFs remain subject to verification in accordance with the provisions set out in Part V of the Verification Annex. Temporary conversion of CWPFs into CW destruction facilities is not addressed in the table above.

CW Destruction		
	Declared*	Destroyed
Total Weight of Chemical Agents	71,373.422MT	11,773.701MT (Category 1, 2 and binary components)
Total of Munitions /Containers	8,679,072	2,260,840 (Category 1 unitary and binary munitions and containers, Category 2 and 3 items and OTCs)

Table 4. Progress with respect to the destruction or conversion of CWPFs, June 2005

Destruction and conversion of chemical weapons production facilities	
CW production facilities	**Number**
- declared	64
- certified as destroyed	37
- still under destruction	5
- certified as converted	14
- still under conversion	8

4 Routine verification of non-production of chemical weapons at chemical industry and other facilities

Article VI relates to activities not prohibited under the Convention. It is linked directly to Article II where these activities are defined, associated with the definition of chemical weapons. Article VI is a consequence of the comprehensive scope of the Convention (the so-called "general purpose criterion" used in the definition of chemical weapons), and the fact that many toxic and precursor chemicals that can be used for CW purposes are 'dual-use' chemicals with legitimate applications which the Convention does not intend to restrict.

This 'dual-use' feature sets the context for verification under Article VI, which is based on declaration and verification regimes related to scheduled chemicals and facilities associated with their production (and in the case of Schedule 2 also processing and consumption) as well as to certain "other ('capable') chemical production facilities". There are also requirements for States Parties to control transfers with scheduled chemicals to prevent CW proliferation.

The specifics of these regimes are set forth in Parts VI to IX of the Verification Annex. Three of these regimes are linked to the Schedules of Chemicals contained, together with guidelines on them, in the Annex on Chemicals. The fourth regime, under Part IX, relates to facilities producing discrete organic chemicals (DOCs), with a focus on facilities producing DOCs that contain one or more elements of phosphorus, sulfur or fluorine (PSF chemicals).

There is an intimate relationship between Article VI and Article VII (National Implementation Measures). Repeating the general requirement for each State Party to 'adopt the necessary measures to implement its obligations under this Convention' from paragraph 1 of Article VII, and specifying them for the purpose of Article VI 'to ensure that toxic chemicals and their precursors are only developed, produced, otherwise acquired, retained, transferred, or used within its territory or in any other place under its jurisdiction or control for purposes not prohibited under this Convention', Article VI provides the legal framework for implementation measures that each State Party will have to undertake in respect to its legitimate activities in the chemical field. Taken together with the provisions in Parts VI to IX, these measures will, *inter alia*, have to encompass:

- enacting of restrictions/prohibitions regarding the manufacturing, possession transfers and use of Schedule 1 chemicals;
- the establishment of a national reporting system in order to gather, ascertain and submit data to be provided in declarations under Article VI;
- the establishment of a legal framework for the conduct of on-site inspections by the OPCW in their private industry;
- legal and administrative measures necessary to implement the export restrictions and controls *vis-á-vis* States not Party to the Convention.

At the same time, paragraphs 10 and 11 of Article VI and the provisions of Article XI will have to be taken into account. These provisions, *inter alia* limit the right of intrusion by the Technical Secretariat in conducting verification activities, and make an explicit cross-reference to the Annex on the Protection of Confidential Information ('Confidentiality Annex')[26]. Paragraph 11 links the implementation of verification and other provisions under Article VI to Article XI and its basic principle that the provisions of the Convention, and hence those of Article VI, shall be implemented 'in a manner which avoids hampering the economic or technological development of States Parties and

[26] This Annex covers all verification activities by the TS.

international cooperation in the field of chemical activities for purposes not prohibited ...'.

The Convention thus creates a delicate balance between:

- the right of each State Party to use chemicals for non-prohibited purposes;
- the obligation of each State Party to do so in a responsible manner, and in particular in accordance with Articles I and VI of the Convention;
- the right of the Organization to verify such activities in order to prevent violations of the basic obligations under the Convention; and
- the requirement for the Organization to do so without undue interference with or hindrance of those legitimate activities.

Article VI requires *initial declarations* from States Parties. As in the case of Article III, a baseline for verification is so established, except that this is not a static situation and the baseline will change every year as industrial activity in relevant field evolves in the States Parties. Simultaneously, Article VI requires States Parties to provide access to declared chemical facilities[27] for the purpose of verification through data-monitoring and on-site inspection[28].

There is a common presumption that verification conduct under Article VI is the main contribution that the Convention makes to CW non-proliferation. In fact, the direct contribution of Article VI verification to CW non-proliferation (understood in the narrow sense, i.e. meaning the spread of chemical weapons and related technologies) is limited[29]. Article VI verification has been designed, in most respect, as verification of non-production of CW, a much narrower concept. That is not to say that Article VI verification does not contribute to CW non-proliferation, but it should not be portrayed as a primary non-proliferation tool. Its primary function is to enhance confidence in State Party compliance with the prohibition to develop and produce CW,

[27] The Convention uses two different thresholds of annual production (in the case of Schedule 2 also processing or consumption), one for declaration and another one, typically one order of magnitude higher, for liability to on-site inspection.

[28] In the case of Schedule 1 for systematic verification through on-site inspection and monitoring with on-site instruments, similar to facilities covered under Articles IV and V.

[29] The most important contribution to CW non-proliferation under the Convention is actually made by the States Parties themselves. They are to enact penal legislation which, *inter alia* needs to be designed so as to criminalise proliferation attempts (Article VII). At the same time, the States Parties are required to impose trade regulations to control the transfer of scheduled chemicals in respect to States not Party. Finally, and most importantly, they are bound by Article I which amongst others contains the undertaking of the parties never under any circumstances to assist, encourage or induce anyone to engage in any activity prohibited by the Convention. This obligation of the States Parties requires their active and constant implementation work to *prevent* proliferation.

not to detect proliferation attempts by States not party or diversions within the territory of the State Party itself[30].

There are four distinct verification regimes established under Article VI. These are set out in Parts VI - IX of the Verification Annex. Following the risk to the object and purpose of the chemicals involved, these (sub)regimes range from systematic verification in the case of Schedule 1 to risk-assessment based verification in Schedule 2 and qualified random-check approaches for Schedules 3 and OCPFs. As a tendency, from Schedule 1 to OCPFs, the number of facilities declared under a given sub-regime increases, inspection frequency, time and intensity reduce, notification times increase, access rights get more qualified, sampling and analysis is seen as less stringent, the role of facility agreements changes from mandatory to unnecessary unless specifically requested by the inspected State Party - in short the regime changes from systematic, highly quantitative and procedurally stringent to a kind of qualitative spot check.

This concept of risk to the object and purpose governs verification at two inter-connected levels: as for the chemicals, risk is a key determinant for placing a compound into one of the three Schedules. The CWC assumes that that risk decreases from Schedule 1 through Schedule 2 to Schedule 3 (with the so-called "discrete organic chemicals" that trigger OCPF verification being considered not to pose any particular risk themselves - it is the facility that is of interest in the OCPF context, not the chemical *per se*). Risk as it applies to inspection frequency and conduct, however, relates not only to the chemicals involved but also to the characteristics present at a given facility and the activities carried out there. There may well be facilities that deal with low-risk (in CWC terms) unscheduled chemicals but that pose a high risk to the object and purpose of the Convention if compared to other facilities dealing with scheduled chemicals, given their chemical process and technological configurations and other features. The regimes for Schedules 1 and 2 chemicals, consequently, contain provisions for risk assessment as the basis for decisions on inspection frequency and intensity.

An overview of inspections conducted so far is given by Figure 3.

4.1 Schedule 1 chemicals and facilities

Paragraph 21 of Part VI establishes as the aim of verification at Single Small-Scale Facilities to ascertain that 'the quantities of Schedule 1 chemicals produced are correctly declared' and that aggregate amount does not exceed the 1-tonne annual limit. In other words, the Convention does not *attempt to verify closed material cycles for Schedule 1 chemicals but relies upon verification*

[30] The detection of diversion is one of the inspection goals for Schedule 1 and 2 facilities, but at the level of the facility, not country-wide. Downstream users of Schedule 1 chemicals, or chemical traders, are *not* included in the routine verification system.

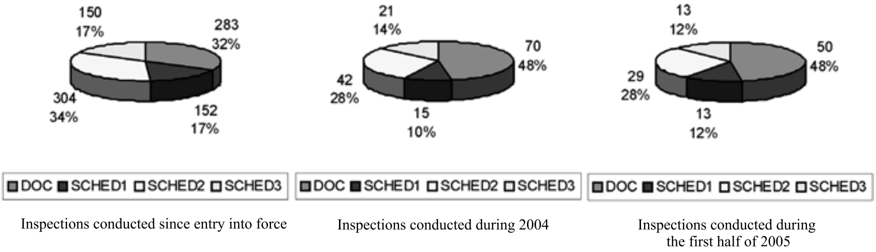


Fig. 3. Article VI inspections, distribution of inspections conducted since entry into force, in 2004, and during the first half of 2005

of production, irrespective of what happens to the material after it leaves the Schedule 1 facility. While this is consistent with the declaration requirements under Part VI, it also means that the Organization will *not have any systematic means to verify compliance with the upper limit of 1 tonne concerning the total holdings of Schedule 1 chemicals in a State Party.*

Essentially the same is true for other Schedule 1 facilities: the provisions on verification aims in paragraph 28 of Part VI include verifying that:

- the facility is not abused for undeclared activities;
- the produced, processed and consumed quantities of Schedule 1 chemicals are as declared; and
- no diversion has occurred at the facility.

While the second and third verification aim appear to convey at first glance that a thorough material accountancy approach is envisaged, it has to be repeated that the verification regime ignores facilities outside the area of Schedule 1 producers and hence *cannot* give reliable answers regarding diversion at the State level. Answers on diversion will primarily relate to diversion *within* the facilities subject to verification, not to potential diversion of material after it has left the premises, for which the TS will have no authority to conduct verification activities on its own initiative[31].

The Schedule 1 verification regime of the CWC is thus geared towards providing transparency with respect to the activities of facilities that actually produce the chemicals, rather than for the use of the chemicals themselves. Part VI of the Verification Annex also contains a number of restrictions on these facilities (in particular with respect to the Single Small-Scale Facility. This, then, is an attempt to control possible *break-out capabilities* associated with sensitive facilities, and not primarily to control the high-risk chemicals themselves (which continue to have legitimate uses in chemical defence and certain kinds of research).

[31] That could only happen in the context of a challenge inspection.

As for the risk posed by the chemicals themselves, the CWC attempts to contain it primarily through the quantitative restrictions on aggregate annual production and possession per State Party (both 1 tonne, and the latter essentially non-verifiable), and controls and prohibitions with respect to transfers (prohibitions vis-à-vis States not party and reporting requirements for transfers between States Parties).

4.2 Schedule 2 chemicals and facilities

Part VII of the Verification Annex contains provisions with respect to the reporting of aggregate national data (AND) on production, processing, consumption, export and import, as well as facilities producing, processing or consuming Schedule 2 chemicals above threshold.

The reporting and data monitoring of AND will not be discussed here in any detail. These data are essentially non-verifiable and the resolution of any discrepancies (for example with respect to differences between declarations of exporting and importing States Parties) have to be attempted between the States Parties concerned, rather than by independent verification measures of the OPCW.

With respect to on-site inspection of declared Schedule 2 facilities, paragraph 15 of Part VII establishes one general and three particular inspection aims.

The relationship between 'general' and 'particular' inspection aims is not entirely clear. Obviously, both types of aims apply to each inspection, in accordance with the inspection mandate. A possible interpretation of the word 'general' would be that it allows:

- going beyond the particular inspection aims which are set against declared data (i.e., an inspection does not have to be limited to verifying declared data); and
- including inspection aims that involve compliance with the basic obligations under, for example, Article I.

That interpretation is supported by the provision itself, which stipulates as one general inspection aim that 'activities are in accordance with obligations under this Convention'. In other words, the Technical Secretariat will not be limited to merely checking during inspections whether declarations were correct and complete and whether activities in regard to the scheduled chemical were in accordance with the obligations undertaken. It *will also have a more general right to aim inspection activities at detecting illegal activities such as development of chemical weapons or proliferation attempts, whether related to the scheduled chemical that triggered verification in the first place or not.*[32]

The second part of paragraph 15 sets forth the specific inspection aims. First, it triggers verification activities in regard to compliance with the regime

[32] See also the discussion of paragraph 25 of Part VII.

of Part VI, i.e. the absence of Schedule 1 chemicals as well as their production above the 100 grams threshold for non-declarable production. However, the provision also invokes implicitly the question of compliance with other provisions, in particular in respect to Articles I and V regarding the prohibition of chemical weapons production facilities. The absence of production also implies absence of means of production of Schedule 1 chemicals (to the extent that such means are specific).

'Consistency with declaration levels' is another inspection aim, indicating on the one hand that quantitative assessments are a part of inspections. On the other hand, a systematic material balance verification approach, following the example of nuclear safeguarding, is not necessarily implied[33].

The third specific inspection aim is to verify non-diversion. As it is formulated as an inspection aim, it does not automatically imply a rigid material balance verification approach either[34]. However, it opens the door for inspection not only of chemicals, process equipment and the like, but also of facility records and documentation.

Paragraph 17 of Part VII stipulates the requirement of drafting, during the initial inspection, a facility agreement[35]. The facility agreement will relate to the whole plant site. Another element, however, is that the requirement for a facility agreement can be waived by agreement between the State Party and the TS.

Under paragraph 18 of Part VII, inspectors are required to undertake a 'risk assessment' during the initial inspection, in order to get guidance on the 'frequency[36] and intensity[37]' of inspection. Certain criteria that will have to be taken into account for that risk assessment are listed in the Convention. The Conference of the States Parties adopted at its First Session after entry into force a decision listing risk factors to be considered[38]. A methodology for how to apply these risk factors was discussed for several years but never formally agreed. The methodology used by the TS is essentially a simplification of what the Conference decision seems to imply, and concentrates heavily on

---

[33] For a more detailed discussion, see R. Trapp *Verification in the Chemical Weapons Convention - Inspection in Chemical Industry*, SIPRI CBW Studies Series No. 14, Oxford University Press, Oxford etc. 1993.

[34] Such an approach would require a number of additional mechanisms (pre-notification of material transfers into and out of the facility, agreed inventory procedures, agreed standards etc.), and access to additional facilities other than those opened the Convention for verification (e.g., traders).

[35] This means discussing the possible content of the Facility Agreement (FA) and exchanging necessary information. The actual negotiation takes place after completion of the inspection.

[36] i.e., the desired number of inspections per year.

[37] i.e., factors such as desired inspection duration, team size and composition and the like.

[38] C-I/DEC.32 dated 16 May 1997.

production quantity, the types of chemicals handled and the nature of the activities (production, and/or processing and/or consumption).

Paragraph 25 is of paramount importance as it stipulates the access provisions to plants and objects, buildings or structures at the plant site. It has to be seen in conjunction with paragraph 15, which aims at an inspection at the whole plant site[39].

Through the explicit reference to paragraph 51 of Part II, one can open any other building or structure located in the plant site for inspection to resolve ambiguities. Provisions for how to proceed in such a situation will have to be agreed in the facility agreement or procedures according to the 'managed access' concept that normally applies under challenge inspection and can be applied by the inspection team (as well as the inspected State Party).

Paragraph 26 provides access for the inspection team to appropriate records and documentation. The paragraph limits the type of records that can be accessed to those related to possible diversion of the scheduled chemical and to declaration consistency (i.e., production, processing or consumption data). On the other hand, the right of the inspected State Party to restrict access to records is not unlimited. Under paragraph 47 of Part II, the *inspectors* have the right to inspect documentation and records 'they deem relevant'[40].

Paragraph 28 specifies areas that 'may be inspected'. Access to these areas will have to be provided. With the inspection focus being on the declared Schedule 2 plants but the inspection otherwise directed at the plant site as a whole, the list of areas would have to be applied to the specific plant(s) to be inspected *and* to elements of the common infrastructure of the plant site.

In practice, issues that the TS and States Parties needed to come to grips with were often the result of changes in the operations of the chemical industry, which had evolved and considerably changed since the end of the negotiations. Some of the definitions contained in the CWC could no longer easily be matched with the existing structures and conditions in the industry. But key verification provisions, in particular the rights of access and the domain where inspectors had unimpeded (as opposed to managed) access, were based on these definitions. There was therefore a need to come to pragmatic and sensible arrangements to ensure that the verification objectives of the Convention could be met under these changed circumstances. That need for pragmatism and flexibility will continue to be important also in the future.

---

[39] This emerged rather late in the negotiations as a compromise between those States who wanted to limit the inspection to the declared Schedule 2 plants only, and those who wanted to avoid a situation in which an inspection team would, at larger plant sites, have to 'jump from island to island' closing its eyes to the rest of the plant site.

[40] The inspected State Party will have to receive a copy of all data so gathered, under Part II 50.

4.3 Schedule 3 chemicals and facilities

The first difference between Schedule 2 and Schedule 3 facilities is the verification threshold: there is only one verification threshold (200 tonnes of annual production)[41].

The second difference relates to provisions on frequency of inspection and distribution of verification effort (including site selection). Part VII handles this problem in the context of risk assessment, facility agreements and budget allocation. Part VIII links to Part IX (OCPFs) in respect to the overall ceiling of inspections per State Party, and establishes a qualified random selection approach for site selection. Two weighing factors are specifically mentioned: equitable geographical distribution and information available to the Secretariat[42]. The Secretariat, following advice from the Executive Council, actually uses a methodology involving in a first step the selection of the State Party to be inspected, and in a second step the selection of the actual inspection site from among the declared and verifiable Schedule 3 plant sites of the selected State Party. Paragraph 16 establishes a direct link to Part IX and fixes a combined limit of inspections per State Party per year. The formula looks rather complicated but basically means that this maximum number shall be between 3 and 20, with States Parties having a larger combined number of Schedule 3 and OCPF plant sites qualifying for a higher ceiling than for those with very few such plant sites.

In accordance with paragraph 17, the general inspection aim under this Part is the same as under Part VII (see the discussion above). The specific verification aim repeats one of the specific verification aims under Part VII (absence of Schedule 1 chemicals and especially their production except in accordance with Part VI)[43]. This highlights a more qualitative inspection approach under Schedule 3 as compared to Schedule 2.

In respect to inspection conduct, there are profound differences between the regime under Part VII and this regime:

- facility agreements will only be concluded if the inspected State Party makes an explicit request;
- access to plants other than the declared Schedule 3 plants requires agreement from the inspected State Party;[44]
- access to records and documentation can be restricted by the inspected State Party;[45]
- off-site analysis of samples requires agreement by the inspected State Party (and on site analysis "may" rather than "shall" be conducted)[46]; and

[41] Part VIII 12
[42] This concept is broader than just a reference to declared information.
[43] See Part VII 15 (a).
[44] But see the discussion of Part VII 25 in regard to other declared plants.
[45] Part VIII 21.
[46] Part VIII 22.

- the inspection period is restricted to 24 hours although it can be extended by agreement.[47]

The notification time before arrival at the inspection site is 120 hours[48], the same as the notification time stipulated in Part IX for OCPF plant sites.

4.4 Other Chemical Production Facilities

These facilities were included (it should be recalled against considerable opposition) in order to address what some negotiators had called the 'capability issue'. Certain facilities that do not produce scheduled chemicals pose nevertheless a risk to the object and purpose of the Convention because thy have an inherent capability (or may easily acquire it) given their local integration of raw materials, production equipment and infrastructure. The perception is (and with respect to a good number of these facilities continues to be) that they can rather easily be converted into a CW production facility, and that they therefore need to be kept under verification. The verification regime for these OCPFs is set out in Section B of Part IX, conditioned by the provisions of Section C of the same Part.

Paragraph 9 defines the scope of on-site inspection activities: liable for inspection are all plant sites declared pursuant to paragraph 1 (a) *as well* as all plant sites declared pursuant to paragraph 1 (b) which contain at least one plant producing more than 200 tonnes of a certain PSF chemical[49].

Selection of OCPF plant sites for inspection shall be at random[50]. However, it is clear from the following subparagraphs that 'random' is qualified by weighing factors, to focus the verification effort on plant sites that are perceived to pose a particular risk to the object and purpose of the Convention. Paragraph 11 lists three weighing factors for the selection process, in subparagraphs (a) to (c). These are equitable geographical distribution of inspections; information available to the Technical Secretariat; and proposals by States Parties. The basis for such proposals remains to be agreed upon[51].

This last weighing factor has a long and rather controversial negotiation history. The concept of national proposals for routine inspections can be traced back to the British concept of ad-hoc verification[52]. It was then received by many delegations in the Conference on Disarmament as an attempt to introduce a kind of 'challenge inspection in disguise' mechanism. That, however,

[47] Part VIII 24.
[48] Part VIII 25.
[49] Although the verification thresholds are in both cases 200 tonnes per year, it should be noted that for plant sites declared pursuant to paragraph 1(a), this figure is an aggregate of all discrete organic chemicals on a plant site basis while for PSF plant sites, it relates to a specific chemical and to a specific (yet not identified in the declaration) plant.
[50] VA-X.11
[51] See paragraph 25.
[52] Compare document CD/909 of 30-3-1989, also issued as CD/CW/WP.232.

would not be appropriate under Article VI. The controversy on this issue continues to this day, and the selection methodology for OCPF inspections remains on the facilitation agenda of the OPCW's Executive Council.

The inspection aims under Part IX are identical to the inspection aims under Part VIII, and the emphasis is on verifying the absence of Schedule 1 chemicals and in particular their production (see above).

For the actual conduct of OCPF inspections, paragraph 17 is of fundamental importance. It establishes the access rights. These are different for the declared plants and for the surrounding plant site. For the plants triggering the declaration under Part IX, access will be mandatory yet the inspected State Party will have the right to apply managed access, a set of procedures designed for challenge inspection, to protect confidential information unrelated to the Convention[53]. For the rest of the plant site, access can be provided upon two conditions: firstly, a request for access would have to be made under paragraph 51 of Part II (clarification of an ambiguity). Secondly, access under such a request would be agreed and by consent of the inspected State Party. However, that does not mean that the inspected State Party would have no obligation whatsoever to provide access. Under paragraph 7 of Article VII, States Parties are required, as a principle, to co-operate with the Organization and to assist the Technical Secretariat in the discharge of its functions. The Technical Secretariat can thus expect (and in fact has encountered as a matter of routine) co-operation in attempts to resolve ambiguities.

Paragraph 19 focuses the purpose of any sampling and analysis during an inspection under Part IX to check for the absence of undeclared scheduled chemicals. It is worth noting that this goes beyond the particular inspection aim specified in paragraph 14 which relates to Schedule 1 chemicals.

Different from the general provisions set forth in Part II in regard to sampling and sample transfers to designated laboratories, the right of inspection teams to take samples off-site is limited to situations when an ambiguity has occurred and *when the inspected State Party agrees that the sample be taken off site.*

4.5 Crosscutting issues in inspections in the chemical industry

Irrespective of the specific regime under which an on-site inspection under Article VI is being conducted, there are some general issues that should briefly be reflected here. These are often the result of tensions between what the Convention seems to imply (or was built from), and evolving reality in the chemical industry as well as practical considerations (and some residual political constraints as well, see for example the reluctance of many States Parties to contemplate the sue of sampling and analysis in industry inspections as a routine verification tool).

[53] See Part X 46 to 52.

Facility agreements

Much time and efforts has been spent by the OPCW and its Member States on preparing, negotiating, reviewing in Council and finally adopting facility agreements. The value of all these efforts frankly must be called in question. Essentially the only true benefit that flows from these agreements (which are supposed to facilitate the preparation and conduct of subsequent inspections) is that they clarify some information that often is not specifically delineated, or even not contained, in the declarations of the facilities under inspection. This is particularly the case for the delineation between declared plants and the declared plant site where they are located.

But this benefit is marginal. The re-inspection frequency is such that even that information may well be obsolete when the next inspection team arrives at a given facility, and a re-negotiation will be required. Many of the other provisions are either a replica of the Convention itself (and add nothing to the inspection conduct), or are country-specific (as opposed to facility-specific) arrangements in such areas as inspection logistics.

There is therefore a good reason for the OPCW to review the usefulness of facility agreements under Article VI, with the exception of Schedule 1 facilities where the re-inspection frequency indeed justifies maintaining this approach. The CWC provides flexibility for that practical adjustment, as it contains the possibility to reach agreement between the Technical Secretariat and a State Party that for a particular Schedule 2 facility, a facility agreement will not be needed.

Sampling and analysis

Sampling and analysis was an issue hotly debated in the negotiations of the CWC in Geneva. Much consideration also went into it during the work of the Preparatory Commission, and the very acceptance of certain types of analytical equipment for use by OPCW inspection teams (in particular the gas chromatography /mass spectrometry) was uncertain until such concepts as "blinding" were agreed.

Today, the OPCW has, in principle, a working capability that could be deployed for on-site analysis, including if needed at chemical industry sites. The instrumentation works and can be handled logistically (transport ruggedness, storage requirements, set-up times etc. are all reasonable), the analysts are constantly being trained and certified as part of a broader quality assurance effort, the instruments can be set up and run-in in reasonable time frames, the OPCW central analytical database from which the instrumental databases are extracted contains a large number compounds so that the absence of scheduled chemicals at inspection sites can in fact be demonstrated to good standards, and the "blinding software" (AMDIS) works fine. In fact, the OPCW's Scientific Advisory Board concluded that this combination of database, software and instrument provides a good standard of assurance for verification purposes whilst being extremely non-intrusive with respect to the possible exposure of confidential business information unrelated to CW matters[54].

However, in practical terms, there has been little opportunity for the OPCW to actually deploy its on-site analytical capability to industrial inspection sites, and essentially all industry inspections could be completed (and their mandates implemented) without a need to undertake on-site (or off-site) chemical analysis.

That is not to say there will not be situations where it may turn out to be essential to use chemical analysis. The OPCW, now that it has established an operational capability for sampling and on-site analysis, will begin phasing-in a more frequent use of this inspection method at chemical industry facilities (Schedule-2 plant sites) beginning in the second half of 2006.

Access

Access by inspectors (to buildings or structures located at the inspection site, but also to people, records, and the like) is an important issue, in particular if one takes account of the fact that verification aims of Article VI inspections relate to the inspection site as a whole (i.e., the plant site under inspection, not just the declared plant(s)).

For the inspected party, this is an issue of controlling the inspection process and avoiding unnecessary intrusion and exposure. In some cases, it also relates to the context of national implementation (in particular, which is legally the entity that is being inspected, for example in industrial parks that may appear as a single location but involve multiple owners/operators). For the inspectors, this is often an issue of planning an inspection at a (potentially quite large) site in such a way that they can implement the inspection mandate within the tight time frames available to them.

The CWC addresses this by making a clear demarcation between the declared plant (where access is unimpeded and where the inspectors have a large discretion with respect to what they can access) and the remainder of a plant site (where access is based on a clarification requirement and managed, and the inspected State Party essentially controls the process). But as usual, the devil is in the detail. Views about how a declared plant ought to be delineated within a given plant site (and what a plant site comprises within a given location, such as an industrial park or complex) can vary, as well as change over time. The definitions contained in Part I of the Verification Annex are, unfortunately, of rather little help, as they were constructed against an industrial organisation and structure that is less and less typical for the real configuration of the chemical industry.

[54] See the Report of the Scientific Advisory Board (SAB) in preparation of the First Review Conference, submitted under a Note by the Director-General, RC-1/DG.2 (Annex) dated 23 April 2003, paragraph 5.4.

There is therefore a need for pragmatic and sensible, result-driven interpretation and problem resolution by the States Parties as well as the Technical Secretariat, based on the desire to implement inspection mandates.

5 Challenge inspection

Routine verification deals with declared facilities and activities, and its reach is thus within the control of the declaring State Party. It provides guarantees that the disarmament process is actually being implemented. With respect to the prevention of proliferation, it provides assurances through transparency with respect to activities and installations that might raise concerns with respect to compliance, and that the States Parties have agreed to open up for access to an international verification agency. That agency (the OPCW) acts on behalf of all States Parties, conducts on-site inspections and other verification measures, and reports the verification results to all States Parties so as to enable them to make their own assessment of the compliance situation.

But when such compliance assessments are done, it is not unusual that the results of routine verification measures implemented by an international agency only address some of the concerns that exist with respect to other countries' activities. Others concerns either have not been picked up by the routine system, or lie outside its scope. The options that countries have from here, in the case of the CWC, include consultation mechanisms (bilateral or through the OPCW) as well as challenge inspection.

The concept of challenge inspection (CI) is explicitly built into the provisions of the CWC itself, where challenge inspection takes up 13 separate paragraphs in the body of the treaty and a whole Part in the Verification Annex[55]. There is therefore no need here to again present all the details. It should suffice to recall that the concept of challenge inspection as set out in the CWC rests on:

- a "red-light approach" towards decision making, i.e. a CI request will be implemented by the OPCW unless the Executive Council (EC) decides, within 12 hours after receiving the request and with a three quarters majority of all its members, to abandon the inspection;
- the obligation of the requesting State Party to keep any request within the scope of the CWC[56] and to take caution not to abuse its right to request a CI;

[55] To which one could add that many provisions of Parts I and II of the Verification Annex also apply, and of course the provisions of the Confidentiality Annex. If a challenge inspection relates to a suspected CW use, the provisions on investigations of alleged use contained in Part XI of the Verification Annex will also be invoked.

[56] This would for example exclude CI requests related to the alleged use of toxic chemicals for crop destruction or defoliation during warfare, or CI requests relating to infective agents.

- the obligation on the inspected State Party to provide access into the requested site, whether declared or not, and to make any reasonable effort to demonstrate its compliance;
- the possibility for the requesting State Party to send an observer to the CI;
- the concept of perimeter negotiations to allow an inspected State Party to keep an inspection team outside the inspection site for a certain period of time (whilst observation, environmental sampling and analysis, and managed-access inspection of heavy-duty traffic leaving the site would be ongoing) so as to gain time to prepare the site for inspection; and
- the concept of managed access as a negotiation strategy that can be used by the inspection team as well as the inspected party to control and manage access in such a way that sufficient information can be collected by the inspection team to answer the compliance concern contained in the request, whilst allowing to inspected party to protect sensitive and confidential information (unrelated to CW) from exposure and/or loss.

The concept of managed access is at the heart of all of this, and was in fact a precondition for many States to agree to challenge inspection. Some countries, in particular the United Kingdom (UK), undertook extensive trials at highly sensitive military as well as at private facilities, to ensure that the mechanism would be workable and acceptable without compromising secrecy or confidential business information.[57]

[57] On the 'Practice challenge inspections of Government facilities' carried out by the UK, the following was concluded, inter alia: 'Managed access is the key to a balance between the protection of legitimate security interests and the degree of intrusiveness necessary for effective verification; no UK site is so sensitive that we could not allow some form of access, appropriately managed, to an inspection team under the provisions on challenge inspection. A system of selective access is useful in a number of potentially difficult situations; managed access is a process of negotiations between inspectors and inspected; there should be no sanctuary sites, safe from inspection. See, UK, Ministerial Statement in CD/PV. 564, pp. 3 to 6 and Practice challenge inspections of Government facilities: Analysis of results CD/1012. For other results of such inspections, see, i.a., USSR, Experimental challenge inspection at a military installation (CD/966); Germany, Report on a trial challenge inspection (974); Germany, Report on the second trial inspection (challenge inspection) in the FRG; GDR, Report on a trial challenge inspection in a chemical industry plant (CD/996); GDR, Inspection methodology for challenge inspections in industrial chemical plants (CD/997); GDR, Application of trace analysis to exploit memory effects in challenge inspections (CD/998); The Netherlands, Report on a trial challenge inspection ((CD/1018); GDR, report on a trial challenge inspection (CD/1020); Czechoslovakia, Report on a challenge inspection at a chemical facility (CD/1021); Czechoslovakia, Report on a challenge inspection at a military facility (CD/1022); France, Report on a trial challenge inspection); Canada and the Netherlands, Report on a joint chemical weapons trial inspection (CD/1052); Germany and UK, Report on two joint chemical weapons practice inspections (CD/1056 Corr.1); France, Second trial request

The development of an operational concept to implement CI was facilitated by the degree of detail already contained in the Convention itself. The Preparatory Commission, which in many other areas contributed considerably to the volume of criteria, procedures, formats and so forth to be used in verification conduct, needed to add little more than some notification formats to the system. But on the other hand, making sure that CI would actually work was (and is) by no means trivial. Here a number of problems to be addressed and overcome:

- by its very nature, CI is a complex undertaking that occurs in unpredictable and possibly hostile circumstances; the procedural framework is not as simple as it is in a routine inspection, where the affair is essentially a bilateral one involving an international agency and a sovereign State, and where the issue is not charged with accusation or allegations - the innocence of the inspected is presumed at the outset. In CI, there are many more actors (a requesting State Party, an Executive Council, and possible external actors including the media), and there is of course what amounts to an accusation of non-compliance[58];
- there is the question whether States Parties have sufficient confidence in the ability of the OPCW (its Director-General as much as its Executive Council[59]) to handle the political dimension of a CI in such a manner that neither the mechanism would be compromised or harmed nor the compliance concern would remain unresolved;
- on the part of a State Party that considers invoking the CI mechanism, there is the wider issue of whether it is prepared to live with the outcome, and any subsequent consequences, of the CI - that is less a matter of how to operationalise the concept than it is a question of how CI compares to alternative policy options in a given situation;
- on the practical side, there is firstly the issue of logistics: preparation times for CI are inherently short, team sizes unpredictable but potentially large, equipment requirements uncertain and there will be a tendency to cater for any unforeseen requirements by selecting equipment (some of which

inspection (CD/1063); UK, Verification of the CWC: Practice challenge inspections at civil chemical plant (CD/1080); Poland and USSR, Joint report on a trial inspection on request (CD/1094); USA, Report on the third US trial inspection exercise (CD/1100); Germany, Report on a trial inspection at a large chemical plant side (CD/1101); Germany, Report at an international trial challenge inspection (CD/1102); USA, Report on the fourth US trial inspection exercise (CD/1107/Rev.1); Spain, Report on a trial challenge inspection (CD/1152).

58 The word "challenge inspection" may not convey that latter aspect that strongly but it may be worthwhile recalling, for example, that the Spanish variant of the term is "inspección por denuncia".

59 The action of the EC was tested in one of the OPCW CI trials. One lesson that emerged from that was essentially a conformation of one of the design principles of CI: that it is extremely difficult for the EC to stop a CI from being executed, no matter what the specific circumstances of the request are.

may require specialised transport and storage) for a variety of conceivable circumstances, and requirements for team and equipment air transportation may be difficult to meet on short notice - there obviously is a need for the Secretariat to make preparations that go far beyond what it normally does to sustain its routine inspection effort;

- secondly, the conduct of CI required a more direct involvement of the Director-General personally (given its specific profile), and in any case would involve a variety of elements of the Technical Secretariat that are not normally involved in the routine of inspection conduct (for example, the Secretariat of the policy making organs which services the Executive Council, or the media and public affairs branch which would have to manage the fall-out of a CI in the press and other media) - there was therefore a need to set up internal mechanisms and procedures that could rapidly be activated when a CI was requested, and that would take over from the routine mechanisms of command, control and communications (the ongoing inspection efforts would, however, have to continue in parallel); different from routine inspections, the concept of a temporary, dedicated and centralised mission control group under the direction of the Director-General was established by the OPCW;
- thirdly, there is the issue of competence (experience, skills, and "mindset"). OPCW inspectors spend a considerable time of their professional life conducting routine inspections at declared facilities, where the parameters for the inspection, the boundaries of the site, and the procedures that are accepted are all clearly defined and agreed. Does this create a bias in a CI scenario? How easy will it be for inspectors to adjust to the rather different procedural and methodological framework (and political conditions) that they would encounter in a CI[60]? For example, how well will they perform as negotiators in managed access situations? Clearly, there is a need for the Secretariat to ensure through ongoing training that such special skills are kept at a high standard; there is equally a need to ensure that *States Parties are aware of the state of readiness*, if they are to have confidence in the Secretariat's ability to execute a CI. One way of accomplishing this is by conducting on a regular basis training exercises that involve experts from States Parties, and/or that are hosted by States Parties coming from different regions.

On balance, the OPCW has today achieved a state of readiness and a degree of competence that place the question of whether or not a challenge inspection should be requested firmly with the State Party contemplating such a step. Decisions to request (or not to request) CI are no longer influenced by worries about whether the OPCW could actually conduct a credible CI in a competent and timely fashion - although improvements can always be made

[60] In general terms, the CWC recognises this problem by requiring that inspectors to be designated for challenge inspection need to have adequate qualification, experience, skills and training- see Part X Verification Annex, paragraph 1.

and although the present state of affairs needs to be maintained also in the future, confidence now exists that the OPCW inspectorate can be relied upon in a CI. The question is back to where it was in the negotiations - in the political world of compliance assessment and decision making on how to test and ensure compliance. This, one could argue, is a world of perceptions (based on knowledge and experience, of course) and what matters is not so much whether a CI was actually executed successfully, but whether the actors are convinced that if requested, it would be executed and it could actually work.

In practice, CI has not been requested by any States Parties, who instead choose to clarify their compliance concerns through reliance on the OPCW's routine verification mechanisms, or through bilateral clarification measures[61]. It has been argued that the reluctance to invoke CI to clarify compliance concerns may undermine the role of the CI mechanism, and even make it progressively more difficult to request a CI as time goes by. But a strong case can also be made that what really matters is that State actors remain convinced that the mechanism *could* actually be invoked by one of the parties, and that in such a case it would be extremely *difficult* to stop it, and the inspection *would* actually work and provide conclusive results (or strong evidence of non-compliance through blatantly obvious procedural obstruction). The Secretariat, in that view, has an important responsibility to maintain readiness. The Executive Council has an obligation to guide in this process, and to maintain a thorough understanding of its own role in the CI process. The fact that CI has not so far been used may actually be of less importance, as long as these two requirements are met.

6 Concluding Remark

Eight years after the entry into force of the CWC, the OPCW has more or less reached a steady state in operations; an overview on staff at the TS is given by Table 5 and Figure 4. It now has agreed core objectives and top-level indicators of achievement in all operational areas, and there is an increased level of predictability of the content and extent of overall programme activity. Note, however, that the OPCW has no as yet been called to undertake a challenge inspection or investigation of alleged use, an that it has also not as yet been requested to provide assistance after an alleged use or threat of use of chemical weapons. Programme activity in these areas remains at the level of training and exercises. Also note that the current list of activities of the Executive Council contains 15 items for further work under a facilitator

[61] It is worth noting that the First CWC Review Conference in its final report (RC-1/5, paragraph 7.86) stated: "this mechanism was valuable in ensuring compliance with the provisions of the Convention, and in clarifying and resolving concerns. The First Review Conference **encouraged** the States Parties to make full use of this bilateral-consultation mechanism."

dealing with chemical weapons issues, and another 18 such issues in the cluster of industry issues.

A summary of some key technical challenges facing the OPCW is presented in Table 6.

Table 5. Staff at the Technical Secretariat (June 2005)

	Number of posts /staff	**Number of States Parties from where staff come**	**Regional distribution off staff**
Fixed-term posts (total)	502		
Posts actually filled	458	77	
Professional staff thereof	316	71	Africa - 10% Asia - 26% E. Europe - 21% Latin America - 9% WEOG - 34%
Inspectors thereof	171	58	Africa - 12% Asia - 29% E. Europe - 26% Latin America - 6 % WEOG - 27%

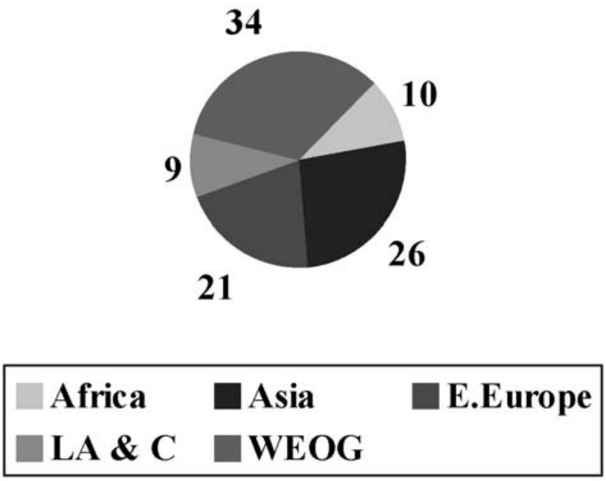


Fig. 4. Regional distribution of professional staff at the OPCW (June 2005)

Table 6. Some key technical challenges facing the OPCW

Challenge	Process for resolution / status	Other remarks
Completion of national implementation measures (including legislation and subsidiary administrative measures, identification of all declarable facilities, establishment of transfer control mechanisms).	Action Plan on Article VII (target date: November 2005) includes technical assistance with respect to legislative drafting, setting up effective implementation mechanisms and identifying declarable facilities in the chemical industry. Additional technical assistance by the OPCW and States Parties will be needed to ensure that all States Parties have fully implemented their requirements.	National implementation is a precondition for complete and accurate declarations. OPCW resources for technical assistance and implementation support are stretched. The TS offers legislative assistance, on-site technical assistance to National Authorities, regional and thematic workshops and other technical support measures
Improvement and harmonisation of tracking systems of States Parties for exports and imports of scheduled chemicals.	Considerable discrepancies remain between declared export and import data of States Parties. Decisions aimed at reducing such discrepancies have been taken by the Conference of the States Parties. Transfer regulations are an important aspect of the OPCW's implementation support programme	The discrepancies also reflect lack of administrative or legislative measures in some States Parties, see above.
Selection mechanism for OCPF inspections	Discussions in the Executive Council continue on this mechanism, including on how to deal with "proposals from States Parties" as foreseen in paragraph 11 of Part X of the Verification Annex. The interim selection mechanism used by the TS combines geographical factors with weighing factors derived from the information on the facilities as contained in declarations.	TS assessment is that some 10-15 % of all declared OCPF facilities are highly relevant to the object and purpose of the CWC given their technological features and the nature of the chemistry they undertake (based on literature research and practical experience from inspections)
Analysis of biomedical samples in investigations of alleged use	The OPCW has yet to establish a capability to analyse biomedical samples in investigations of alleged use. A proposal has been prepared to that end by the SAB, further elaboration and explanation is being prepared by the TS before a specific proposal will be ready for submission to the EC.	There will likely be a need for a Conference decision on this matter, as the system established for off-site analysis of environmental samples is not a suitable model for how to analyse biomedical samples
Further optimisation of the verification system, with particular focus on CWDF verification	This is an ongoing process which involves *inter alia* verification concept development for each CWDF, reduction in team sizes, increased use of recording devices and other instrumental monitoring.	As a complementary measure, the OPCW uses on-call inspectors (contractors on a special service agreement) in CWDF inspections to beef up its inspectorate resources; the alternative of hiring additional inspectors was so far avoided.
How to reflect new threat agents in the verification system (including whether to reflect them in the Schedules)	These issues have been raised by the OPCW's Scientific Advisory Board in the preparation of the First CWC Review Conference, and suggestions for how to approach the issue have been made. The Executive Council has been asked to address the SAB recommendations submitted to the Review Conference; this particular issue has not as yet been discussed.	There have been increasing pressures in some States Parties to revisit the provisions dealing with the prohibition of riot control agents as a method of warfare, and to allow for the use of certain "non-lethal" weapons.
How to respond to technological change in the chemical industry (new processes, multipurpose equipment, micro-reactors)	These issues have been included in inspector training to ensure that OPCW inspectors recognise new types of processes and equipment and make adequate assessments with respect to risk/capability of facilities under inspection.	Note that in addition to technological change, structural changes in the chemical industry have had an impact on the verification system – for example with respect to plant site delineation.
The precise nature of assistance to be provided by the OPCW in case of use or threat of use of CW	This issue has been under consideration in the Executive Council for several years now. The role of OPCW in the early investigation / assessment phase is agreed; what remains to be agreed among States Parties is what role the OPCW should play with respect to participation and coordination in assistance delivery operations.	A joint assistance exercise will be conducted by the OPCW together with NATO's Euro-Atlantic Disaster Response Co-ordination Centre (NATO/EADRCC) and the government of the Ukraine in October 2005, it may further clarify the issues at stake here.

Biological Weapons Convention

Kathryn Nixdorff

1 The problem with the Biological Weapons Convention

Efforts to prevent the use of biological weapons (BW) began with discussions about international controls towards the end of the nineteenth century, just at the time when microbiology was becoming established as a science. Following the large-scale use of chemical weapons in World War I, a milestone in the control of chemical and biological weapons (CBW) agents was reached with the signing of the Geneva Protocol in June 1925. This treaty, which subsequently entered into force in February 1928, prohibits the "...use in war of asphyxiating, poisonous or other gases and of bacteriological methods of warfare" [1], thus banning the *use* of both chemical and biological weapons. Although the treaty allows States to have reservations on retaliation which renders the protocol a no-first-use agreement only, it has now become accepted as customary international law [2].

For quite some time thereafter, it was extremely difficult to strengthen controls by moving towards a ban not only on use but also on possession of chemical and biological weapons. After World War II, negotiations that considered both chemical and biological weapons together were contentious and reached an impasse. There was an indication that the United States (US) were concerned that CBW disarmament might set a precedent for nuclear weapons [3]. It was subsequently reasoned that it might be easier to agree on a treaty on biological weapons if it were handled separately. This was no doubt due to the reluctance of some states to give up completely an established and proven chemical weapons capability, which could be used for deterrence or retaliation. Biological weapons on the other hand were not as extensively developed and regarded by many to be of uncertain utility.

In the end, a British proposal to handle biological weapons separately was followed [4]. Negotiations over a Biological Weapons Convention (BWC) received a decided boost when Richard Nixon announced on February 25, 1969 that the US were unilaterally renouncing its offensive BW programme and would from that time on engage solely in defensive BW research. Several explanations for this startling announcement have been offered [5,6]. One reason was that extensive US analysis of BW capabilities concluded that these weapons had limited tactical utility and were not a reliable strategic deterrent. The military nevertheless preferred to retain an offensive capability because of the realization that biological weapons could have equivalent lethality to nuclear weapons, but they yielded to the argument that it was important to discourage other countries from acquiring them. Indeed, it has been suggested that the US had actually become convinced about how devastating the use of biological weapons could be [7]. At the same time, Nixon could deflect criticism of the US over the war in Vietnam, in which it had used chemical riot control agents and herbicides.

During the negotiations over the BWC, one very contentious issue from the start was that over the verification of compliance [8]. The US view was that a verification regime would have to be totally intrusive if it were going to be effective, and it demanded tough verification measures accordingly. The Soviet Union on the other hand was stubbornly unwilling to accept on-site inspections. The reasons why the Soviet Union did not want an effective verification system became clear in later years, when it became known in 1992 that it had engaged in a massive offensive BW programme all along, even after signing the convention [9]. Although the US insisted throughout negotiations upon tough verification measures, it actually held the view that the types of measures it was calling for still could not guarantee a fool-proof system of verification. Possibly for this reason, the US finally gave up its insistence upon a tough verification regime.

The BWC, referred to as the Biological and Toxin Weapons Convention (BTWC) [10], was subsequently agreed in 1972, and it entered into force in 1975. To date, some 154 countries are states parties to this convention. Agreement was primarily achieved after the introduction of the General Purpose Criterion, which formed the basis of the prohibitions laid out in Article I of the Convention, which states, in part, that:

"Each State Party to this Convention undertakes never in any circumstances to develop, produce, stockpile or otherwise acquire or retain:

1. Microbial or other biological agents, or toxins whatever their origin or method of production, *of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes*". (emphasis added)

Clearly, the General Purpose Criterion (itialicised above) allows the peaceful uses of biological agents but prohibits any use that is not for peaceful purposes. The Convention thus applies to all possible agents and future developments and is not a prisoner of the technology of the 1970s. This is the real strength of the Convention; its weakness lies in its ineffective implementation [11].

1.1 Verification mechanisms within the BWC

As a result of non-resolvable disagreement over verification measures, and the fact that few states were willing to accept intrusive investigation procedures, only rudimentary verification provisions were written into the Convention in the form of Articles V and VI [12].

Article V mechanisms: Consultations

Article V of the BWC calls upon states parties to "undertake to consult one another and to cooperate in solving any problems which may arise in relation to the objective of, or in the application of the provisions of, the Convention." It does not, however, specify how these consultations are to proceed. It merely states an obligation to consult in a cooperative manner when there is a question of non-compliance, and that these consultations can take place either on a bilateral or multilateral basis, in response to a reasonable request. This mechanism has been invoked in two instances, but the results in both cases were inconclusive.

One of these attempts employed a bilateral procedure under Article V. The US tried on three separate occasions to obtain an official clarification from the Soviet Ministry of Foreign Affairs about the outbreak of human anthrax in the Soviet city of Sverdlovsk in April, 1979. Each time, Moscow denied any wrongdoing and claimed the outbreak was of natural origin, occurring from the ingestion of infected meat. However, many questions remained unanswered, so the question of compliance remained unresolved [13]. Years later, a forensic investigation of the Sverdlovsk incident reached the conclusion that the outbreak was the result of accidental release of anthrax spores from a military facility [14].

Article V also provides for multilateral consultations. This mechanism was invoked for the first time in answer to an allegation by Cuba that the US government had deliberately released a crop-destroying insect pest over the island from an aircraft in order to disrupt its agricultural system [15]. Again, the issue could not be resolved bilaterally, so Cuba turned to the Russian Federation (which was one of the BWC depositary states to be approached in the event of a request for a multilateral consultation procedure) in 1997 and requested a meeting of the states parties to consider the issue. The consultations were subsequently held in Geneva in August 25-27. The evidence was reviewed and thirteen States parties submitted their written comments on the case. Most of these said they were not convinced of a causal link between the flight of the US aircraft over the island and the infestation, and three States argued that the lack of detailed information and the technical complexity of the issue made it impossible to reach a clear verdict. As a result, it was concluded that it "has not proved possible to reach a definitive conclusion with regard to the concerns raised by the Government of Cuba" [16].

In both cases outlined above, the US and Cuba chose not to invoke the mechanisms available in Article VI.

Article VI mechanisms

Article VI provides that any party "which finds that any other State Party is acting in breach of obligations deriving from the provisions of the Convention may lodge a complaint with the Security Council of the United Nations (UN). Such a complaint should include all possible evidence confirming its validity...". Article VI also requires each State Party "to cooperate in carrying out any investigation which the Security Council may initiate...". Although some attempts were made by the United Kingdom (UK) during negotiations to structure Article VI so that a permanent member of the Security Council could not veto an investigation (i.e. that investigations of alleged use be carried out under the auspices of the UN Secretary General), the final language of Article VI retained the right of veto by a permanent member of the Security Council. The implicit threat of a Soviet veto was no doubt why the UK and the US refrained from requesting an investigation into the Sverdlovsk incident [17].

1.2 Efforts to strengthen the BWC

The Second Review Conference of the BWC in 1986 coincided with the initial stages of the ending of the east-west Cold War, and there was some optimism about the possibility of introducing confidence building measures (CBMs) into the Convention. Indeed, a series of CBMs (mainly annual data exchanges) were agreed in 1986 [18] and were expanded and developed in 1991 at the Third Review Conference [19]. Unfortunately, it was not possible to add these CBMs as legally binding measures to the BWC, so they remain only politically binding. It is clear from numerous analyzes [20] that these merely voluntary CBMs have not been treated seriously by most States Parties and have done little to increase transparency and trust.

The Third Review Conference of the BWC took place just after the 1991 Gulf War amid great concern about the possible use of biological weapons by Iraq. Thus, a group of governmental experts under the name of "Ad hoc Group of Governmental Experts to Identify and Examine Potential Verification Measures from a Scientific and Technical Standpoint (VEREX)" was mandated to examine potential verification measures and to consider their technical feasibility. This series of VEREX meetings took place in 1992-93 and the group submitted a positive report in 1993. A special Conference of States Parties examined the report in late 1994, and then mandated the work of an Ad Hoc Group (AHG), which met in Geneva from 1995 until 2001. Though the mandate of the AHG was much broader than just the strengthening of the Convention through improved verification measures, it crucially was:

"...to consider appropriate measures, including possible verification measures, and draft proposals to strengthen the Convention, to be included, as appropriate, in a legally binding instrument..." [21]

So this marked a clear change in approach. States Parties agreed that there should be an attempt to agree *verification measures* to be included in a *legally binding* instrument (i.e. compulsory, not voluntary) as part of the process of strengthening the BWC.

The initial stage of the Ad Hoc Group's work was devoted to building on the studies of VEREX in order to identify the elements required in a legally binding Protocol to the BWC. This initial stage of work lasted from 1995 through to mid 1997. It was only in the July-August session of 1997 that the group made a transition in its work to the consideration of a rolling text of the Protocol. The Fourth Review Conference of the Convention itself, in 1996, had called for an intensification of the work of the AHG [22] and with the transition to a rolling text, more detailed provisions could be included in a systematic manner. According to Ambassador Tibor Tóth, the chairman of the AHG, a third stage of negotiations began in January 1999 with "the move to a final framework for the Protocol and the detailed negotiation on key elements" [23]. Numerous statements made to the AHG by ministers from States Parties at the March 2000 session, which coincided with the 25th anniversary of the Convention, stressed that the text was at an advanced stage and that an agreement could be reached prior to the Fifth Review Conference of the BWC in late 2001 [24].

Ambassador Tòth subsequently produced what is called the chairman's compromise text, which is an impressively long and complex document, containing 30 Articles and numerous Annexes which extend to over 200 printed pages [25], and it was possible to see how the remaining contentious issues might be successfully resolved to produce a strong Protocol [26]. However, it was clear at the same time that numerous points of serious disagreement remained to be resolved. For example, there were concerns that some states wished to use the Protocol definitions to limit the General Purpose Criterion of the Convention. There were also strong divisions between the developing and developed world over how export controls and assistance and co-operation in biotechnology should be handled in the future. Finally, there were differing views concerning crucial elements of the central compliance (verification) measures of the Protocol [27].

The European Union has consistently held the view that the compliance measures should consist of the mandatory declaration of the most relevant facilities and activities and a system of visits to ensure the accuracy of these declarations, backed up by the possibility of challenge investigations in the event of well-founded concerns. Furthermore, a modest organisation to ensure that the undertakings in the Protocol are carried out was also required. In effect, this would provide the same overall compliance architecture as is being successfully implemented in the Chemical Weapons Convention (CWC), but with a smaller organisation and costs. Comparison of these proposals with the requirements of the Ad Hoc Group's mandate suggests that such a BWC

Protocol would be just as adequate as the CWC in achieving the desired ends [28].

A difficult problem arose from the position taken by the pharmaceutical industry in the United States. Its trade association Pharmaceutical Research and Manufacturers of America (PhRMA) says that it supports the strengthening of the Convention but it has consistently opposed a key element of the European Union's position. It has stated often that it is opposed to the kinds of visits necessary to adequately check the mandatory declarations (earlier called routine visits) [29]. It is clear that this influenced the position taken by other trade associations and, more particularly, the US government [30]. If this position of industry were to be accepted, then declarations would essentially be equivalent to the previously agreed - and demonstrably ineffective - Confidence Building Measures.

At the last meeting of the Ad Hoc Group in July-August 2001 and after over six years of negotiations, an agreement on the chairman's compromise text was supposed to be reached. However, the US government decidedly rejected not only the Protocol text but also the whole process of further negotiations over the Protocol [31]. As a result, no agreement could be reached, the meeting ended in disarray, and the future of negotiations was placed in an uncertain position. One reason Ambassador Mahley gave for rejecting the Protocol was that its provisions were too weak to test compliance. This appears to be in accord with the long-held belief of the US government that effective verification of the BWC is not possible (see discussion above). Another reason offered was that the verification measures contained in the Protocol would pose a risk to the protection of sensitive confidential national security as well as commercial proprietary information [32]. At the same time, it has been pointed out that the Protocol contains more far-reaching measures to protect confidential information and is less intrusive than the CWC [33].

Potentially embarrassing for the US government in the light of its position taken in rejecting the Protocol was the revelation of some secret activities in the area of biological defense research that were being carried out or were being planned for the future [34]. On the one hand, a factory was built that was capable of producing biological agents in large amounts (by the pound). Although only harmless simulants were actually produced, the operation was supposed to show that a clandestine BW production facility could be built from commercially available materials and equipment. In addition, the US Department of Defense has plans to repeat some experiments carried out by Russian scientists, which are potentially dangerous and could be viewed as contributing to arms proliferation. Briefly, the Russian investigators changed the anthrax bacillus by genetic engineering so that the immunity provided by the normal vaccine was no longer effective against this manipulated strain [35]. US defense researchers want to develop a vaccine that would be effective against such a manipulated strain. They have apparently tried unsuccessfully to obtain the strain from the Russian researchers who produced it, so they plan to repeat the experiments themselves. According to the provisions and prohibitions formulated in Article I of the BWC, these activities would be allowed, because they would be carried out with the intention of building a defense against potential biological weapons. Nevertheless, because of the nature of the activities, they can be interpreted as being dangerously close to the line of illegality.

The third activity that was revealed is even more controversial and more difficult to justify as biodefense. The Central Intelligence Agency (CIA) constructed a model of a small Soviet bomb filled with a biological agent (once again, in this case a harmless simulant) with the aim of testing the dispersion properties of the agent contained in the bomb. It was argued that these tests were made in order to build a proper defense against such a weapon. However, some critics of these activities point to the possibility that the general purpose criterion of Article I of the BWC does not apply here. Instead, the second paragraph of Article I explicitly forbids the development, production, storage, or acquisition of "weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict." In this respect, these experiments of the CIA were not in compliance with the rules and the spirit of the BWC [36].

The fact that these activities were kept secret together with the rejection of the Protocol on the grounds that it poses a risk to the protection of sensitive national security information raises the suspicion that the US government does not want its activities in the area of biodefense to be monitored. This position taken by the US definitely sends the wrong signal to other nations, encouraging them to act in like form.

Following the Fifth Review Conference of the BWC in November-December 2001, strengthening the Convention with measures to test compliance became even more uncertain. Once again, the US played a major role. Two hours before the Conference was to come to an close, the US delegation proposed ending the mandate of the Ad Hoc Group, in order to crush any further attempts at negotiation over the Protocol and to prevent agreement on a Final Declaration of the Conference that would not be suitable to the US government. With that, there was a general agreement not to conclude the Conference but rather to adjourn it until November 2002, in order to achieve a "cooling off" period and to avoid total failure [37].

The politics of the US government at the resumption of the Fifth Review Conference in November 2002 did not change. An agreement to resume negotiations over the Protocol or even verification measures was not possible. In the Final Document of the Fifth Review Conference, the States Parties agreed on a new procedure of work for the coming years until the Sixth Review Conference in 2006. It agreed [38]

"to hold three annual meetings of the States Parties of one week duration each year commencing in 2003 until the Sixth Review Conference, to be held not later than the end of 2006, to discuss, and promote common understanding and effective action on:

i. the adoption of necessary national measures to implement the prohibitions set forth in the Convention, including the enactment of penal legislation;
ii. national mechanisms to establish and maintain the security and oversight of pathogenic microorganisms and toxins;
iii. enhancing international capabilities for responding to, investigating and mitigating the effects of cases of alleged use of biological or toxin weapons or suspicious outbreaks of disease;
iv. strengthening and broadening national and international institutional efforts and existing mechanisms for the surveillance, detection, diagnosis and combating of infectious diseases affecting humans, animals, and plants;
v. the content, promulgation and adaption of codes of conduct for scientists."

The first two topics were discussed in 2003, while topics iii. and iv. were covered in 2004. In the eyes of many observers these discussions up to now have resulted in no substantive improvements or strengthening of the Convention. On the positive side, the States Parties have continued talks in a multilateral arena, and some discussions have been useful. For example, more time than usual has been devoted to discussions over implementation of the Convention, which is a crucial topic. Still, little has been forthcoming in the way of promoting effective action.

A great deal of hope is being placed on the last topic, that of the formulation and adoption of codes of conduct for scientists, which will be the topic of the Meeting of Experts and the Meeting of the States Parties in 2005.

2 The technology available for BW verification

After the end of World War II, the US began several programs that were designed to strengthen defenses against biological weapons. Above all, the development of the capacity to detect BW on the battlefield was a high priority. The design of automatic, remote sensing systems similar to the types used to detect chemical weapons was intended. The names of some of the programs that are in development include the Biological Integrated Detection System (BIDS), Long Range Biological Stand-off Detection System (LR-BSDS), Short-Range Biological Stand-off Detection System (SR-BSDS), Joint Biological Remote Early Warning System (JBREWS) and the Joint Biological Point Detection System (JBPDS) [39].

In addition to the remote sensing systems, other methods of detection based on sample-taking are being developed. All of these systems are not so highly developed that they can detect biological agents automatically and differentiate among them. Some systems can detect and differentiate up to 4-7 different agents, and improvements can be expected. Some of the innovations include attempts to integrate antibody or DNA detection methods into these systems, in order to achieve a better differentiation of the agents. Although definite progress has been made in this area, the methods are not yet suitable for battlefied use. The following represents an analysis of further new developments in biotechnology that may be useful for verification. Some parts have been excepted from a recent study [40].

2.1 Antibodies as diagnostic reagents

Normally, when an animal is immunized with an antigen (usually a protein or a polysaccharide molecule that is foreign to the animal), it responds by producing antibodies to that antigen. These antibodies are directed against a small region of the molecule, for example four to six amino acids in the protein or four to six sugar molecules in the polysaccharide. These regions are called antigenic determinants or epitopes, and the respective antibodies bind with these epitopes in a very specific manner. Since, for example, proteins contain a characteristic (usually large) number of amino acids, the immune system produces antibodies directed against several different regions or epitopes of that protein molecule when responding to the antigenic stimulus. Each of these specific antibodies is produced by a single antibody-producing cell, which multiplies to a clone of cells during the response, producing identical antibody molecules termed monoclonal antibodies. Normal immune responses are composed of a mixture of clones of antibody-producing cells, and are therefore polyclonal in nature. Accordingly, polyclonal antibodies are a mixture of antibodies with varied specificity, secreted into the serum of that individual.

Hybridoma Technology

Hybridoma technology involves the production of monoclonal antibodies in cells known as hybridomas. Monoclonal antibodies have a single specificity, being derived from a single clone and directed against one single antigenic determinant with which they can bind. They are thus exquisitely specific reagents that can be used to detect the presence of a particular antigen, thus identifying a particular microorganism in an unequivocal manner. Antibody-producing cells do not divide in culture and die after a few days, never living long enough in vitro to produce significant quantities of their monoclonal antibodies. Malignant cells, on the other hand, are immortal and can be kept in culture continuously, where they divide and multiply. Malignant antibody-producing cells can be isolated from individuals afflicted with the cancerous disease myeloma, but these cells secrete monoclonal antibodies of unknown specificity (the antigen epitope against which they are directed is unknown). In 1975, Georges Köhler and Cesar Milstein devised a method for generating monoclonal antibodies in vitro [41] that has revolutionized all areas of biological research. In this case, a normal, mortal, antibody-producing cell of defined specificity (obtained from an animal immunized with a particular antigen) is fused with a malignant antibody-producing cell that has, however, lost the capacity to produce antibody itself. The result is a hybrid cell (hybridoma) that is immortal and produces monoclonal antibody of a defined specificity. The hybridoma can be placed in cell culture, where it continues to divide and produce relatively large quantities of a monoclonal antibody. Usually, the antibody-producing cell is obtained from a mouse, but other small animals such as rats and hamsters have also been used routinely. Monoclonal antibodies have been invaluable for research, diagnostic, and therapeutic purposes.

Enzyme-linked Immunosorbent Assays (ELISA)

Reference has already been made to the exquisite specificity of monoclonal antibodies in binding to antigens. They therefore represent a powerful potential means of identifying specific epitopes on antigen molecules, such as unique surface structures on microorganisms or unique antigenic determinants on toxin molecules. Their usefulness in supporting verification measures in a compliance regime depends to a large extent on how they are coupled to detection systems, which in turn determines their sensitivity and facility in identifying agents. Solid-state enzyme immunoassays (EIA) based on enzyme-linked immunosorbent assays (ELISA), have in the past few years been very useful tools in diagnostic laboratories for detecting microorganisms and cell products. Naturally, it is essential to obtain antibodies with high affinity binding capabilities, and this is the first limitation often encountered; experimentally, not all hybridomas produce high affinity antibodies. Some amount of skill is needed to set up the sandwich ELISA for new antigens, especially because of the requirement for two antibodies recognizing non-overlapping epitopes on the antigen. However, once the system functions well the test is extremely simple to perform, even for less-skilled personnel, and it is relatively sensitive, having a level of detection capability in the picogram (10^{-12} grams) range. Most microorganisms and toxins can be identified by this method.

While the ELISA can be carried out and results measured in a mobile laboratory, it does take one or two hours to perform, and the sensitivity may not be adequate for some situations. Modifications of the system are therefore being explored. One reported example is a semiautomated EIA test system using paramagnetic beads to capture the antibodies [42]. The assay can be performed in suspension, which increases its sensitivity. The first and second antibodies are added to the antigen and allowed to react. The beads, which are coated with a substance that can bind antibodies non-specifically, are subsequently added to the suspension to capture the antibodies. The beads with the captured antibodies can be immobilized magnetically to facilitate washing. The second antibody of the two employed in the system is linked to a substance that produces a chemiluminescent reaction when activated, which can be measured in a special instrument. With this method, femtogram (10^{-15} grams) sensitivity levels were achieved for several antigens tested. Also, the testing time was reduced to 20-40 minutes.

The application of ELISA methods in the form of high-throughput microarrays [43,44] is a development that is especially promising for the identification of biological agents. The principle is illustrated in Figure 1. Using a bifunctional N-hydroxysuccinimid ester, specific antibodies are bound to a micro glass plate (a chip) in a designated order. Antigens that bind to these antibodies can be detected with monoclonal antibodies (specific for those antigens) that have been labeled (tagged) with biotin. Biotin binds to a streptavidin molecule that has been coupled to an enzyme (in this case alkaline phosphatase). After addition of a fluorescent substrate of the alkaline phosphatase, the enzyme cleaves a phosphate group from the substrate, allowing the substrate to become fluorescent, which can be visualized under ultraviolet light. Fluorescence would then indicate that an antibody-antigen reaction had occurred, that is, that the antigen was present in the sample under investigation.

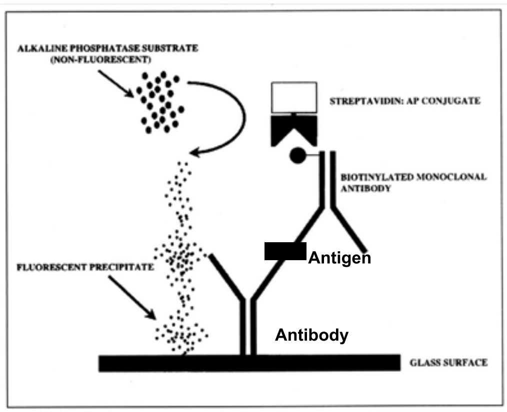


Fig. 1. Schematic representation of an indirect ELISA format for the detection of antigens in antibody arrays. Specific antibodies are bound to a glass plate in a designated order using a bifunctional N-hydroxysuccinimide ester reagent. Antigens that can bind these antibodies are detected with biotin-labeled monoclonal antibodies specific for those antigens. The antigen-antibody reaction is visualized by the addition of streptavidin coupled to an enyme that can change a substrate to a fluorescent molecule. Source: Mendoza et al. (1999) [45], modified

The schematic representation of a glass chip of this kind can be seen in Figure 2. In this case, a microarray plate consisting of 96 wells has been used. Each of the wells consists of an area containing 5 x 6 antibody arrays. With this system, 96 different samples can be tested for the presence of antigens that can bind the antibodies in the arrays.

Developments in antibody-detection systems are advancing at a rapid pace, with accuracy, ease of performance, and automation in mind. There should be no problems involved in applying these methods in a practicable manner to situations calling for verification of compliance to the BWC.

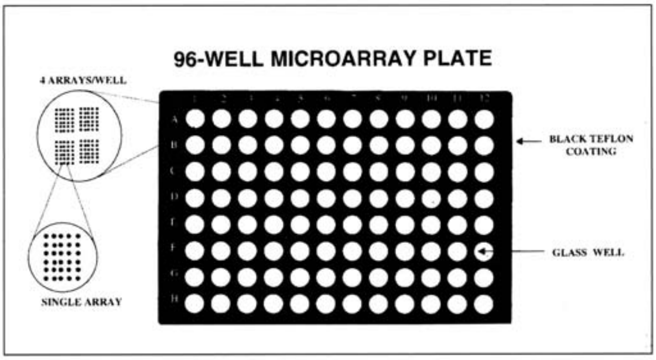


Fig. 2. Antibody arrays for use with microtiter plates with 96 wells. Each well contains an antibody array consisting of 5 x 6 different antibody specificities. In this system, 96 different samples can be tested for the presence of antigens that are able to bind the antibodies in the array. Source: Mendoza et al. (1999) [46]

2.2 Nucleic Acid Hybridization Techniques

In general, the composition of the genetic material that a microorganism carries determines its characteristics. However, the activity of a particular gene can be turned on and off according to regulation, so that some traits may not always be expressed under certain conditions, even though the genes are present and functional. While traits are of great practical importance in handling microorganisms, it is their nucleic acid base sequence that most accurately identifies the organisms and classifies them into phyla, groups, genera, species and strains. In the past decade, there has been a virtual revolution in the area of science describing the evolutionary relatedness of living beings, using nucleic acid base sequence analysis as a tool [47]. In general, highly conserved nucleic acids such as ribosomal Ribonucleic Acid (RNAs) have been most useful for such analyses, although the genes encoding particular proteins have also yielded valuable information. Nucleotide base sequence analysis can also provide information regarding traits of microorganisms, such as the possesion of genes determining virulence factors, for example, toxins. This would be of particular interest in the case of microorganisms that are potential biological weapons.

To identify microorganisms or trait-determining genes on the basis of nucleic acid base sequence, it is not necessary to actually sequence Deoxyribonucleic Acid (DNA) or RNA. Instead, the technique of nucleic acid hybridization has proved to be very practical. Hybridization reactions take advantage of the ability of heat to break the bonds holding the nucleotide bases on opposing DNA strands together. If a labeled "probe", consisting of a synthetic oligonucleotide or a DNA fragment, is added and the mixture allowed to cool, a single strand of the probe will anneal or bind (hybridize) to one of the nucleic acid strands, if it contains the proper complementary base sequence. The molecule thus produced is a hybrid of the DNA target strand and the probe. Hybridization is accordingly a measure of the nucleotide sequence match between target and probe nucleic acids. The label (reporter group) on the probe allows the visualization of successful hybridization.

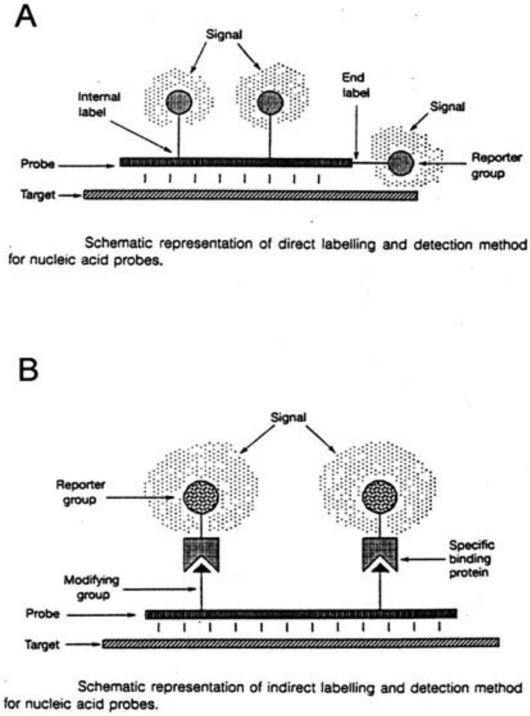


Fig. 3. Schematic representation of labeling and detection methods for nucleic acid probes. The nucleic acid probe hybridizes (binds) with homologous base sequences on the target nucleic acid. The label (reporter group) allows visualization of successful hybridization. In (A), the label is bound directly to the probe. In (B), a modifying group has been attached to the probe. The label is placed on a molecule that can bind specifically to the modifying group on the probe. Indirect methods are in some cases more sensitive than direct methods. Source: Reprinted from Kluwer Academic Publishers book *Molecular Methods for Microbial Identification* 1993, pages 64-92, Chapter 3, Identification and typing by nucleic acid hybridization techniques, K.J. Towner and A. Cockayne, figures 3.1 and 3.2, with kind permission from Kluwer Academic Publishers

A schematic representation of direct and indirect detection methods for hybridization of a probe with its target can be seen in Figure 3 [48]. In this procedure, the target DNA is heated to separate the two strands. When these are allowed to cool in the presence of a probe that has a nucleotide sequence complementary to one of the DNA strands, that probe will bind or hybridize with the target DNA. By using probes defining specific DNA sequence regions, the target DNA can be identified. Reporter groups for visualizing the hybridization reaction are attached to the probe. These are very often radioactive isotopes such as [^{32}P] that have been incorporated into the nucleic acid, or enzymes that produce either a color or a chemiluminescent reaction when the appropriate substrate is added. Hybridization tests using nucleic acid probes are being applied extensively by many laboratories today for the detection of specific microorganisms.

A requirement for identification by hybridization procedures is the possession of specific probes for the genes that are to be detected. Specific probes for many microorganisms and viral genes are available, and others can be made by applying various gene cloning procedures. Even if nucleotide base sequences are not known, gene probes and hybridization analyses can still be usefully applied by employing methods designed for scanning nucleic acids by amplification with arbitrary oligonucleotide primers [49].

A particularly promising application of hybridization procedures for the detection and identification of microorganisms is the use of high-density DNA microarrays [50]. In this case, DNA sequences (oligonucleotides) specific for the DNA of different microorganisms are used. These oligonucleotides are immobilized on micro glass plates or chips. For the immobilization of the oligonucleotides, microscope slides that have been coated with poly-L-lysine are employed. Alternatively, other substances such as different silicium compounds, can be used for coating the slides. The oligonucleotides are "printed" on the slides in a designated pattern, and more than 250,000 different oligonucleotides pro square centimeter can be placed in the array.

For the investigation of a sample, either RNA or DNA is isolated from the sample and labeled with fluorescent compounds (e.g. Cy3- and Cy5-dUTP). These labeled nucleic acids are then pipetted onto the oligonucleotide arrays, and the presence of a particular microorganism in the sample can be seen by a positive hybridization reaction with one of the oligonucleotide spots in the array (fluorescence of the particular spot).

2.3 The Polymerase Chain Reaction

One main problem in using molecular biology procedures is having enough of a specific DNA molecule or gene sequence in hand to work with. Cultivating organisms, extracting DNA, identification of specific gene sequences and amplification (reproduction) of the material by cloning can be time-consuming undertakings. The polymerase chain reaction (PCR) was developed in the mid 1980's and has since revolutionized molecular biology and genetics. It is a method for the rapid amplification of DNA in vitro (in a test tube). It can multiply DNA molecules by up to a billionfold in the test tube in the span of a few hours, yielding sufficient amounts for identification, cloning, sequencing, or for use in mutation studies.

For the replication of DNA, the enzyme DNA polymerase synthesizes a new strand of DNA, using a single strand of the old DNA as a template. In addition, the polymerase requires a short piece of double-stranded DNA as a primer, to begin the synthesis. By using primers with specified nucleotide sequences, the starting point and the stopping point of the DNA synthesis can be precisely determined. Thus, one major advantage of the PCR is that a specified region of the DNA used as a template will be amplified, dictated by the nucleotide sequence of the primers that define the boundaries of the region. The PCR method requires that at least a portion of the nucleotide sequence of the gene to be amplified be known in order to make the specific primers. The primers with the desired nucleotide sequence can be readily synthesized, and many biotechnology firms offer production of these at affordable prices for research. In the PCR reaction (Figure 4), a cycle of synthesis includes melting the DNA by raising the reaction temperature to about 94°C to form single DNA strands, cooling the reaction mixture to about 72°C to allow annealing (binding) of the single strands with the primers to create the short pieces of double-stranded DNA needed by the polymerase, and extention of the primers by the polymerase, using the DNA single strands as a template. After extention, the mixture is heated again to separate the strands and a new cycle begins. The exact temperatures used for melting and annealing, the time intervals optimal for each step, and a variety of other parameters must be standardized for each system. A final PCR product is obtained, which represents many copies of the DNA region specified by the two primers, which has a characteristic nucleotide chain length. To detect and identify this product, the different molecules in the reaction mixture are separated according to length by electrophoresis in an agarose gel, and visualized with a special dye.

The PCR method has certainly had a major impact on basic research, allowing a totally new approach to the study of molecular genetics. Reagents for investigations can be made readily and with greater precision than before, and knowledge about the regulation of gene function can be gained at a faster pace. In many cases it can replace time-consuming cloning procedures. In regard to biological weapons control, the PCR has to be viewed as a dual-purpose technique with respect to the BWC and its verification; because manipulations are generally facilitated by the PCR, it could serve an aggressor in a negative way. On the other hand, the PCR method can have a definite positive impact on verification, specifically in the area of identification of microorganisms in the environment. Recent investigations using the PCR have been centered on determining the diversity of microorganisms in a particular habitat, even when these organisms are not able to be cultured [51]. The PCR can be combined with new, rapid nucleotide sequencing methods. This represents a relatively rapid procedure for investigating possible changes in nucleotide sequence of genes, which may provide information about mutations or genetic manipulations.

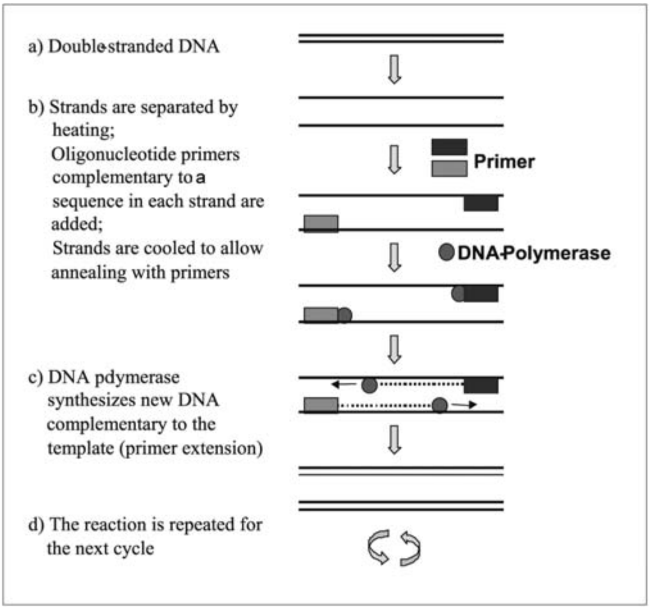


Fig. 4. The polymerase chain reaction (PCR). (a) Starting material is double-stranded DNA that acts as a template. (b) The strands are separated by heating and subsequently cooled to allow annealing with primers. The primers bind on the ends of the section to be replicated. (c) The polymerase synthesizes new DNA strands complementary to the template (primer extention). (d) The cycle is repeated. Drawing by Mark Hotz

The successful application of hybridization analyses depends upon how well all parameters and reaction conditions in the PCR and in hybridization techniques have been standardized for a particular system in question, such as a signature sequence probe or a specific toxin gene probe in reaction with their corresponding target DNAs. While it is conceivable that some analyses (such as detection of virulence genes) using systems that have been properly standardized may be carried out in appropriately equipped mobile laboratories on-site, more often than not investigations will require extensive analyses that can best be performed in better equipped off-site laboratories.

The combined equipment needed for the different phases of analysis, such as DNA extraction, amplification with PCR, electrophoresis, hybridization and hybridization detection represents a rather bulky array for a mobile on-site laboratory. However, more compact versions of instruments in use today can surely be expected in the future, because clinical laboratories and the pharmaceutical industry, which represent the primary markets for desk-top, automated equipment for nucleic acid analyses, are very interested in such developments. The identification of biological agents by molecular biological procedures such as PCR are being used more and more frequently in clinical laboratories [52].

2.4 Genetic profiles of microorganisms using molecular typing with nucleotide sequence information

Nucleotide sequencing and genome analyses are concerned with the determination of the necleotide base sequence of the genomic (chromosomal) DNA of organisms. The complete sequencing of the genomes of some 100 prokaryotic microorganisms and many viruses has been achieved, and many others are currently being sequenced [53]. Recently, considerable progress has been made in the area of high-throughput automated DNA sequencing in connection with many genome sequencing projects that will ensure an even more rapid pace of data gathering in the future. These methods are being intensively applied to the sequencing of the genomes of pathogenic microorganisms, with the aim of discovering and identifying new virulence determinants. It is hoped that targets for the development of diagnostic and chemotherapeutic reagents as well as vaccines can be defined in the course of these investigations [54]. Naturally genomic sequencing has dual use relevance for the BWC [55].

At the same time, these activities can play a very positive role for verification of compliance to the BWC. The need for effective methods of identifying microorganisms with increased virulence or transmissibility as well as antibiotic-resistant strains has prompted a novel approach to molecular typing primarily designed for global epidemiology. This approach is called multilocus sequence typing (MLST) [56], which involves using the polymerase chain reaction (PCR) to amplify DNA fragments of a limited set (for example seven) of designated genes of a particular bacterium and then sequencing the PCR products either manually or by using an automated sequencer. For each gene, deviating sequences in different isolates of the bacterium are designated as alleles of that gene and the alleles of the seven loci provide an allelic profile, which unambiguously defines the sequence type of each isolate. The accumulation of nucleotide changes (mutations) in what is known as conserved genes is relatively slow, and the allelic profile based on such slowly evolving genes is stable enough over time for the method to be well suited for global epidemiology. Genes that change more rapidly may be useful for short-termed, local epidemiology to determine, for example, if different isolates from a localized outbreak of disease are the same or different strains.

The technique has been successful in identifying antibiotic resistant clones of *Streptococcus pneumoniae* isolated from an outbreak in Taiwan, and in tracing the origin of these clones [57]. In these studies, some isolates were identified as members of a multiply-antibiotic-resistant clone originating from Spain, while others had a far east origin. Further successful applications have been made, such as in the case of *Neisseria meningitidis* strains [58], as well as with many other microorganisms [59].

Especially pertinent to BWC compliance, a similar approach was recently used to study genetic relationships within *Bacillus anthracis* [60]. Even though this bacterium is one of the most genetically homogeneous pathogens known, the authors of the study were able to determine genomic regions containing enough variability to allow discrimination among different *Bacillus anthracis* isolates. The sequences used for profiling were those found in DNA areas known as variable number tandem repeat (VNTR) sequences, whose function is essentially unknown.

These studies have been extended in a comparison of whole-genome sequences that identify further markers that can be used to distinguish among *Bacillus anthracis* strains [61]. Particularly useful markers in addition to VNTRs were single nucleotide polymorphisms (SNPs) and inserted or deleted sequences (indels). For example, the investigators observed two SNPs and two indels that differed between *Bacillus anthracis* isolated from the letter attack in Florida and the Ames strain from Porton Down, which lacks both virulence plasmids. In another example, the authors found that two other *Bacillus anthracis* strains, each of which carried one of the two virulence plasmids lacking in the Porton Down stain, differed from the Florida strain by 38 SNPs, three indels and eight VNTRs. The researchers hypothesize that polymorphisms can appear after relatively few generations of the bacteria. Their work shows in any case that genome-based analyses can indeed be useful in determining the origin of *B. anthracis* strains.

The applicability to particular microorganisms of relevance that have not yet been examined in this context will of course have to be rigorously tested. In this regard, intensive research involving the participation of many scientists working with pathogenic organisms all over the world is called for, to contribute by determining allelic profiles of isolates in their locations and submitting the sequences to open genome databases. The method has proved its usefulness in several cases and has tremendous potential with regard to cooperative measures in the area of disease surveillance and tracking of pathogenic organisms. Genome-based analysis of microbial pathogens will certainly provide a powerful new tool for investigation of infectious disease outbreaks [62]. As such it could contribute decidedly to promoting transparency and building confidence in a BWC compliance regime, which is a strong criterion for preventive arms control.

2.5 Beyond genomics

We are right in the middle of what has been termed the pharmacological revolution, in which combinatorial chemistry, genomics and proteomics all play essential roles in drug-discovery [63]. Combinatorial chemistry refers to the methods used to create complex sets or repertoires of compounds, whose reactivities with other molecules can be tested. One example of this is phage display, in which a set of recombinant bacteriophage clones are made to display a peptide component, whose structure may be varied from clone to clone [64]. These displayed peptides can then be tested with various other molecules for their reactivities in systems similar to ELISA.

Proteomics is the large-scale study of proteins, normally by using biochemical methods for protein preparation and identification [65]. For example, one and two-dimensional gel electrophoresis systems can be used to separate complex mixtures of proteins, which can be identified with the help of antibodies. Other techniques such as affinity chromatoraphy or high pressure liquid chromatography can also be used to separate and isolate proteins. The most significant breakthrough in proteomics has been the matrix-assisted laser description ionization time of flight mass spectrometry (MALDI-TOF-MS), in which pulsed energy from a laser is transferred to the molecules to be analyzed with the help of a matrix [66]. The molecules are ionized and released into the gas phase of the mass spectrometer, which results in a time-of-flight distribution of molecules in a mixture. These can then be identified by their characteristic peaks in the mass spectrum. MALDI-TOF has also been used for rapid identification of microorganisms [67]. Furthermore, peptide sequencing can be achieved by a two-step procedure employing mass spectrometry [68].

One of the stated goals of genomics and proteomics lies in drug discovery, which is developing at a rapid pace. Within the drug discovery campaign, it can be expected that many of the substances produced will fall into the category of bioregulators (compounds that are chemical in nature and regulate the operation of physiological systems). Bioregulators will be gaining more and more significance for biochemical arms control as time progresses [69,70].

There is clear evidence of a shift in focus from the agents themselves to the targets of interacting physiological systems which they can affect [71]. In the light of this shift, dealing with advances in the life sciences becomes enormously more complex. The BWC, which has no treaty organization and does not contain adequate measures for verifying compliance, is running into the danger of being completely overwhelmed by scientific and technological developments in the future in the sense that the states parties to the convention will not be able to cope with the complexity of science and technology advances.

Renewed interest in so-called "non-lethal" chemical weapons (which include bioregulators) threatens to undermine the current CBW control regimes and calls into question their future robustness [72]. For one, the US military shows a strong interest in developing this kind of capability [73,74,75]. The BWC prohibits any agent categorically "for hostile purposes or in armed conflict". The CWC prohibits all chemical agents for non-peaceful purposes, but the convention contains an undefined exception, permitting the use of such agents for purposes of "law enforcement", in which case this is difficult to define. From a scientific and technical point of view the major problem with "non-lethal" weapons lies in the fact that they are not non-lethal, as the

Moscow theater hostage crisis in 2002 has clearly demonstrated [76]. The fentanyl derivative used by the Russian security forces represents just the tip of the iceberg. Although it can be claimed that the Russian fentanyl use falls under the CWC law enforcement provision, a thorough discussion of the matter in the interest of clarification at the First Review Conference was prevented by a few powerful states [77]. This does not speak well for the capability of the CWC to deal with changes that might affect the sustainability of the prohibitory norm against chemical weapons [78].

3 The problem of dual use biotechnology

The problem of biochemical incapacitants reaches new proportions when viewed from the arena of interacting biological systems. It is being recognized more and more that the immune system interacts intricately and extensively with the nervous and the endocrine systems. There is a fine network of checks and balances exerted on the operation of all three systems by the elements within these systems. The perturbation of one system will invariably affect the operation of the others. All three systems are interconnected through the hypothalamus-pituitary-adrenal (HPA) axis via cytokines, hormones, neurotransmitters, peptides and their receptors, and also through hardwiring of neural and lymphoid organs [79].

To illustrate how the one system can affect the other, with possible detrimental effects for both, the interaction of soluble bioregulators of the immune system (cytokines) and the neuroendocrine system (hormones and neurotransmitters) within the HPA axis will be taken as an example. The proinflammatory cytokines inter leukin (IL)-1β, tumor necrosis factor (TNF)α and IL-6 are produced by cells of the immune system after contact with microorganisms or their products [80]. The cytokines gain entry into the circulation from sites of the immune response in tissues and organs. Normally, these cytokines are of sufficiently large size that would prevent them from passing the blood-brain barrier. However, a window in the barrier can be found in a particular area of the hypothalamus (a part of the brain), which allows the entry of the cytokines into this region [81,82]. They subsequently bind to receptors on cells in the hypothalamus and trigger reactions collectively known as sickness behaviour, which is characterized by fever, drowsiness, lethargy and loss of appetite [83]. With this reaction, the brain signals the body that a fight against infection is underway.

Another effect the proinflammatory cytokines have on the hypothalamus is to induce the production of corticotropin-releasing factor (CRF), which in turn causes the pituitary to produce adenocorticotropic hormone (ACTH) [84]. This hormone enters the circulation and acts on the adrenal cortex to induce the production of glucocorticoids, which have a profound effect in supressing immune responses, as outlined in the previous section. However, CRF also has an effect on the central nervous system. In this regard, overproduction of the hormone has been implicated with neurotoxicity and neurodegeneration in animal studies. For example, in an animal model of acute ischemia (stroke), it was shown that CRF antagonists could protect against the loss of neurons which occurs as a result of a stroke. In addition, CRF has been associated with major depression, anorexia nervosa and Alzheimer's disease [85]. Normally, these interactions within the HPA axis work as a check and balance system to keep reactions from getting out of hand. However, it is easy to see that a selective overproduction of proinflammatory cytokines could tip the balance to potentiate effects on both the immune and the neuroendocrine systems, leading to debilitating sickness behaviour, significant immune suppression and even damage to neurons.

This scenario is not at all far-fetched. The ability to attack biological systems through the use of biochemical incapacitants is intimately related to developments in targeting technology. This technology is being intensively developed for use in cancer and gene and drug therapy, and is still mainly in the experimental stage. Nevertheless, it is evident that cytokines as bioregulators can be delivered quite effectively by viruses engineered to carry cytokine genes, as was illustrated in the mousepox experiment with the cytokine interleukin 4 [86]. In addition, the US Army has apparently investigated the absorption of endogenous bioregulators through the aerosol route, to determine how effectively such substances can be taken up by inhalation. It has reported, for example, that the hormone insulin and the proinflammatory cytokine interleukin 1 were effective in aerosol form in basic pulmonary absorption studies [87]. Indeed, it has been stated that the greatest potential for delivering drugs is through the pulmonary route by inhalation of particles of a particular size [88]. There is a great deal of interest in developing drug delivery systems consisting of defined nanoparticles mixed with substances to enhance absorption.

A final point to be made here is that the interaction of these systems and the interdependence of the resulting reactions on this interaction raises the dual use dilemma to a new order of complexity. With the rapid advances in the accumulation of knowledge concerning the mechanisms of interaction of these systems that will surely occur, trying to deal with this information to exploit the benefits while minimizing the risks is going to become more and more of a Herculean task in the future.

4 Looking ahead

Rapid advances in life sciences research are essential for the fight against infectious diseases. However the same techniques used to improve health and protect against infections can be misused to produce new and more effective biological weapons. In this context, the dual use dilemma is absolute. Trying to exploit the benefits while minimizing the risks that these developments pose will be an enormous task in the future.

Biosecurity measures designed to counteract misuse of biotechnology for biological warfare and bioterrorist activities will invariably affect biomedical research developments and must therefore be carefully drafted so as not to impede this research. No blanket prohibitions should be placed on research activities of any kind that are carried out with peaceful intent. This is in agreement with the view expressed in the recent report of the National Research Council of the National Academies in the US that even the results of research that present the most danger of being misused may still provide beneficial aspects essential for combatting infectious diseases [89].

Preventive arms control criteria emphasize the need for monitoring research, to provide possible early warning of potentially dangerous developments. An oversight program for reviewing research proposals involving work relevant to the BWC has been drafted in the Project on Controlling Dangerous Pathogens [90]. In this proposal, the review process would be a mandatory, tiered procedure (at the local, national or international level according to the potential danger) and it would be applied to government and industry as well as academia. If such a process could be implemented, this would definitely be a step forward. Transparency in science is just as essential. Results of legitimate research which can benefit progress in biomedicine should not be censored in any way [91].

The new BWC process of yearly meetings of the States Parties preceded by an Experts Meeting to discuss ways of further controlling biological weapons could be beneficial. The issues that are being handled are, however, limited in scope and in international application. Nevertheless, the mechanisms being discussed would without a doubt be useful in strengthening the BWC, but as the meetings progress it is evident that there is a need for the States Parties to demonstrate that they are serious about living up to their obligations. In 2005 the subject of these meetings is the formulation and promulgation of a Code of Conduct for the Life Sciences. A Code of Conduct could represent an effective element in preventing the hostile use of biological agents, if it is designed to promote awareness of the complex dual use dilemma and at the same time pro-actively obligate the research scientist to engage in reflective activities such as risk assessments and consideration of alternative approaches during the research process [92]. The scientist should therefore obligate himself to become informed and be aware of possible dual use aspects of biomedical and bioscience research, to carry out risk assessments at each stage of the research process as a reflective action and to consider alternative approaches as the risks demand.

Naturally, this code element can only be applied if the scientist engaging in biomedical and bioscience research is aware of the dual use problem and is well informed about ethical decision-making processes. Unfortunately, these subjects are not a part of the curriculum at many universities. Governments should therefore encourage universities to place such instruction into their biomedical and bioscience curricula as required courses. Special incentives should be offered to those universities that do so.

The registration or licensing of all facilities and their scientists working with pathogenic microorganisms (or genetic material and toxic products from these microorganisms) of biological weapons relevance would be another potentially beneficial biosecurity measure. Many States already issue licenses or permits to scientists allowing research in the areas of genetic engineering and work with pathogenic microorganisms. In this regard, the awarding of a license or permit should be contingent upon receiving instruction about the content of the Biological Weapons Convention and the obligations of the scientist under this treaty, as well as instruction about ethical decision-making and risk assessment [93] processes. It would take little effort to include such instruction in these licensing programs. Receiving a permit should further be contingent upon signing a code of conduct.

References

1. United Nations (1925): *Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare.* Reprinted in: Geissler, E. (ed.) (1986) Biological and Toxin Weapons Today, Appendix 1, SIPRI, Oxford University Press, Oxford, p. 131.
2. Dando, M.R. (2002): *Preventing Biological Warfare. The Failure of American Leadership.* Palgrave, Basingstoke and New York, pp. 3-4.
3. Chevrier, M.I. Chapter 15, The politics of biological disarmament. In: Wheelis, M., L. Rozsa and M. Dando (ed.), *Deadly Cultures: Bioweapons from 1945 to the Present.* Harvard University Press, Cambridge, forthcoming.
4. *Ibid.*
5. Tucker, J.B. (2002): A farewell to germs, *International Security*, Vol. Summer 2002, pp. 126-128
6. Nixdorff, K., M. Hotz, D. Schilling and M. Dando (2003): *Biotechnology and the Biological Weapons Convention.* Agenda, Münster, pp. 34-36. This chapter entitled The problem with the Biological and Toxin Weapons Convention was authored by M. Dando.
7. Dando, M.R. (2002): p. 6, *op. cit.*
8. Dando, M.R. (2002): pp. 5-15, *op. cit.*
9. Dahlberg, J.T. (1992): Russia admits violating biological weapons pact, *The Los Angeles Times*, Washington Edition, 15 September.
10. United Nations (1972): *Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction. United Nations General Assembly Resolution 2826 (XXVI)*, United Nations, New York. (full text available at http://www.brad.ac.uk/acad/sbtwc).
11. Nixdorff et al. (2003), *op. cit.*
12. For a more thorough discussion of these mechanisms, see Sims, N.A. (2001): *The Evolution of Biological Disarmament.* SIPRI Chemical and Biological Warfare Studies No. 19, Oxford University Press, Oxford. Also, see Investigations of alledged non-compliance with the BTWC, BioWeapons Report 2004, pp. 35-50. Available at www.bwpp.org .

13. Sims, N.A. (1988): *The Diplomacy of Biological Disarmament: Vicissitudes of a Treaty in Force*, 1975-1985, Macmillan, London.
14. Meselson, M., J. Guillemin, M. Hugh-Jones, A. Langmuir, I. Popova, A. Shelokov and O. Yampolskaya (1994): The Sverdlovsk anthrax outbreak of 1979, *Science*, Vol. 266, pp. 1202-1208.
15. Zilinskas, R.A. (1999): Cuban allegations of biological warfare by the United States: Assessing the evidence., *Critical Reviews in Microbiology*, Vol. 25, pp. 206-217.
16. Quoted from a letter addressed to all states parties from Ambassador S.I. Soutar, UK, chairman of the multilateral meeting, reported in *BioWeapons Report 2004*, p. 38, available at www.bwpp.org .
17. *BioWeapons Report 2004*, p. 39, available at www.bwpp.org
18. United Nations (1986): *Second Review Conference of the Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction. Final Documents, Part II, Final Declaration*. BWC/CONF. II/13/II. (full text available at http://www.brad.ac.uk/acad/sbtwc).
19. United Nations (1991): *Third Review Conference of the Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction. Final Document*. BWC/CONF.III/23. (full text available at http://www.brad.ac.uk/acad/sbtwc).
20. Hunger, I. (1996): Confidence-building measures. In: Pearson, G.S., and M.R. Dando (ed.)(1996): *Strengthening the Biological Weapons Convention: Key Points for the Fourth Review Conference*. Department of Peace Studies, University of Bradford. Available at http://www.brad.ac.uk/acad/sbtwc.
21. United Nations (1994): *Final Report. Special Conference of the States Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction.* BWC/SPCONF/1, Geneva.
22. United Nations (1996): *Fourth Review Conference of the States Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction. Final Document*. BWC/CONF.IV/9. (full text available at http://www.brad.ac.uk/acad/sbtwc).
23. Tóth, T. (1999): Time to wrap up, *The CBW Conventions Bulletin*, Vol. 46, pp. 1-3, December.
24. Rissanen, J. (2000a): BWC update: Protocol negotiations continue through 25th anniversary of Convention's entry into force, *Disarmament Diplomacy*, April, pp. 32-35.
25. United Nations (2001): *Protocol to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction*. BWC/AD HOC GROUP/56-2, Annex B, pp. 347-565.(full text available at http://www.brad.ac.uk/acad/sbtwc).
26. Pearson, G. S., N.A. Sims, M.R. Dando, and I.R. Kenyon (2000): *The BTWC Protocol Evaluation Paper No 19: Proposed Complete Text for an Integrated Regime*. Project on Strengthening the Biological Weapons Convention, University of Bradford. Available at http://www.brad.ac.uk/acad/sbtwc.
27. *Ibid.*

28. Dando, M. R., and G.S. Pearson (2000): The emerging BTWC Protocol: an essential prerequisite to prevent proliferation of biological weapons. Memorandum and oral evidence, *Foreign Affairs Committee Eighth Report: Weapons of Mass Destruction.* House of Commons, London, 25 July, pp. 55-59.
29. PhRMA (1996): *Statement of Principle on the Biological Weapons Convention.* Pharmaceutical Research and Manufacturers of America, Washington D.C.: May, 1996.
30. Rissanen, J. (2000b): BWC update: The BWC Protocol negotiations 18th Session: Removing brackets, *Disarmament Diplomacy*, January/ February 2000, pp. 21-25.
31. Mahley, D.A. (2001): *Statement to the Ad Hoc Group of the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction.* Geneva, July 25, 2001.
32. *Ibid*
33. Rosenberg, B. (2001): Bush treaty moves puts us in danger, *Baltimore Sun*, September 5.
34. Miller, J., S. Engelberg, and W.J. Broad (2001): U.S. germ warfare research pushes treaty limits. *The New York Times*, September 4.
35. Pomerantsev, A.P., N.A. Staritsin, Yu.V. Mockov and L.I. Marinin (1997): Expression of cereolysine AB genes in Bacillus anthracis vaccine strain ensures protection against experimental infection, *Vaccine*, Vol. 15, pp. 1846-1850.
36. Miller, J. (2001): When is a bomb not a bomb? Germ experts confront U.S., *The New York Times*, September 5.
37. Butler, D. (2001): Bioweapons treaty in disarray as US blocks plans for verification, *Nature*, Vol. 414, p. 675.
38. United Nations (2002): *Fifth Review Conference of the States Parties to the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction. Final Document.* BWC/CONF.V/17, Geneva 2002. Available at www.opbw.org
39. Valdes, J.J. (2000): Biological agent detection technology. In: Dando, M.R., G.S. Pearson, and T. Toth (ed.) (2000): *Verification of the Biological and Toxin Weapons Convention*, Kluwer Academic Publishers, Dordrecht, pp. 181-197.
40. Nixdorff, K., M. Hotz, D. Schilling, and M. Dando (2003): *op. cit*
41. Köhler, G., and C. Milstein (1975): Continuous cultures of fused cells secreting antibody of predefined specificity, *Nature*, Vol. 256, pp. 495-497.
42. Gatto-Menking, D.L., H. Yu, J.G. Bruno, M.T. Goode, M. Miller, and A.W. Zulich (1995): Preliminary testing and assay development for biotoxoids, viruses and bacterial spores using the ORIGEN immunomagnetic electrochemiluminescence sensor. In: *Proceedings 5th International Symposium Protection Against Chemical and Biological Warfare Agents: Supplement*, Stockholm, Sweden, 11-16 June 1995, National Defence Research Establishment, Umea: 65-72.
43. Borrebaeck, C.A.K. (2000): Antibodies in diagnostics - from immunoassays to protein chips, *Immunology Today*, Vol. 21, pp. 379-382.
44. Mendoza, L.G., P. McQuary, A. Mongan, R. Gangadharan, S. Brignac, and M. Eggers (1999): High-throughput microarray-based enzyme-linked immunosorbent assay (ELISA), *BioTechniques*, Vol. 27, pp. 778-788.
45. *Ibid*
46. *Ibid*

47. Woese, C.R., O. Kandler, and M.L. Wheelis (1990): Towards a natural system of organisms: proposal for the domains archaea, bacteria and eukarya, *Proceedings of the National Academy of Sciences USA*, Vol. 87, pp. 4576-4579.
48. Towner, K.J., and A. Cockayne (1993): *Molecular Methods for Microbial Identification and Typing*, Chapman & Hall, London.
49. Caetano-Anolles, G. (1996): Scanning of nucleic acids by in vitro amplification: new developments and applications, *Nature Biotechnology*, Vol. 14, pp. 1668-1674.
50. Rappuoli, R. (2000): Pushing the limits of cellular microbiology: microarrays to study bacteria-host cell intimate contacts, *Proceedings of the National Academy of Sciences*, USA, Vol. 97, pp. 13467-13469.
51. Hugenholtz, P., and N.R. Pace (1996): Identifying microbial diversity in the natural environment: a molecular phylogenetic approach, *Trends in Biotechnology*, Vol. 14, pp. 190-197.
52. Check, W. (2001): Nucleic acid-based tests move slowly into clinical labs, *ASM News*, Vol. 67, pp. 560-565.
53. *Genomes, for a current overview of genome sequences see* http://www.ncbi.nlm.nih.gov:80/PMGifs/Genomes/micr.html
54. Jenks, P.J. (1998): Sequencing microbial genomes–what will it do for microbiology? *Journal of Medical Microbiology*, Vol. 47, pp. 375-382.
55. Fraser, C.M., and M.R. Dando (2001): Genomics and future biological weapons: the need for preventive action by the biomedical community, *Nature Genetics*, Vol. 29, pp. 253-256.
56. Urwin, R., and M.C.J. Maiden (2003): Multi-locus sequence typing: a tool for global epidemiology, *Trends in Microbiology*, Vol. 11, pp. 479-487.
57. Enright, M.C., and B.G. Spratt (1999): Multilocus sequence typing, *Trends in Microbiology*, Vol. 7, pp. 482-487.
58. Maiden, M.C.J., J.A. Bygraves, E. Feil, G. Morelli, J.E. Russell, R. Urwin, Q. Zhang, J. Zhou, K. Zurth, D.A. Caugant, I.M. Feavers, M. Achtman, and B.G. Spratt (1998): Multilocus sequence typing: a portable approach to the identification of clones within populations of pathogenic microorganisms, *Proceedings of the National Academy of Sciences USA*, Vol. 95, pp. 3140-3145.
59. Urwin, R. and M.C.J. Maiden (2003): *op. cit.*
60. Keim, P., L.B. Price, A.M. Klevytska, A.L. Smith, J.M. Schupp, R. Okinaka, P.J. Jackson, and M.E. Hugh-Jones (2000): Multiple-locus variable-number tandem repeat analysis reveals genetic relationships within *Bacillus anthracis*, *Journal of Bacteriology*, Vol. 182, pp. 928-2936.
61. Read, T.D., S.L. Salzberg, M. Pop, M. Shumway, L. Umayam, L. Jiang, E. Holtzapple, J.D. Busch, K.L. Smith, J.M. Schupp, D. Solomon, P. Keim, and C.M. Fraser (2002): Comparative genome sequencing for discovery of novel polymorphisms in *Bacillus anthracis*, *Science*, Vol. 296, pp. 2028-2033.
62. *Ibid*
63. Wheelis, M. (2002): Biotechnology and biochemical weapons. *The Nonproliferation Review*, Vol. 9,9 pp.
64. Rader, C. and C.F. Barbas III. (1997): Phage display of combinatorial antibody libraries, *Current Opinion in Biotechnology*, Vol. 8, pp. 503-508.
65. Pandey, A. and M. Mann (2000): Proteomics to study genes and genomes, *Nature*, Vol. 405, pp. 837-846.
66. *Ibid.*

67. Claydon, M.A., S.N. Davey, V. Edwards-Jones, and D.B. Gordon (1996): The rapid identification of intact microorganisms using mass spectrometry, *Nature Biotechnology*, Vol. 14, pp. 1584-1586.
68. Pandey, A. and M. Mann (2000), *op. cit.*
69. Dando, M. (2001): Genomics, bioregulators, cell receptors and potential biological weapons, *Defense Analysis*, Vol. 17, pp. 239-258.
70. Wheelis, M. (2002), *op. cit.*
71. Nixdorff, K. (2005): Assault on the immune system, *Disarmament Forum*, No. 1 (2005), pp. 25-35.
72. Kelle, A. (2005): Science, Technology and the CBW control regimes, *Disarmament Forum*, No. 1 (2005), pp. 7-16.
73. Dando, M. (2002): Scientific and technological change and the future of the CWC: the problem of non-lethal weapons, *Disarmament Forum*, No. 4 (2002), pp. 33-45.
74. Lewer, N. and N. Davison. (2005): Non-lethal technologies - an overview, *Disarmament Forum*, no. 1 (2005), pp. 37-51.
75. See also the website of the Sunshine Project for documentation of the US non-lethal weapons programmes, at www.sunshine-project.org
76. Wax, P.E., C.E. Becker and S.C. Curry (2003): Unexpected gas casualties in Moscow: A medical toxicology perspective, *Annals of Emergency Medicine*, Vol. 41, pp. 700-705.
77. Kelle, A. (2003): The CWC after its first review conference: is the glass half full or half empty? *Disarmament Diplomacy*, No. 71 (June/July), pp. 31-40.
78. Kelle, A. (2005), *op. cit.*
79. Straub, R.H., J. Westermann, J. Schlmerich and W. Falk (1998): Dialogue between the CNS and the immune system in lymphoid organs, *Immunology Today*, Vol.19, pp. 409-413.
80. Steinman, L. (2004): Elaborate interactions between the immune and nervous systems, *Nature Immunology*, Vol. 5, pp. 575-581.
81. *Ibid.*
82. Licinio, J. and P. Frost, (2000): The neuroimmune-endocrine axis: pathophysiological implications for the central nervous system cytokines and hypothalamus-pituitary-adrenal hormone dynamics, *Brazilian Journal of Medical and Biological Research*, Vol. 33, pp. 1141-1148.
83. Inui, A. (2001): Cytokines and sickness behaviour: implications from knockout animal models, *Trends in Immunology*, Vol. 22, pp. 469-473.
84. Straub et al. (1998): *op. cit.*
85. Licinio, J. and P. Frost, (2000): *op. cit.*
86. Jackson, R. J., A.J. Ramsay, C. Christensen, S. Beaton, D.F.R. Hall and I.A. Ramshaw (2001): Expression of mouse interleukin-4 by a recombinant ectromelia virus suppresses cytolytic lymphocyte responses and overcomes genetic resistance to mousepox, *Journal of Virology*, Vol. 75, pp. 1205-1210.
87. USAMRIID (1987): Basic studies seeking generic medical countermeasures against agents of biological origin. In: *Annual Report for Fiscal Year 1987*, p. 19.
88. Shohet, S. and G. Wood (2002): Delivering biotherapeutics - technical opportunities and strategic trends, *Journal of Commercial Biotechnology*, Vol. 9, pp. 59-66.

89. National Research Council of the National Academies (2003): *Biotechnology Research in an Age of Terrorism: Confronting the DualUse Dilemma*. The National Academies Press, Washington, D.C. Available at www.nap.edu.
90. Steinbruner, J.D. and E.D. Harris (2003): Controlling dangerous pathogens, *Issues in Science and Technology*, 19, 47-54. www.nap.edu/issues/19.3/steinbruner.htm
91. Atlas, R.M. (2002): Bioterrorism: the ASM response, *ASM News*, Vol. 68, pp. 117-121.
92. Rappert, B. (2004): *Towards a Life Science Code: Countering the Threats from Biological Weapons*, Bradford Briefing Paper no. 13, September 2004. Available at: http://www.brad.ac.uk/acad/sbtwc
93. Bender, W., K. Platzer and K. Sinemus (1995): On the assessment of genetic technology: reaching ethical judgments in the light of modern technology, *Science and Engineering Ethics*, Vol. 1, pp. 21-32.

Comprehensive Nuclear-Test-Ban Treaty Verification

Martin B. Kalinowski *

1 Introduction

The first national approaches for detecting foreign nuclear explosions date back to the very early times of nuclear weapons testing. The first test ban treaties (Partial Test Ban Treaty (PTBT), 1963; Threshold Test Ban Treaty (TTBT), 1972) had no provisions for verification and relied on national technical means (NTM). The Group of Scientific Experts formed at the Geneva based United Nations (UN) Conference on Disarmament carried out a number of technical tests to investigate and demonstrate a global seismic monitoring operation. All these experiences lead to the conclusion that a test ban treaty is verifiable.

The Comprehensive-Nuclear-Test-Ban Treaty (CTBT) has been negotiated at the Conference on Disarmament in Geneva between 1993 and 1996. It was opened for signature in September 1996. Though the CTBT has been signed by 176 states and ratified by 126 (as of December 2006), it is not yet in force due to its specific conditions for entry-into-force. However, the Preparatory Commission for the CTBT Organisation has a mandate to establish the International Monitoring System (IMS), the International Data Centre (IDC) and prepare the procedures for On-Site Inspections (OSI). This is carried out by the Provisional Technical Secretariat (PTS) based in Vienna, Austria. The goal is to have the completed verification system in place and ready to operate as soon as the CTBT enters into force.

The CTBT has several provisions for verification of compliance. The International Monitoring System consists of four networks with different sensor technologies: seismic, hydroacoustic, infrasound and radionuclides. In addition, the CTBT allows for confidence building measures, consultation and clarification as well as On-Site Inspections.

* The views expressed herein are those of the author and do not necessarily reflect the views of the CTBTO Preparatory Commission.

2 Historic test ban treaty verification

2.1 National approaches

Up to 1998, a total of 2057 known nuclear explosions occurred [1,2]. Their distribution by year and country can be seen in Fig. 1. Most of them were detected either by seismic or radionuclide signals or by both of them. Satellites were able to detect atmospheric nuclear explosions by their electromagnetic radiation and satellite imagery has been applied not only to detect testing preparation activities at test sites but also to locate underground tests by change detection [3]. Hydroacoustic sensors were not only able to detect the very few underwater tests that were ever conducted, but could also pick up signals from explosions near or under the oceans. Infrasound sensors were used to detect atmospheric tests until they were terminated in 1980.

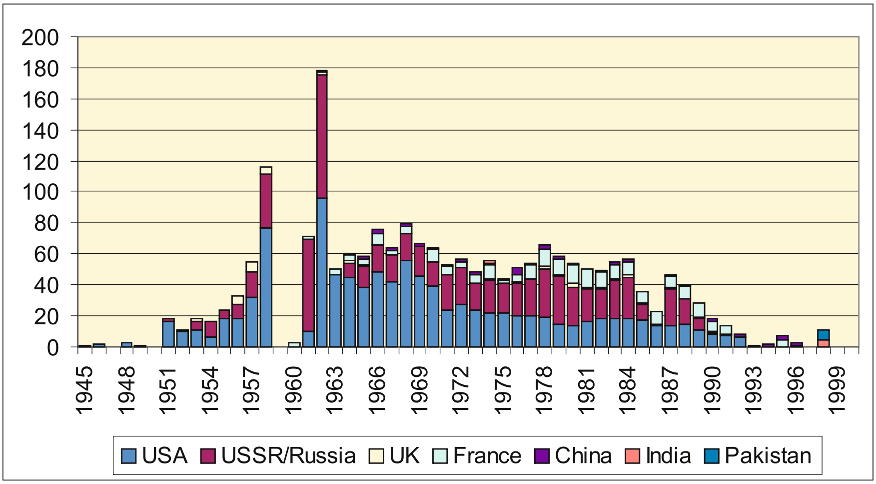


Fig. 1. History of known nuclear weapons tests. Data source: NRDC (2002)

Before the Partial Test Ban Treaty was agreed, most nuclear tests were conducted in the atmosphere and caused world-wide radioactive fall-out. This has been detected and analyzed by many countries. Initially, total beta counting of rain samples and auto-radiographs of single hot fall-out particle were widely applied. Increasingly, continuous monitoring with high volume air filters was conducted. In 1949, the first nuclear explosion undertaken by the Soviet Union was detected by the analysis of aerosol particles in air filter samples taken by the United States (US) Air Force. With nuclear testing activities moving underground seismic monitoring became the primary detection tool.

In 1958, a Geneva Conference of Experts on the Means of Detection of Nuclear Explosions brought together and evaluated the expertise from 10 countries [4]. The goal was to determine whether a comprehensive ban on nuclear explosions would be verifiable. The experts considered radioactive debris as the specifically nuclear indication of an explosion that is available for analysis at large distances. Accordingly, ground-based as well as airplane mounted air filtering devices and analysis of the collected fission products were suggested as a means to detect nuclear explosions at distances of several thousand miles and at times of ten to twenty days after the event. Seismic monitoring was understood as the method to detect underground. Since seismic waves travel around the earth, national seismometers could detect nuclear tests in any part of the world.

2.2 Partial Test Ban Treaty

The Partial Test Ban Treaty (PTBT, also known as Limited Test Ban Treaty, LTBT) was agreed by the USA and the Soviet Union (USSR) in 1963. It had been under consideration since 1954 and was originally aimed to be a comprehensive test ban treaty. However, there was opposition against completely ending nuclear testing and there was a controversy over the question whether underground tests could be reliably detected and cheating made impossible. Eventually, the compromise was to ban "any nuclear weapons test explosion, or any other nuclear explosion" that is conducted "in the atmosphere; beyond its limits, including outer space; or underwater". It has the additional obligation not to test "in any other environment if such explosion causes radioactive debris to be present outside the territorial limits of the State...". Accordingly, it may be viewed as an environmental protection measure rather than an arms control treaty.

The two-page treaty was negotiated by Averill Harriman and Nikita Khrushchev in only 10 days in July and August 1963. It was signed on 5 August 1963 and entered into force on 10 October 1963. The USA, USSR and United Kingdom (UK) were the first parties but in the meantime it had been signed by most states of the world.

The PTBT has no verification provisions and it was understood that national technical means would be sufficient for verification. In fact, when the Cold War ended and Russia released a list of all Soviet nuclear explosions, it turned out that only few had escaped seismic detection by the open scientific world community. Even radioactivity had occasionally been detected from underground explosions and resulted in controversial debates and exchange of notes on the question whether this had been a violation of the PTBT. Especially the question whether or not radioactive noble gases would be covered by the ban on transboundary movement of radioactive "debris" because that term could be interpreted as applying to aerosol particles only.

2.3 Threshold Test Ban Treaty and Peaceful Nuclear Explosions Treaty

The Threshold Test Ban Treaty (TTBT) is a bilateral Treaty between the USA and the USSR signed in 1974 and went into effect in 1976. The parties agreed to prohibit all nuclear tests having a yield exceeding 150 kt Trinitrotoluol (TNT) equivalent. In order to avoid the loophole of circumventing the TTBT by declaring higher yield explosions as peaceful, the Peaceful Nuclear Explosions Treaty (PNET) was signed in 1976, putting the same threshold limit on so-called peaceful nuclear explosions.

Verification became an issue that resulted in both treaties to enter into force only after new protocols were agreed and signed in December 1990. Originally, both sides were confident that national technical means would be sufficient to verify the threshold, given that the exchange of relevant data was agreed in the original protocol. Seismic monitoring is able to determine the explosion yield from the magnitude of the seismic waves. In fact, it was already possible to detect and quantify explosions of much lower size.

The new Protocol allowed both sides to use techniques for on-site measurement of explosion yields and in-country seismic monitoring. It even allowed for on-site inspections. Already during the negotiations of the Protocol, the Nuclear Risk Reduction Centres were established and a Bilateral Consultative Commission (BCC) was set up in order to discuss issues like alleged non-compliances. In 1988, the USA and the USSR conducted the Joint Verification Experiment with one nuclear test at Nevada and one at the Semipalatinsk test sites. Each country was permitted to observe the nuclear explosion with on-site hydrodynamic measurements.

2.4 Group of Scientific Experts

The parallel development of the global verification system and the political conditions for the Comprehensive Nuclear-Test Ban Treaty (CTBT) took half a century. This is illustrated in the timeline given in Table 1. Obviously, there were simultaneous developments. However, it is remarkable that there were phases when the political process was in a deadlock and, nevertheless, scientific activities were carried on even with a political mandate. For some years, the scientific activities kept up the momentum and prepared the ground for political progress by developing the technical means for verification and demonstrating how well they function [5]. This was clearly the case with the Geneva Group of Experts (1958-1960) as well as with the Group of Scientific Experts (GSE) (since 1976) which formed the main basis for continuity for almost two decades until the CTBT negotiations started with a resolution of the UN General Assembly in 1993.
Lessons from the Geneva Group of Experts (1958-1960) are:

- For the first time, scientists were given an independent role in negotiating security issues.

- Scientists negotiated before diplomats were able to negotiate.
- Scientists prepared the ground (verification, circumvention).
- Comprehensive treaty anticipated, limited achieved.

Table 1. Parallel development of the global verification system and the political conditions for the Comprehensive Nuclear-Test Ban Treaty (CTBT)

	Verification related scientific activities	**Political developments**
1945		First nuclear explosion
Since 1945	National technical means to detect nuclear tests	
1958 - 1960	Geneva Group of Experts (with experts from 10 countries)	
1963	PTBT verification with national technical means	Partial Test Ban Treaty (PTBT)
1974	TTBT verification with national technical means	Threshold Test Ban Treaty (TTBT)
1976	PNET verification with national technical means	Peaceful Nuclear Explosions Treaty (PNET)
1976	Establishment of the Group of Scientific Experts (GSE)	by the Geneva Conference of the Committee on Disarmament (CCD)
1977-1980		Trilateral test ban negotiations
1978	First comprehensive GSE report	
1980-83	GSE Global Telecommunication System technical tests	
1982/83		Ad Hoc Committee at the Conference on Disarmament
1984	GSE Technical Test GSETT-1	
1986/87		US-USSR bilateral negotiations
1990		New protocols agreed for the TTBT and the PNET
1991	GSE Technical Test GSETT-2	
1993-1996		CTBT negotiated at the Conference on Disarmament in Geneva
1995	GSE Technical Test GSETT-3 with Prototype International Data Center in Arlington	
1996		CTBT opened for signature
Since 1997	The Provisional Technical Secretariat of the Preparatory Commission for the CTBTO is being established in Vienna. It builds up the International Monitoring System and the International Data Centre.	

Lessons from the Group of Scientific Experts (since 1976) are:

- The GSE had a political mandate.
- Scientific members were appointed by governments.
- Progress was not at all times connected to political negotiations.
- At times, the GSE established a substitute for negotiations.
- International coordination of national technical means was started.
- The work was based on a lasting common agenda.
- The work was supported by infrastructure financed through States.
- The GSE created a common understanding and furthered knowledge.

3 The International Monitoring System

3.1 The Comprehensive Nuclear-Test Ban Treaty

The Comprehensive Nuclear-Test Ban Treaty (CTBT) was negotiated from 1993 to 1996 at the Conference on Disarmament in Geneva. It was opened for signature in September 1996 in New York. As of May 2005, there are 175 Signatories and 121 Ratifications. The CTBT enters into force after all 44 states defined in Annex II have signed and ratified the Treaty. The current score is 41 Signatories and 33 Ratifications. The UN General Assembly has passed a resolution in November 1996 that created the Preparatory Commission with its Provisional Technical Secretariat in Vienna [6, www.ctbto.org]. It is building up the International Data Centre as well as the International Monitoring System with 321 stations worldwide. The latter is done in cooperation with the hosting State Signatories.

The basic obligation of the CTBT for State Parties is "not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control" (Article I).

3.2 International Monitoring System overview

In order to verify compliance with this obligation, the International Monitoring System (IMS) consisting of 321 stations is being established in order to monitor the whole globe. Fig. 2 shows their geographic distribution. Subnetworks are under construction for all four relevant sensor technologies. The seismic network will consist of 50 primary and 120 auxiliary seismological stations; the hydroacoustic network comprises 11 stations to monitor all oceanic waters; 60 infrasound and 80 radionuclide stations are being set up [7].

The purpose of the four IMS sensor networks is to detect signals that are indicative for nuclear explosions, as well as to identify and to locate nuclear explosions underground, underwater or in the atmosphere. Depending on the environment, a certain sensor technology will receive the strongest signal, while others may still detect the explosion by the primary signal coupling into another geological system. For example, underwater explosions cause primarily hydroacoustic signals and release most of their radioactivity, while the acoustic wave couples into the ocean bed or sea shore where part of its energy is transformed to generate a seismic wave. The detection goal is to identify a nuclear explosion with a yield of 1 kt TNT equivalent with at least 95% probability.

3.3 Seismic monitoring

Seismic events release energy in the form of waves that travel through the earth. There are body waves penetrating deep into the earth core and surface

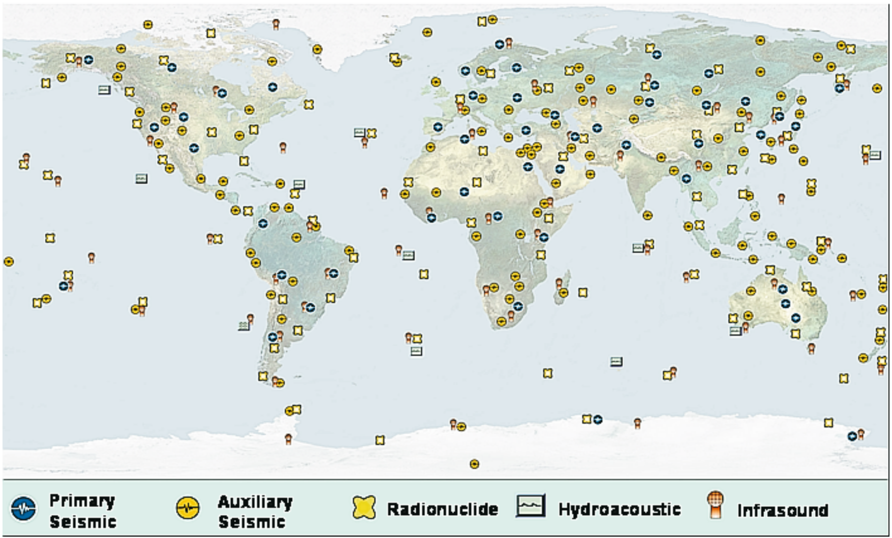


Fig. 2. Facilities of the CTBT International Monitoring System (Source: CTBTO PrepCom PTS)

waves that travel through the earth crust. The possible origin of these energies can be explosions, earthquakes or other events [8].

Two different types of seismic detectors are used in the monitoring system, three-component detectors and arrays. The three-component stations measure seismic waves in three dimensions at a single site and their strength is to determine the magnitude of an event. Array stations have sensors distributed over a large area in order to allow them to determine the direction and distance from a particular event.

Seismic monitoring has the advantage of providing highly accurate information about the location in time and space of a seismic event [9,10]. The precondition for this is that three stations pick up a signal from the same event that can then be located by triangulation. It is required that the area of the related error ellipse remains below 1000 km^2 because, according to the Protocol to the Treaty, this is the maximum size to which an on-site inspection would be limited.

In order to test the location accuracy, a chemical explosion with 0.1 kt TNT was conducted in the area of the former test site at Semipalatinsk in Kazakhstan on 25 September 1999. The IDC achieved to localise the origin of the seismic event with a distance of only 8.3 km from the ground truth location.

Every day, about 50 to 100 seismic events are registered. In one year, the IMS seismic network detects more than 20,000 earthquakes with a magnitude above 3.5. In Fig. 3 the first 100,000 events are marked clearly showing the tectonic plate boundaries. Seismic analysis is capable to distinguish between natural events like earthquakes and anthropogenic events like explosions [11,12,13]. There are various parameters that can be used as indicators for the type of an event. The most reliable one is the magnitude ratio of body waves vs. surface waves. Another method makes use of the fact that explosions cause a seismic spectrum with higher frequencies (1-30Hz) being more pronounced than for earthquakes.

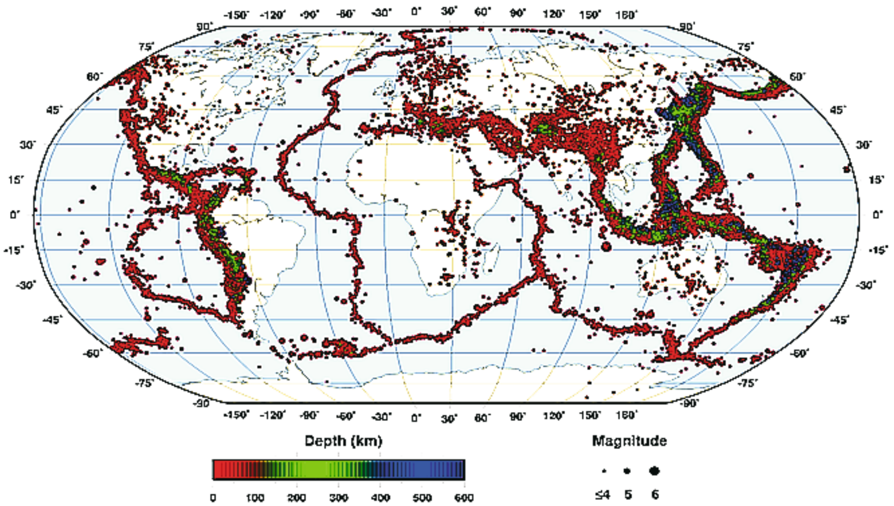


Fig. 3. The first 100,000 seismic events reported in the Reviewed Event Bulletin by the International Data Centre (Source: CTBTO PrepCom PTS)

3.4 Hydroacoustic monitoring

The hydroacoustic sensors make use of the special phenomena of acoustic waves in seawater [14,15]. Due to the density change of water with depth, the sound is channelled and transmitted at a certain depth in the so-called SOFAR channel. The low-frequency acoustic waves can travel over thousands of kilometres in the oceans without loosing much of their energy. Therefore, only 11 hydroacoustic stations are required for all oceans even though they cover about 70% of the earth's surface. Six of them are hydrophone stations and the other five are T-phase stations. Hydrophones are extremely sensitive underwater microphones that are mounted off-shore at a depth of about 1000 meter. The data are transmitted through cables to a shore facility. T-phase stations are seismic sensors on islands coasts that make use of the fact that the hydroacoustic wave converts into a seismic wave at the flank of the island.

Earthquakes are the main source for hydroacoustic detections. They can be distinguished from explosions in similar as in seismic analysis.

3.5 Infrasound monitoring

Atmospheric explosions create a shock wave and the lowest frequencies can be detected at distances of several hundred and possibly at significantly more than 1000 kilometres. Several other natural and man-made phenomena such as volcanoes, meteorites, rocket starts or the sonic boom of aircrafts produce infrasound signals [16].

The IMS network will have 60 infrasound stations. Their sensors detect pressure differences in the atmosphere caused by these low sound frequencies. These stations apply approximately 4-8 sensors that are located a few kilometres apart from each other. Since these systems are very susceptible to wind, each sensor element consists of a radial pipe system with their inlet tubes being at a few meters distance from each other in order to suppress the wind-generated noise. In addition, they are placed, if possible, in wind-shaded areas like in woods.

3.6 Radionuclide monitoring

The radionuclide network consists of three components: 80 particulate stations, 40 noble gas systems collocated with particulate stations and 16 radionuclide laboratories [17,18]. The number of 40 noble gas systems is a compromise after some delegations were hesitant during the Geneva negotiations to agree to this technique at all. Experience gained at these 40 sites will help to evaluate their capabilities [19,20]. It will then be up to the Conference of States Parties to decide after Entry into Force of the CTBT whether the number of noble gas systems should be increased to 80.

Atmospheric radioactivity is the only possible evidence that a suspected explosion has in fact been a nuclear one [21]. For the CTBT, the list of relevant particle-bound fission and activation products is long and includes barium-140, lanthanum-140, zirconium-95, as well as anthropogenic radioisotopes with other legitimate sources like cesium-137, iodine-131 and technetium-99m. There are four CTBT relevant noble gas isotopes, ^{135}Xe, ^{133m}Xe, ^{133}Xe and ^{131m}Xe. The selection of these isotopes as indicators is based on their production rate in an explosion as well as on their half-life [22]. The particulate and noble gas sensors are taking daily samples. A high sensitivity of 30 Bq/m^3 for ^{140}Ba and 1 μBq/m^3 for ^{133}Xe can be achieved. Isotopic activity ratios can be used to determine the explosion time and to discriminate between a nuclear explosion and nuclear reactor sources. Fig. 4 shows a nuclide chart with histogram bars indicating the distribution of the first 250 relevant anthropogenic nuclides that were detected in air filter samples in the first years of operational testing. Most of them are from radiopharmaceutical applications using technetium-99m or iodine-131 for diagnostic or therapeutic purposes. Cesium-137 is resuspended from ground deposits still remaining from the Chernobyl accident or from historic nuclear tests. Sodium-24 is most likely of natural origin, but it is reported because it could also indicate a nuclear explosion.

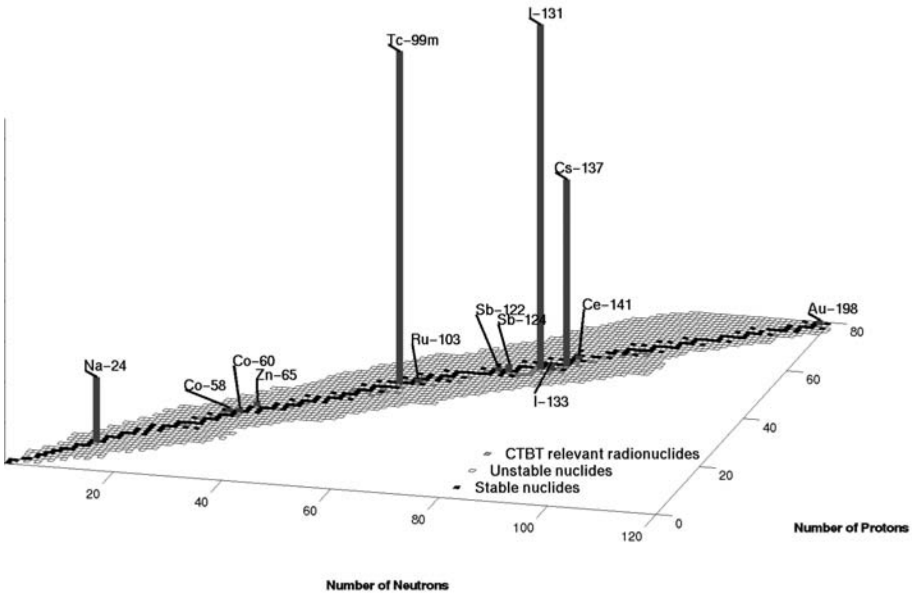


Fig. 4. Nuclide chart with histograms for the distribution of the first 250 cases of relevant anthropogenic radionuclides reported by the International Data Centre to be present in air filter samples

For underground explosions there is always a risk that the containment fails and radioactivity is released unintentionally into the atmosphere. This can happen in a quick high pressure venting or as a seeping that extends over hours, days and longer periods. It may also happen that radioactivity is released in controlled manner related to operational activities, e.g. the controlled cavity purging to allow either for recovery of experimental data or reuse of part of the underground testing area. Between 1962 and 1988, 19 US underground nuclear tests inadvertently released sufficient radioactivity to be detected by ground monitoring equipment off the testing site [23]. From 1971 to 1988, late-time seeps happened in four cases, controlled tunnel purgings were carried out following ten explosions and for 108 other tests smaller operational releases were detected [23]. More than 500 tests at the Nevada Test Site were followed by operational releases of radioactivity within a few days or weeks after the explosion measured at the point of release [24].

3.7 Radionuclide laboratories

Sixteen radionuclide laboratories have been chosen during the Geneva negotiations to further evaluate selected samples from radionuclide stations. They are considered to have existing expertise in order to make an independent evaluation. These radionuclide laboratories are being certified by the PTS regarding their procedures and their quality management.

4 The International Data Centre

4.1 Overview

The seismoacoustic data (seismic, hydroacoustic and infrasound) are all continuous waveform data. They are transmitted in near-real time through the global communication infrastructure to the International Data Centre (IDC) in Vienna. The radionuclide stations submit their measurement data once per day. The IDC does the analysis and sends reports to the National Data Centres (NDCs) of the member states. The waveform monitoring technologies allow for a highly precise location of explosions in time and space. However, only the association with a relevant detection of radionuclides could provide an indication for an explosion to possibly be a nuclear event. In order to facilitate the required data fusion, i.e. the combination of events from these different sensor technologies, atmospheric transport modelling is applied to determine the possible source region in order to allow for an event correlation in time and space.

4.2 The global communication infrastructure

The Provisional Technical Secretariat operates the Global Communication Infrastructure (GCI) for data transmission between the IDC and IMS stations as well as to National Data Centres. Through the GCI the IMS stations send their raw data, state-of-health data and, in case of radionuclide stations, meteorological data to the IDC. The data are transmitted through Very Small Aperture Terminals (VSAT) to one of five satellites. The latter send all data to a hub that is linked through a frame relay network to the IDC. The telecommunication services are provided by a private company.

4.3 International Data analysis and products

The mission of the International Data Centre (IDC) is to support the verification responsibilities of States Signatories by providing objective products and services necessary for effective global monitoring. Especially, the IDC shall according to the Protocol, Part I:

- "Receive, collect, automatically process, interactively analyse, report on, and archive data from IMS facilities;
- Carry out special studies, provide technical assistance, and technical analysis of IMS or other data on request by a State Party."

The routine operational work of the IDC can be compared to a factory. The raw products are the data from IMS stations. Once all stations are operational, the amount of data from the four monitoring technologies received by the IDC will exceed 10 GigaByte per day, including data for at least 120 radionuclide samples (the precise number of daily noble gas samples has still to be determined). Analysis of the raw data is required to extract the relevant information, characterise it and to make the results available in daily products that are released according to a defined schedule. It is important to note that the IDC provides standard products with no prejudice to final judgements that are up to the State Signatories and carried out basically at their National Data Centres.

The processing pipeline starts with automated processing, followed by interactive analysis. The automatic signal detection lists and event reports are released as soon as possible after the receipt of the raw data. Then follows interactive analysis performed mainly for quality control of the automated processing. Within a certain number of hours after receipt of the raw data, the reviewed report or bulletin is released and made available to authorized users.

4.4 Data fusion

Since a nuclear explosion generates signals that can be detected by different sensor technologies, an important task is the physics-based fusion of data from the four monitoring technologies. This is based on information about the propagation of signals through the earth, oceans and atmosphere. The waves can couple from one medium into the other. For example, in average about one seismic event per day is registered by hydroacoustic sensors as well. By fusing waveform signals detected by seismic, infrasound or hydroacoustic sensors, so-called seismoacoustic events can be formed. These can be located very accurately in space and time. In contrast, the origin in space and time of radionuclide events is determined with significantly larger uncertainties. A capability is needed to fuse seismoacoustic events with detections of relevant radionuclides in the atmosphere because only radionuclide monitoring has a potential for getting evidence that an explosion is a nuclear one. Atmospheric transport and dispersion modelling is applied to get indications for the possible source location of radionuclides detected at one of the 80 sampling sites. If available, suitable isotopic ratios could be utilized to determine their possible release time, and with this information the related geographical area can be accordingly confined.

4.5 Atmospheric transport modelling

The radionuclide stations provide information only about the atmospheric radioactivity at the sampling site. In order to determine its possible release point and the transport through the atmosphere, meteorological simulations are done [21]. In order to support the CTBT member states, the International Data Centre (IDC) runs its own atmospheric transport models on a routine basis for every air sample and cooperates with the World Meteorological Organization (WMO) to do more extensive modelling for relevant cases. A framework agreement between the CTBTO PrepCom and the WMO was finalized in 2001 and is now being put in operation. Under this agreement the WMO Regional Specialised Meteorological Centres will run their models to determine potential source regions for radionuclide events of interest and the IDC will receive meteorological analysis data to drive its atmospheric transport models.

The agreed method for source location is based on the calculation of source-receptor relations for all 80 sampling sites as receptors and a large number of grid cells on the earth surface as sources. Suitable post-processing tools are applied to generate different products from the source-receptor matrix [25]. Various products have been proposed [26]. The main results are time-integrated as well as differential Fields-of-Regard indicating the geographic area from which the air arrived at the detector during one full sampling period. Alternatively, a quantitative result would determine for each area the dilution ratio that air parcels experience during the transport time. This can be used to derive a hypothetical release strength that could explain the measured concentration. A special product is the Possible Source Area as a correlation result for various samples that have received or might have received a signal from the same source. Another possible outcome is the combination of the full source-receptor matrix for an extended period of time in order to demonstrate the network capability by showing a plot of the total geographic coverage or the detectable concentration threshold for each hypothetical release point.

4.6 National Data Centers

It is up to the member states to interpret the signals and make a judgement about suspected treaty violations. For this purposes, National Data Centers (NDCs) are being established. The first national data centers were already established in the context of the technical tests of the Group of Scientific Experts (GSE, see above). As of April 2005, 43 State Signatories have nominated their NDC. More than 650 authorized users from 84 States, including station operators and other designated establishments, have initiated the use of the IMS data and IDC products. In 2004, more than half a million products were delivered on subscription. More were received on request, through the interactive webpage or by direct database access. In addition, the States are free to use data from National Technical Means (NTM) in order to draw their conclusions. However, cooperating nationally facilities need to be certified by the PTS in order for their data to be officially used for CTBT verification. Other kinds of sensors may be applied for national analysis. This will include satellite imagery [3] and high-altitude air sampling.

Currently, the use of IMS data and IDC products is restricted to CTBT related purposes. As long as the Treaty is not in force, they are used for testing the system rather than for verification. A few exceptions have been made. The International Seismological Center (ISC) in the United Kingdom has received the seismic reviewed event bulletin in order to do quality controls and improvements on their own global analysis of seismic events. The World Meteorological Organisation (WMO) receives on a continuous basis the meteorological observations that are made at the radionuclide stations. For the future, the huge amount of global monitoring data bears a tremendous potential for serving a broad variety of possible scientific and civilian applications like climate research or tsunami warning.

5 Non-monitoring verification provisions

5.1 Introduction

Besides of the routine monitoring with the IMS, the CTBT has also provisions for on-site inspections for the case that doubts about a suspicious event cannot be removed by a consultation and clarification process.

5.2 Confidence building measures

In order to support the interpretation of seismic events with explosion characteristics, the CTBT foresees States' reports of chemical explosions as a confidence building measure. On a voluntary basis, each State Party could report to the Technical Secretariat chemical explosions with a yield of more than 0.3 kt TNT. This notification should preferably be made in advance and should contain information about location and time as well as purpose of the explosion. A State Party could even invite representatives of the Technical Secretariat or other State Parties to visit the site of such an explosion. Another confidence building measure is support the calibration of the International Monitoring System especially by carrying out chemical calibration explosions or by providing relevant information about other chemical explosions conducted for mining, construction or other purposes.

No such provisions are defined for radionuclide releases anywhere in the Treaty text.

5.3 Consultation and clarification

In case of a suspected treaty violation a process of consultation and clarification is foreseen. Whenever possible, States Parties should first make every effort to clarify and resolve any matter which may cause concern about possible Treaty violations. The CTBT defines a strict timeline for providing answers to a request in order to make sure that no time is wasted and the short-lived signatures are not vanished in case an on-site inspection is wanted.

5.4 On–site inspection

If a suspected case cannot be resolved by consultation and clarification, the Member States may call for an On-Site Inspection. The requirement on the relevant area is given in the Protocol to the CTBT, Part II (On-Site Inspections - A. General Provisions):

"3. The area of an on-site inspection shall be continuous and its size shall not exceed 1,000 square kilometres. There shall be no linear distance greater than 50 kilometres in any direction."

As long as the CTBT has not entered into force, no on-site inspections will be carried out. In this phase, the methods and procedures are discussed and noted in a draft operations manual. Demonstration equipment is being acquired and tested in field exercises.

Various measurement methods are suitable for on-site inspection. In addition to visual inspection and photographic documentation from the ground and by overflights, several methods are under consideration to collect early information about seismic aftershocks and radioactivity. Further investigations will include the inspection of underground structures. Passive seismic survey would be conducted with seismometers. Active seismic equipment could include active sources like vibrations and explosions that are recorded with geophones. Underground structures could be explored with ground penetrating radar, gravitation field mapping, ground-based or airborne magnetic field mapping and electrical conductivity measurements.

As far as radioactivity is concerned, the OSI would first conduct a radiological survey with handheld devices like Geiger counters. A strong indication is expected from the radioactivity in sub-soil gases. Underground nuclear explosions do not only generate fission products but also activation products that are useful as indicators during on-site inspections. For on-site inspection at the site of a suspected underground explosion, 21 fission products were identified as relevant residuals from a nuclear explosion [27]. The most important radionuclides are the xenon isotopes as fission products and with calcium rich environments argon-37 as activation product as well. These noble gases may be sucked through geological faults by atmospheric depressions and thus can escape with some delay even from well contained underground explosions [28,29].

6 Conclusions

The CTBT verification system is defined in the Treaty and its Protocol that was opened for signature in September 1996. The routine global monitoring is based on four sensor networks: seismic, hydroacoustic, infrasound and radionuclide. The technologies for this monitoring system, the communication procedures and the analysis software and review have been developed and demonstrated over decades and especially by the technical experiments conducted by the Group of Scientific Experts. The detection goal is to identify a nuclear explosion with a yield of 1 kt TNT equivalent with at least 95% probability. The International Monitoring System is currently being established by the Provisional Technical Secretariat of the Preparatory Commision for CTBTO in cooperation with the hosting State Signatories. The effectiveness of this monitoring system has repeatedly been affirmed [30,31,32,33]. The International Data Centre analyses the data with no prejudice to source interpretation and prepares bulletins for the National Data Centres. The State Parties will be responsible for interpreting the IMS data and IDC bulletins. They may use national technical means in addition. In order to support the interpretation of seismic events with explosion characteristics, the CTBT foresees States' reports of chemical explosions as a confidence building measure. In case of a suspected treaty violation a process of consultation and clarification is foreseen. If it cannot be resolved, the Member States may call for an On-Site Inspection.

References

1. Yang, X., R. North and C. Romney (2000): CMR Nuclear Explosion Database (Revision 3). Center for Monitoring Research Technical Report CMR-00/16.
2. NRDC (2002): Table of Known Nuclear Tests Worldwide. Natural Resources Defense Council, www.nrdc.org/nuclear/nudb/datab15.asp, last update 25 November 2002, accessed on 23 May 2005.
3. Jasani, B. (2006): Satellite imagery. This volume.
4. Mark, C. (1959): The Detection of Nuclear Explosions. *Nucleonics 17*, No.8, 64-73.
5. Sykes, L.R. (2002): Four decades of progress in seismic identification help verify the CTBT, Eos - Transactions American Geophysics Union (AGU), vol. 83, no. 44, p. 497.
6. Hoffmann, W., B. Wrabetz (2005): Der Umfassende Kernwaffenteststoppvertrag. In: Neuneck, G. and Ch. Mölling (eds.): *Die Zukunft der Rüstungskontrolle*. Baden-Baden, Nomos-Verlag, pp.193-201.
7. Hoffmann, W., R. Kebeasy and P. Firbas (1999): Introduction to the verification regime of the Comprehensive Nuclear-Test-Ban Treaty. *Physics of the Earth and Planetary Interiors*, 113, 5-9.
8. U.S. Office of Technology Assessment (1988): Seismic Verification of Nuclear Testing Treaties, Government Printing Office, Washington D.C.
9. Evernden, J. F. (1969): Precision of Epicenters Obtained by Small Numbers of Worldwide Stations, *Bulletin of the Seismological Society of America*, Volume 59, pp. 1365-1398.
10. Kennett, B. (1995): Event Location and Source Characterization. In: Husebye, E. and A. Dainty (eds.) (1995): *Monitoring a Comprehensive Test Ban Treaty*, NATO ASI Series, Series E: Applied Sciences, eds., Volume 303, Kluwer Academic Publishers, Dordrecht, pp. 501-520.

11. Weichert, D. H. (1971): Short-period Spectral Discriminant for Earthquake and Explosion Differentiation. *Zeitschrift für Geophysik*, Volume 37, pp. 147-152.
12. Marshall, P. D. and P. W. Basham (1972): Discriminating Between Earthquakes and Underground Explosions Employing an Improved Ms Scale, *Geophysical Journal of the Royal Astronomical Society*, Volume 28, pp. 431-458.
13. Bolt, B. A. (1976): *Nuclear Explosions and Earthquakes: The Parted Veil*, W. H. Freeman.
14. Urick, R. (1983): Principles of Underwater Sound, 3rd Edition, McGraw-Hill.
15. Burdic, W. (1991): Underwater Acoustic System Analysis, Prentice Hall.
16. Gossard and Hook (1975): Waves in the Atmosphere. Elsevier Scientific, Amsterdam.
17. Schulze, J., M. Auer and R. Werzi (2000): Low level radioactivity measurement in support of the CTBTO. *Applied Radiation and Isotopes 53*, 23-30.
18. Kalinowski, M.B., J. Schulze (2002): Radionuclide Monitoring for the Comprehensive Nuclear-Test-Ban Treaty. *Journal of Nuclear Materials Management*, vol. 30, No. 4, pp.57-67.
19. Auer M., A. Axelsson, X. Blanchard, T.W. Bowyer, G. Brachet, I. Bulowski, Y. Dubasov, K. Elmgren, J.P. Fontaine, W. Harms, J.C. Hayes, T.R. Heimbigner, J.I. McIntyre, M.E. Panisko, Y. Popov, A. Ringbom, H. Sartorius, S. Schmid, J. Schulze, C. Schlosser, T. Taffary, W. Weiss and B. Wernsperger (2004): Intercomparison experiments of systems for the measurment of xenon radionuclides in the atmosphere, *Applied Radiation and Isotopes 60*, 863-877.
20. Bowyer, T.W., C. Schlosser, K.H. Abel, M. Auer, J.C. Hayes, T.R. Heimbigner, J.I. McIntyre, M.E. Panisko, P.L. Reeder, H. Sartorius, J. Schulze and W. Weiss (2002): Detection and analysis of xenon isotopes for the Comprehensive Nuclear-Test-Ban Treaty international monitoring system. Jo*urnal of Environmental Radioactivity 59*, 139-151.
21. Kalinowski, M.B., J. Feichter, M. Nikkinen, C. Schlosser (2006): Environmental Sample Analysis. This volume.
22. De Geer, L.-E. (2001): Comprehensive Nuclear-Test-Ban Treaty: relevant radionuclides. *Kerntechnik 66/3*, 113-120.
23. U.S. Office of Technology Assessment (1989): The containment of underground nuclear explosion. Congress of the United States, Office of Technology Assessment, Report OTA-ISC-414. Available at http://govinfo.library.unt.edu/ota/Ota_2/DATA/1989/8909.PDF
24. Schoengold, C.R., M.E. DeMarre, E.M. Kirkwood (1996): Radiological effluents released from U.S. continental tests 1961 through 1992. United States Department of Energy - Nevada Operations Office, DOE/NV-317 (Rev.1) UC-702, Las Vegas, August 1996.
25. Wotawa, G.; Denier, Ph.; DeGeer, L.-E.; Kalinowski, M.B.; Toivonen, H.; D'Amours, R.; Desiato, F.; Issartel, J.P.; Langer, M.; Seibert, P.; Frank, A.; Sloan, C.; Yamazawa, H. (2003): Atmospheric transport modelling in support of CTBT verification - Overview and basic concepts. *Atmospheric Environment 37*, 18, 2529-37.
26. Kalinowski, M.B. (2001): Atmospheric transport modelling related to radionuclide monitoring in support of Comprehensive Nuclear-Test-Ban Treaty verification. *Kerntechnik 66/3* 129-133.
27. Takano, M. and V. Krioutchenkov (2001): Technical methods employed for the On-Site Inspection. *Kerntechnik 66/3*, 143-146.

28. De Geer, L.-E. (1996): Sniffing out clandestine tests. *Nature* 382, 491-492.
29. Carrigan, C.R., R.A. Heinle, G.B. Hudson, J.J. Nitao and J.J. Zucca (1996): Trace gas emissions on geological faults as indicators of underground nuclear testing. *Nature 382*, 528-531.
30. Independent Commission on the Verifiability of the CTBT (2000): Final Report, VERTIC, London (available at www.vertic.org).
31. Mines, B. (2004): The Comprehensive Nuclear-Test-Ban Treaty: Virtual verifiable now. VERTIC Brief 3. VERTIC, London.
32. NAS (2002): *Technical Issues Related to Ratification of the Comprehensive Nuclear Test Ban Treaty*. National Academy of Sciences, Washington, DC.
33. Shalikashvili, J. (2001): Findings and recommendations concerning the comprehensive nuclear test ban treaty, Report submitted to the US President and Secretary of State, 5 January 2001, Washington, DC.

Treaty on Conventional Forces in Europe

Marc Zwilling

1 Introduction

1.1 General information

The Conventional Forces in Europe (CFE) Treaty, sole Treaty, regulating the non-nuclear armaments on the European continent, is a survival of the cold war era. Negotiated at a time of great political changes, it tallied a bipolar situation which had already disappeared when it entered into force in 1992.

That Treaty demanded the limitation of the volumes of some specific categories of military equipment to an identical level on both sides of the Iron Curtain, a situation which has been reached in 1996. Its main goal was to "*establish [...] a secure and stable balance of conventional armed forces in Europe at lower levels than heretofore, of eliminating disparities prejudicial to stability and security and of eliminating, as a matter of high priority, the capability for launching surprise attack and for initiating large-scale offensive action in Europe*[1]". It is today difficult to appreciate the Treaty's contribution to the achievement of this objective.

The CFE Treaty has inherited imperfections, occulted for a long time by its exceptional nature, which limit its present interest. It has had however unforeseen effects, mainly in the psychological field.

Today the CFE Treaty is outdated. It is scheduled to be replaced by an "adapted" CFE Treaty, struggling to enter into force, mainly because the interest of such a Treaty is not felt anymore. Nevertheless, the CFE Treaty remains an example of conventional arms control and can be considered as a model suitable for exportation.

The CFE Treaty was signed in Paris on November 19th, 1990 by the Heads of State of the main countries of Western Europe and Central Europe, of the United States of America (USA), Canada and the Soviet Union (USSR). The

[1] Preamble to the CFE Treaty, para 12.

Treaty entered into force on July 17th 1992[2] and aimed to limit the number of major combat equipment - tanks and armoured vehicles, artillery guns, aircraft or helicopters - to an identical level on both sides of the Iron Curtain. The Treaty included obligations of transparency, destruction of the armaments in excess and verification of the veracity of information transmitted.

In the chronology of armament limitation agreements, the CFE Treaty originates from the same generation than the USA/USSR bilateral agreements on nuclear weapons (Intermediate Nuclear Forces (INF) in 1987, Threshold Test Ban Treaty (TTBT) in 1990). It was drafted before the Strategic Arms Reduction Treaty (START), which will enter into force before it and shares with it the same logic of destruction of equipment in excess.

Contemporary of the most important political changes in Europe since the end of the Second World War, it has accompanied the transformation the post-Soviet Europe. Its roots lie in the Helsinki[3] process which established the principle of "Confidence Building Measures[4]", but also in the voluntary action of Mr. Gorbachev who in 1987 wished to convince the West of the non-offensive nature of the Warsaw Pact[5]. The latter had at that time acquired over North Atlantic Treaty Organization (NATO) a substantial numerical superiority in the field of non-nuclear armaments. Since 1987, within the framework of the agreements aiming to the reduction of the tensions in Europe, two different logics appeared: on one hand, general measures aimed at reducing the tensions, i.e. the Confidence and Security Building Measures (CSBM) negotiated within what was at that time the Conference on Security and Cooperation in Europe (CSCE) which changed for Organisation for Security and Cooperation in Europe (OSCE), and on the other hand the limitation/reduction agreements negotiated between the NATO and the Warsaw Pact.

However, the long negotiations (from 1987 to 1990) which were necessary to the drafting of the Treaty, coincided with important geopolitical changes which have modified the military forces stationed in Europe. This period witnessed the German reunification, the beginning of the withdrawal of Soviet troops from Central Europe and the access to independence of the Baltic States. How could a Treaty negotiated under an ancient order be able to fit to a new world?

---

[2] Six months after ratification by various States parties.

[3] Conference on Security and Cooperation in Europe (CSCE) final Act, August 1975.

[4] Formalized as "Confidence and Security Building Measures (CSBM)" in the Stockholm agreement (1986) and the agreements which result from it (1990, 1992 et 1999 Vienna Documents).

[5] Though a pact of that name never existed, this term came in to refer to the armed forces of countries member of Warsaw Treaty Organisation set under unified Soviet command.

1.2 What covers the Conventional Forces in Europe Treaty?

The Treaty includes a text of twenty-three uneven articles and eight protocols which are integral part of the Treaty. Three of these protocols are as important as the Treaty itself which they supplement and sometimes contradict: the Protocol on Existing Types (POET), the Protocol on Inspection (POI) and the Protocol on Notifications and Exchange of Information (PONEI).

The goal of the CFE Treaty is clearly defined in its preamble,: "*...establishing a secure and stable balance of conventional armed forces in Europe at lower levels than heretofore, of eliminating disparities prejudicial to stability and security and of eliminating, as a matter of high priority, the capability for launching surprise attack and for initiating large-scale offensive action in Europe". (para. 8) and "ensuring that the numbers of conventional armaments and equipment limited by the Treaty within the area of application of this Treaty do not exceed 40,000 battle tanks, 60,000 armoured combat vehicles, 40,000 pieces of artillery, 13,600 combat aircraft and 4,000 attack helicopters*" (para. 10). To achieve this goal, the Treaty envisages four types of measures:

- Limitation of the quantity of military equipment (limited to some categories) at a smaller level than before, the level being identical for the Warsaw Pact and NATO;
- Exchange of data on the nature, the volume, the position and the hierarchical subordination of the equipment subject to the Treaty,
- Destruction (or the irreversible transformation) of every piece equipment exceeding the agreed levels;
- Intrusive verification measures, intended to control the above points.

The Treaty applies only to some categories of ground or air combat equipment:

- Armored vehicles of several types (tanks, personnel carrier and launched bridge);
- Artillery guns including heavy mortars (but no missiles);
- Armed helicopters,
- Combat aircraft.

Long discussions took place in order to precise the nature of the equipment subject to the prescription of the Treaty. They concluded to categories of equipment wich differ somewhat from their traditional meaning[6]. The wording in the CFE Treaty is Conventional Armaments and Equipment subject to the Treaty, often abbreviated as CAEST, an acronym which will be taken up here. The article 2 of the Treaty defines carefully the various CAEST, however insufficiently, as we will see further. Only some CAEST are subject to numerical limitations; they are named Treaty limited equipment (TLEs).

[6] The Treaty provide for four categories of armament and equipments: tanks, artillery (including mortars), helicopters (several sub-categories), aircraft (ibid), to which one should add the armoured vehicle bridge launcher.

The symmetrical limitation of the CAEST on an identical level on both sides of the former iron curtain

The Treaty applies to a specific area, the "Atlantic To The Urals (ATTU)" Europe, which covers nearly four million square kilometres. It deals only with equipment belonging to the Army and Air force. Navy units[7] (including the important Marine units), and internal security units are excluded from it (specifically, on the Soviet side, all State Security Committee (KGB) and border guards troops)[8].

The volumes of CAEST thus defined should not exceed, for each of the two groups of States parties, the following ceilings (Table 1):

Table 1. The numerical ceilings

TLE	**in ATTU***	**In Each Alliance**
Tanks	40,000	20,000
Artillery	40,000	20,000
Armored Combat Vehicles (ACVs)	60,000	30,000
Aircraft	13,600	6,800
Helicopters	4,000	2,000

The numerical limitations are declined by areas within the ATTU zone. The Treaty applies to three concentric zones, centred on Germany. They are known under the number of the article of the Treaty which describes them: they are zones 4, 3 and 2. The whole ATTU zone is known under the name of zone 1. The part of zone 1 which is not included in zone 2 is named "flanks zone" (see Figure 1).

The Treaty includes some more complex limitations. For example, the numerical limits are submitted to sub limits related to the CAEST stored in depot, or to some type of Soviet aircraft (helicopters and planes).

Exchange of information on CAEST

The main provision of the Treaty lies in a disposition found in the earlier the American-Russian bilateral treaties: the obligation of exchanging precise data on the volume, the position and the hierarchical subordination of the military equipments subject to the Treaty.

---

[7] With the exception of navy land-based aircrafts.

[8] Those troops included many tank and armoured units.

Fig. 1. The four zones (document DTRA)

Concretely, every first of January[9], each State transmits such information in a standardized form, and receives from all the other states the same information. In CFE parlance, this is the "Exchange of Information" (EoI). For an example, see figure 2). When the first EoI took place on November 18th 1990, the information gathered by every country was quickly assessed and compared to the documentation painfully produced by the various intelligence agencies during the past decades. The result was obvious: this first EoI contained far more information than the national intelligence communities had been able to find out.

The destruction, or irreversible transformation in a useless piece of equipment (the Treaty term is "reduction") of the military armaments, which we will extensively cover further on, appears as the most spectacular measure of the Treaty. The corridors of the Western verification agencies are decorated with photographs depicting cemeteries of armoured vehicles, artfully destroyed. Reduction demanded by the CFE Treaty had a visible effect on the offensive capacity. However, the Exchange of Information had permanently modified the mentalities: both blocks moved from an atmosphere of

[9] Application date. The exchange of information is actually exercised on previous 15 December. The Russian Federation must also provide with partial complementary EoI on June 1st of each year. Moreover, the movements of equipments which could change significantly the figures of the EoI must be actualized during the year of the EoI, according to the procedure known as "notification".

secrecy, intended to protect the military capacity of the armed forces, to a - relative - concept of transparency.

To understand that, one only have to imagine the sanctions which would have fallen on the general officer who would have, prior to the Treaty, transmitted to the other block the data contained in the EoI. According to the terms of one of the first officers in charge of START inspections: "He would have been jailed for this![10]" .

Chart IIIB: INFORMATION ON THE LOCATION, NUMBERS AND TYPES OF CONVENTIONAL ARMAMENTS AND EQUIPMENT PROVIDED PURSUANT TO SECTION III OF THE PROTOCOL ON INFORMATION EXCHANGE OF (State Party) VALID AS OF (Date)											
Line Number	Formation or Unit Record Number	Designation or Formation or Unit	Peacetime Location	NOT USED	Combat Aircraft	Reclassified CCT Aircraft	Primary Trainer Aircraft	Attack Helicopters	Combat Support Helicopters	Unarmed Transport Helicopters	Other
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)

Fig. 2. Excerpts from EoI

Limitation and reduction of the armament stockpiles in Europe

The Treaty provided that in a short period (four years), the TLEs in excess should be rendered unfit for combat or, according to the terms of the Treaty, "reduced". The volume of concerned equipments is defined below (Table 2). As we can see, the major effort was made by the Warsaw Pact, especially regarding combat aircraft, which the former USSR and its then allies had in huge quantities.

Table 2. Reduction levels (Note: ACVs= Armoured Combat Vehicles)

Types of TLE	Ceiling / group of States parties	Volume before the Treaty		Volume to be reduced			
		NATO ◇	Warsaw Pact	NATO ◇		Warsaw Pact	
Tanks	20000	25091	33191	5949	24%	13191	40%
Artillery	20000	20620	26953	2334	11%	6953	26%
ACVs	30000	34453	42949	4631	13%	12949	30%
Aircraft	6800	5939	8372	0	0%	1572	19%
Helicopters	2000	1736	1701	0	0%	0	0%

The reduction methods were multiple, from the controlled destruction (by cutting, crushing..., Figure 3) to the conversion into equipments of civil use, including use as a target or static display. Russia resorted then to all possible

[10] Colonel V., US Army, interview, 2003.

artifices (transfers of equipment East of the Urals, i.e. outside ATTU zone; change of subordination of units in favour of the Navy and the Strategic missile command, both not covered by the Treaty;...) to avoid destroying too many TLEs. Long negotiations were necessary in 1991 to obtain compromises acceptable to all the parties. Those compromises lead to some limitation of the scope of the CFE Treaty, and it rapidly became obvious that the Treaty would only cover a part of its original target.

Fig. 3. "Reduced" armoured vehicles. Copyright UFV

Verification

The Treaty provides for monitoring inspections, still carried out nowadays. Within the framework of a strict protocol[11], each country can check the correctness of a - small - part of the information contained in the EoI. These inspections are now[12] of two types[13]:

- Inspections of a "declared site", known as "section VII inspections" according to the name of the part of the POI where they are described, during which a team of inspectors checks the TLEs present in a specific unit, called "Object Of Verification" (OOV), and confronts its findings with the data present in the EoI (Figure 4).

[11] POI - Protocol on Inspection, already quoted.

[12] Another type of inspections, "inspections of the reduction" are no more used today, as the reduction period is closed.

[13] We should exclude the reduction inspections which are obsolete since the reduction period has been closed in 1996.

- challenge inspections within specified areas, where a team inspects all possible sites, civilian or military, in an area of its choice with the aim of discovering possible concealed TLE. In Western countries, such inspections, known as "section VIII inspections", are regarded as prejudicial to the individual freedom and the right of property, and the national legislations sometimes had to be modified to allow them.

Fig. 4. A French inspector (centre) compares his findings with the data submitted by an officer of the OOV, monitored by a local escort team member. Copyright UFV

These inspections are limited in number. Each country has a quota of inspections which it is required to receive which is calculated on a 15% rate of the total number of the OOVs of this country. Moreover, it is not required to receive more than two simultaneous inspections and can not receive more than 50% of its inspections by the same State.

Every inspection team is escorted throughout its stay in the country by a national escort team. Both teams usually come from national verification units, as this job is proved to be quite specific and can difficultly be carried out by untrained soldiers.

The conclusion of an inspection is summarized in a formatted report written by the inspection team, to which can add its remarks. The report shows the number of observed existing CAEST, the differences with the figures given in the EoI and highlights possible ambiguities.

These inspections are constrained both in time and space and the scope of what is open for the inspection team to verify is restricted. The POI lists what is possible and what is not it, and is cause since the very first inspections until nowadays, endless quibbles. As an example, let us have a glance at the question of photography: the POI (Section VI - article 34) allows to take pictures "*for the purpose of recording the presence of conventional armaments* *and equipment subject to the Treaty ...*[14]", but also specifies that the cameras are limited to the 35mm and Polaroid cameras. The POI did not anticipate the invention of digital photography and today, it is still not possible to take digital pictures[15].

The POI allows the control and eventually impound the equipments "*inconsistent with the inspection requirements*[16]". Even nowadays, it happens from time to time that Russian security services deny to Western inspectors the possession of personal equipment such as MP3 players or even electric shavers.

The declared site inspections begin with the handing-over of a plan called "site diagram". This plan must conform to several precise characteristics (scale, north indication...) and is the subject of systematic and sterile objections during the inspections. It must include the indication of the roads and main buildings nevertheless, a building is always missing and a path not marked...

This implementation of the inspections has a lot to say on the state of the CFE Treaty today. Lacking its major interest since the end of the Cold War, the Treaty is reduced to petty-minded application of administrative rules. As a matter of fact, this lack of interest goes back to the early days of the Treaty, before its entry into force.

2 A Treaty already out of date when signed in 1992

This Treaty was already outdated at the time of its entry into force. Of course, it represented a tremendous advance in terms of reduction of volumes of conventional military equipment in Europe. As we pointed out above the simple fact of exchanging honest-looking and easily checkable information on the volume, nature and position of armoured vehicles, aircraft and helicopters represented then a considerable advance in terms of transparency and enabled a significant reduction of the tensions in Europe.

The Treaty suffers of its late birth in 1992. At that time the Berlin Wall had been tore down three years before. Germany was reunified (The German Democratic republic is not signatory to the CFE Treaty) and the Baltic States had got their independence back. At that time, was the *capability for launching surprise attack and for initiating large-scale offensive action in Europe* still on the agenda?

Moreover, what meant a Treaty negotiated between two antagonistic military organizations[17], when one organization was loosing members to the other one everyday, and seemed unable to carry out any type of coordinated action?

[14] CFE Treaty, POI, Section VI para. 34.
[15] Some countries do allow the use of digital cameras.
[16] CFE Treaty, POI, Section V para. 6.
[17] NATO and the Warsaw Pact.

In 1992, it appeared clear that no Warsaw Pact country would follow the USSR, reduced to the sole Confederation of Independent States (CIS), in an attack against the West. In 1992, it was becoming obvious that the improbable battle would never be fought on German soil, but somewhere between Belarus and Poland, definitely closer to Moscow that M. Brezhnev had ever thought of. The Russian armed forces, tailored for a hand-to-hand combat with NATO, unable undertake any form of strategic revolution in less than one generation, where clutching at a now obsolete strategic vision. But we have to remember that, at that time, the Red Army had achieved the feat of being involved in two attempted coups in less than three years.

At the time the Treaty was signed, its goals had already been achieved. The military problems in Europe had evolved. European countries were to focus on the fear of an explosion of the CIS and of the Russian military interventionism within the Russian federation.

Europe did no longer need a Treaty which is able to limit the equipments on both sides of the Oder-Neise border, but a Treaty limiting the movements of significant volumes of equipments from a country to another, with the overhead idea of limiting the movements of military forces unsolicited by the populations and the new sovereign states. This Treaty is the "adapted" Treaty CFE, whose principle was adopted in 1999[18], and which has still not entered in force.

2.1 A persisting two-blocks logic

The CFE Treaty, although signed between twenty-three sovereign countries, "*having signed the Treaty of Brussels of 1948, the Treaty of Washington of 1949 or the Treaty of Warsaw of 1955*[19]", has been negotiated between two integrated military organizations.

Between 1989 and 1994, the Soviet Union, then the CIS, withdrew its five Group of Soviet Forces in Germany (GSFG) Armies (17 divisions, i.e. 364 000 men strong), and 387 000 additional soldiers from other nations in Central Europe. In parallel; the size of American forces stationed in Germany went from 217 000 men in 1990 to 92 000 in 1993[20]. Between the signature (1990) and the entry into force (1992) of the Treaty, the CIS (formed at that time by the majority of the former Soviet Republics) had taken over the ceilings of the former USSR. On May 15th 1992, the CIS Member States signed the Tashkent agreement which distributed between them the CFE ceilings allotted to the former USSR.

But the logic of the blocks is still alive within the Treaty. Some observers are tempted to see in the CFE Treaty one of the last places where the Cold

[18] Final proceedings of the Istanbul Conference of the OSCE.

[19] Treaties establishing respectively the European Economic Community, the NATO and the Integrated Military Organization of the USSR and its satellites (Preamble to the CFE Treaty, para. 9).

[20] 73 5400 now.

War still exists. The reason is to be found in an internal provision with NATO: according to an Intra Alliance Understanding (IAU), the Allies do not inspect each other. The inspections are thus carried out by one block against the other. The progressive extension of NATO, especially the 2004 enlargement which saw ten new countries joining NATO, among them nine former Warsaw Pact[21] members, does nothing but to reinforce this concept of encirclement of a military alliance by another.

2.2 Unilateral withdrawal of the Baltic States

Estonia, Latvia and Lithuania dealt swiftly with the CFE Treaty as soon as they left Soviet rule, and in a similar manner. Their transition towards independence having coincided with one period of influence loss of the central Soviet power[22], it is difficult to determine with precision when, between 1990 and 1993 these three countries got rid of the USSR. Nevertheless, they all three affirmed not to be bound by any treaty signed by the Soviet Union since their annexation, and refused that the CFE Treaty should ever apply on their ground.

A look the map of Europe (Figure 1) helps to understand the importance, ten years later, of such a decision. Contrary to the "non-CFE" area in the South of Europe (the area including former Yugoslavia, Albania, Switzerland and Austria), consisting of non-aligned and neutral countries, some of which have vocation to keep this status, the Baltic States area (all three joined NATO in 2004) can be seen is a bridgehead of the North Atlantic Alliance in the heart of the Russian Federation, pushed between Kaliningrad and Saint-Petersburg.

2.3 "The Wall collapses, the threat disappears, but the Treaty remains"

That comment could summarize the CFE Treaty. The tremendous diplomatic and military progress which allowed easing the military tension in Western and Central Europe was overtook by history. Enslaved by its own logic of "counting equipment and nothing else", bound with red-tape, the day-today implementation of the Treaty was unable to take into account any modification of its environment and carried on with its mistakes. Today, we pointed out, the CFE Treaty has become, according to some, "the last battlefield of the Cold War".

So what can we give the CFE Treaty credit for?

[21] Among which 6 only are signatories of the CFE Treaty.
[22] Coup of August 1990.

3 Positive effects of the Conventional Forces in Europe Treaty

3.1 Effects in the psychological domain

We stressed out in our introduction the psychological importance of the exchange of information. With the exception of the INF bilateral Treaty between the USA and the former USSR, no agreement between the East and the West had ever achieved to make available to the potential enemy such a collection of military information. The significance of that event has gone almost unnoticed and should be praised here.

Moreover, officers of both blocks had the opportunity, during the course of the negotiation of the Treaty and of its protocols, as well as during the fuzzy time from the signature to the entry into force, and after that during 17 years of inspections, to observe and to evaluate each other. Officers of both sides, be them high-ranking advisers to the negotiators or handpicked and trained inspectors or formation commanders receiving an inspection, could get a clearer idea of the state of mind of the members of the armed forces which faced them. The CFE Treaty allowed military commanders of a small level (brigade and under) to observe in their usual working environment a team of soldiers, acting professionally, trained and disciplined, reacting to incidents with reflexes acquired by a long career in the service. For soldiers trained for years to consider those of the opposite block as invaders ready to jump, the inspections acted has reality catalysts, in the line of the Helsinki[23] principles.

There probably reside the bulk of the progresses of the CFE Treaty. But in the 21st century this is no more an innovation factor. The Treaty remaining unchanged, such advantages lie more in OSCE's Vienna Document CSBMs. Although not a strict arms control document, the Vienna Document has been able to adapt and evolve from its original 1990 to a 1999 version[24].

3.2 Effects on volume of the armaments

As regards to the reduction of the military tensions in Europe, the effects of the Treaty have been rather limited. Of course, there was the "reduction" of 39 761 TLE of all types. But this figure should be replaced into its context.

From 1990 to 1992, the USSR, followed by the CIS "lost" a great number of TLE when trying to bring them back to Russia. Most where out of order vehicles or aircraft, and remained rusting on parking lots in Army or Air force bases in the newly independent Republics, who refused to take responsibility

[23] "The Free movement of people and ideas".

[24] There also existed a '92 and a '94 version, which makes the Vienna Document, compared to the CFE Treaty, a very adaptative text, even if not legally binding (tit is only politically binding).

for them. Others were destroyed in combat, during conflicts between Armenia and Azerbaijan for example. On Western side, the 1990-91 Gulf war has given the USA the opportunity to move out of the ATTU zone a great number of TLEs which were never reallocated there. The impact of the CFE Treaty on the reduction of the volume of the major military armaments in Europe is thus not that important.

The CFE inspections, mainly those carried out under "section VII", allowed NATO members to have a clearer idea of the military potential of the former Warsaw Pact. The military equipment inspectable under the provisions of the Treaty (the CAEST), were found of little military value. These tanks, guns, aircraft, helicopters are good military hardware, robust, easy to maintain and interchangeable. They had never been planned to be integrated in a modern logistical support and supply chain. They also suffer from lack of maintenance and shortage of spare parts and they survived only with the help of exhaustive cannibalisation. They had value only in terms of flow: as long as there were new ones leaving the Soviet military-industrial complex, they could pose a threat. When the factories stopped producing uneconomical goods such as military equipment, the flow turned to stock, and its military power plummeted.

The assessment of the conventional military potential of the former Warsaw Pact within the CFE Treaty is worth noticing, because it raises a subject about which all the Treaty signatories are extremely discrete. Up to which point does the CFE Treaty serves the interests of their intelligence services? Note very far, we must say, because cheaper, easier means are at hand. The end of the bipolar world allowed every country to get its hands on specimens of TLE, inherited from GDR or collected on the battle fields of Kuwait. Armament exhibitions make it possible to everybody to scrutinize the capacities of defence industries. If the CFE Treaty and its inspections are of any help to the "intelligence" community, its is ounce in the psychological domain. To be able to assess the operational capacity of a system of forces by on-site confrontation of the weapons, their crew and the unit-level commanders is valuable intelligence, undoubtedly unobtainable without the CFE Treaty.

3.3 The adaptation of the CFE Treaty

While imperfect, the CFE Treaty could be expanded in other areas. A first Treaty review conference took place in March 1996[25] at the end of the reduction period. The principle of an adaptation of the Treaty was laid down. During the OSCE summit of December 1996 in Lisbon the process of negotiation of an adaptation agreement was initiated, and culminated at the OSCE Istanbul summit of 1999, where the members of the organization signed the "adapted" CFE Treaty, whose logic departs from the initial CFE Treaty.

[25] The 3 years long reduction period goes between two validation periods of 120 days. Also the reduction period stretches from July 1992 to March 1996.

This "adapted" Treaty establishes territorial limitations. Each State would have two ceilings, a national ceiling (the volume of its TLEs anywhere in the ATTU zone) and a territorial ceiling (the volume of TLEs - its own or those of another state - which can be stationed at a given time on its territory). This supposes that the States have a full and total control on the TLE stationed on their territory, which is not always the case, neither in Moldova (in the secessionist zone of Transnistria), nor in Georgia (in the secessionist zone of Abkhazia).

So certain preconditions to the ratification of the Treaty have been required by the OSCE during the Istanbul Conference, mostly from the Russian Federation. Some of these conditions[26] have been carried out since, but the question of the withdrawal of Russian ammunition from the former 14th Soviet Army depot in Kolbasna, Moldova and the status of the Russian forces in Georgia[27] are still an issue.

Those requirements having not been met, despite the ratification of the Treaty by Russia and Belarus in 2004[28], the "adapted" Treaty has not yet entered into force.

It is noteworthy that the negotiations on the adaptation of the Treaty have shifted from the "Joint Consultative Group (JCG)" (the body created within the CFE Treaty for resolution of problems within the Treaty) to the OSCE. Indeed, one of the characteristics of this "adapted" Treaty is its openness. No more limited to the 30 initial members, it will allow any state as a member. The three Baltic States, Slovenia and Croatia[29] have declared already stated their willingness to joint it.

However the adapted CFE Treaty, if it enters into force one day, should not escape an in depth debate: should the prevention of the crises in Europe include an accounting control of the armaments?

4 Perverse effects of the Conventional Forces in Europe Treaty

The CFE Treaty has however some darker sides. Because of the dispositions of a restrictive protocol which excludes from the field of the Treaty some equipments, some TLEs can easily evade the application of the Treaty. The application of the Treaty has become formal and gives place to excesses often run down under the unflattering term of "military tourism".

[26] For Russia: a "Declaration of reserve" for the oblasts surrounding the Baltic States and a bringing up of the allocation in the zone known as "of the flanks". For Poland, Hungary, the Czech Republic and Slovakia: a reduction of their national and territorial ceilings. For Germany: a non review upward of its territorial ceiling.

[27] The situation in Georgia is being settle since Mr. Saakashvili came to power.

[28] Germany declared that it was ready to ratify the adapted CFE Treaty.

[29] On condition of its adhesion to NATO.

4.1 Updating the POET

Structurally, the CFE Treaty suffers from a major flaw. The categories of military armaments and equipment which it covers are defined in its article 2 (the famous CAEST). Some are subjected to ceilings, they are the TLEs. In order to avoid counting as TLE armoured vehicles which have no real combat capabilities[30], the Treaty classifies them as "look-alike" and they are not subject to numerical ceilings. These "look-alike" are indicated in the EoI only when they located in the same OOV as TLEs.

TLE and "look-alike" correspond to precise definitions. Consider this: *'The term "armoured infantry fighting vehicle" means an armoured combat vehicle which is designed and equipped primarily to transport a combat infantry squad, which normally provides the capability for the troops to deliver fire from inside the vehicle under armoured protection, and which is armed with an integral or organic cannon of at least 20 millimetres calibre and sometimes an antitank missile launcher. Armoured infantry fighting vehicles serve as the principal weapon system of armoured infantry or mechanised infantry or motorised infantry formations and units of ground forces.*[31]'. But to be really subjected to the Treaty, any TLE must also be of a model included on a list included in the POET[32]. This list was updated several times by the permanent group of study of the Advisory POET of the Joint Group (JCG), but reflects less and less the realities of the military arsenals. BTR-50 and T-34 are still listed but few new pieces of equipment make it to the list. The last (and partial) update occurred in 1999[33].

The number of arguments about the list of the POET is innumerable, as shows the issue of the MTLBu armoured vehicle. The Russians have once listed MTLBus in their EoI, as "look-alike" of another vehicle, the MT-LB. They thereafter did not list it, estimating that it differed from the MT-LB from the outside, and could not be confused with MT-LB. But some vehicles on MLTBu chassis are laid down on the POET list of "look-alike". They are then "look-alike" of a vehicle which does not exist within the scope of the Treaty! Certain State parties continue to consider MTLBus as CAEST. When on of their inspection teams finds a MTLBu during an inspection, it must make a protest and point out in the inspection report that such a vehicle has been observed while not declared by the inspected party.

A State party can also declare any new vehicle like TLE if it thinks the vehicle meets the definitions of article 2. The country the acts as if this type of equipment is on the POET list. It is listed on the EoI and counted it the ceilings. But this commitment is only for this State party. Another state which

[30] Vehicles based on an ACV or an Armored Personnel Carrier (APC), but not intended as infantry vehicles, such as command and control vehicles, fire support teams vehicles,..
[31] CFE Treaty, article 2, para. (D).
[32] Protocol on Existing Types (see paragraphs 1.2).
[33] Decision JCG-TOI/8/99 of July 12, 1999.

has the same equipment could very well not consider it as TLE, and not count it in its numerical ceilings[34]. On the opposite, a State party can bring into service a new equipment which corresponds to the Treaty definitions without declaring it in its EoI. That is the case of the BTR-T vehicle, of which at least sixty unit are today within the Russian armed forces.

These arguments culminated with the 2004 Russian decision to withdraw from their EoI about 300 vehicles of BRM-1K[35] type, alleging that the Danish had never declared a vehicle similar (regarding the definitions of article 2) to it, the M92-ASFV.

Many State parties have fallen back to positions of administrative formalism, pushing the CFE Treaty extremely far away from the spirit which had prevailed at its creation.

4.2 "Military tourism"

The implementation of the Treaty by the inspection teams is, as one can see, extremely complex. It is thus logical that each State party has created its own verification agency bunching specialists of the issue. Over the years, the application in the field of these inspections involving the same small number of qualified military experts gave place to "*modus vivendi*" arrangements between State parties.

The Treaty provides that all the expenses of the inspectors are looked after by the inspected State party. The inspectors also carry diplomatic status. It is thus usually admitted that the inspections continue with a few days "cultural" part and that the inspectors are accommodated in hotels of high standard. These advantages overtake sometimes the inspection itself. Some State parties are known to carry out inspections a few weeks before Christmas, allowing for last-minute duty-free shopping. Some choose to inspect OOVs only in sunny areas. Others still inspect only the OOV closest to the airport.

The execution of the verification missions too often consist merely of a few copious meals interrupted with a brief count of equipments. In its everyday practice, the CFE Treaty is slowly drifting away from its original goals.

5 In conclusion

The CFE Treaty remains the "last battlefield of the Cold War", staying alive by sheer habit. The two main signatories, despite endless talks about the non-cooperation of the other in some legal part of the Treaty or its protocols, seem

[34] The case is existing, but only for certain "doubles" of M113, who are thus not accounted for in the numerical ceilings.

[35] The BRM1K is the command version of an armoured reconnaissance vehicle. This is a token withdrawal because the affected volume does not affect the compliance to its numerical ceilings by the Federation of Russia.

to be very happy with that. The "adapted" CFE Treaty seems so far away, locked behind inaccessible obstacles, that we may ask ourselves if it will ever enter into force. Furthermore, the "adapted" CFE Treaty will solve none of the problems of the present Treaty, having being drafted ten years ago.

The CFE Treaty which entered into force in 1992 was so obsolete at that time that we may see the "adapted" Treaty as the Treaty which was suitable for the situation in 1992. Today, the Treaty is inapplicable, useless and outdated. Inapplicable because its relies on a logic of no cross-border movement by CAEST, while the European military are cooperating more and more everyday, with the result of large full fledged units moving through Central Europe to drill in the large training areas freed by the former Warsaw Pact. Useless, because the trend to reduce the format of the armed forces has grown since 1999 and that now all the State parties all have substantially large "headroom" (the difference between Territorial ceiling and real holdings). Obsolete because counting the conventional armaments is no longer a guarantee of safeguard of peace in Europe.

But if this system is now obsolete in Europe, it nevertheless proved reliable in the past. We outlined earlier its interest in term of reduction of the tensions between two blocks facing one another in a military confrontation. It could prove an exportable model where its conditions are met.

There are places in the world, especially in Asia, where armed nations face each other in an atmosphere of distrust. Basking in the aura of its diplomatic success, in its legend of Cold War hero, the CFE Treaty could be used as an example to promote the installation of a similar system in those areas. Russia and China have already set up such an agreement - limited to a band of 100 kilometers on both sides of their common border - which is a copy of the CFE Treaty. The Dayton-Paris agreements which put an end to the war in Bosnia-Herzegovina also provide for a system of limitation of the armaments inspired by the CFE Treaty.

At a time when many peace-keeping operations end in what the soldiers now call a Disarmament, Demobilization, Reintegration (DDR) mission, the model of the CFE Treaty could be used to formalize a return to a peace situation after a civil war. The scenario of limitation, of reduction and verification and of information exchange has still a future, even if its interest is now somewhat limited for the European theatre.

Developing the Climate Change Regime: The Role of Verification

Larry MacFaul

1 Introduction

Global environmental problems constitute a riddle for the international community to solve. Deeply entwined in the process of trying to understand the nature of the problem and finding an effective response strategy is the need to coordinate action between states. Establishing international environmental treaties is a way of coordinating and promoting action. Ideally, these treaties solve the problem of cooperative action in transboundary environmental problems and find a way to manage shared resources effectively. Verification[1] (including all monitoring, reporting and review processes) and compliance procedures (which are intrinsically linked to the verification system) perform certain crucial functions in the formation and implementation of international environmental treaties:

- measuring and promoting overall and individual state's progress towards a treaty's goals.
- enhancing cooperation between states by demonstrating each state's level of effort and by deterring free-riding (which can include non-compliance with, or non-participation in, a treaty).

These functions are interrelated. The emphasis placed on each depends on the particular treaty's aims and provisions. An effective verification and compliance system should prevent free-riding and leave no room for doubt about parties' levels of compliance: parties must not only comply but be clearly seen to comply. If states are confident that the verification and compliance system can identify and expose non-compliance and that instances of non-compliance can be prevented or rectified they are more likely to cooperate with each other and agree and adhere to a strong treaty. The verification and compliance system can play a large role in inspiring confidence among parties in

[1] In the climate change field, the term 'verification' can also refer more specifically to the checking of greenhouse gas emissions reports for reliability.

the development and maintenance of a treaty. However, while the verification and compliance system must be able to deal effectively with compliance and participation issues, states are unlikely to support a treaty if the system appears disproportionately powerful or intrusive. The ability to measure clearly each state's level of action, in addition to helping to enhance cooperation, shows what progress is being made in reducing the environmental problem being addressed and indicates the adequacy both of parties' efforts and of the provisions in the treaty itself.

The particular characteristics of the environmental problem being faced, the goals agreed on to tackle the problem and the type of provisions, commitments and mechanisms laid down in a treaty will determine what kind of verification system is required. Ideally, such a system includes monitoring and reporting processes, a review process and compliance procedures. The monitoring and reporting processes should show comparably, transparently and accurately how states are progressing towards treaty goals and can allow parties to share experience. The review processes should ensure this information is correct and provide helpful feedback to parties. The compliance procedures should use this information to assess parties' adherence to treaty requirements and progress towards its goals and can contain several ways of promoting and enforcing compliance. An effective verification and compliance system should both reflect the monitoring capacity of the parties and also contain procedures for improving their capacity. Together, the verification and compliance system should ensure the environmental integrity of the regime. Verification and compliance procedures should be considered early in development of a regime so as to establish a rational architecture and avoid ill-fitting provisions.

This chapter examines the role of verification and compliance in the climate change regime. The chapter begins by discussing the verification and compliance systems under the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and its 1997 Kyoto Protocol. It examines progress so far and pathways towards improvement of these systems. It then discusses the role of verification and compliance in the future of the climate change regime. There are currently many different proposals for what shape future climate change action should take, ranging from maintaining the present format to using a different structure. A strong verification and compliance system, covering the overall architecture and individual parts, will serve as a vital component in the future of the climate change regime both as a means of facilitating cooperative action and of assessing the effectiveness of measures taken by parties to tackle climate change. The need to provide and maintain a strong verification and compliance system should therefore play a major part, alongside factors such as environmental effectiveness, economic efficiency and equity considerations, in determining what shape the future climate change regime should take. Verification and compliance issues must be considered early in the negotiations on the future climate change regime to allow sufficient time to implement any new systems which may be decided on.

2 Verification provisions under the United Nations Framework Convention on Climate Change

2.1 The United Nations Framework Convention on Climate Change

The ultimate goal of the UNFCCC is the stabilization of greenhouse gas[2] concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. The convention differentiates between parties in terms of the type and strength of their commitments.[3] It includes an aspirational non-binding emissions reduction aim for Annex I parties (developed countries) of jointly or individually returning to their 1990 emissions levels by 2000. The convention contains provisions relating to adaptation to impacts of climate change and also to technology transfer and financial assistance from developed countries to developing countries. It also contains provisions relating to research and systematic observation, and public involvement. The Annex I group includes both the most developed countries (Annex II parties) which are required to provide financial resources for developing countries to undertake emissions reduction activities and implement adaptation measures to the adverse effects of climate change, and countries with economies in transition (EIT parties) which are allowed some flexibility in meeting their commitments and are not required to provide financial support to developing countries. Non-Annex I parties are mainly developing countries. This group also contains a sub-group of least developed countries (LDCs) who are given special consideration under the convention. Several institutions contribute to the functioning of the convention including the Conference of Parties (COP), which is the primary decision-making body; the Subsidiary Body for Scientific and Technological Advice (SBSTA); and the Subsidiary Body for Implementation (SBI).

[2] The UNFCCC covers all greenhouse gases not covered by the 1987 Montreal Protocol to the United Nations Convention on Protection of the Ozone Layer. The focus of the monitoring and reporting processes and the Kyoto Protocol emissions reduction targets is on carbon dioxide, methane, nitrous oxide, hydrofluorcarbons, perfluorocarbons and sulphur hexafluoride. In order to promote effective policy formulation on climate change the Intergovernmental Panel on Climate Change (IPCC) provides a measurement system for comparing the potential of each greenhouse gas to contribute to global warming. The global warming potential (GWP) of each gas shows how much it contributes to global warming in relation to the reference gas, carbon dioxide, whose GWP is one.

[3] 'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, developed country parties should take the lead in combating climate change and the adverse effects thereof' (Article 3 of the UNFCCC).

2.2 The monitoring and reporting processes[4]

The convention contains provisions both for monitoring the overall progress towards the treaty's goals and individual parties' progress. Parties can also share their experiences in tackling climate change through the reporting systems. The capacity to monitor emissions varies considerably between parties. In recognition both of this and the need to establish a verification system that can accommodate the different types of commitments undertaken by parties, the convention differentiates between groups of parties in their monitoring and reporting requirements. Under the UNFCCC, Annex I parties must submit 'national communications' to the UNFCCC Secretariat every three to four years. Non-Annex I national communications are due within four years of the initial disbursement of financial resources from the Global Environment Facility (GEF) for their preparation, with the possibility of a one year extension.[5] National communications are reports detailing what action a party is taking to implement the convention.[6] Parties must follow UNFCCC guidelines, designed to assist them in meeting their commitments under the convention, when drawing up these reports. The guidelines aim at promoting the provision of consistent, transparent, comparable, accurate and complete information in order to enable a thorough review and assessment by the COP of the implementation of the convention and to monitor parties' progress towards the convention's goals. The guidelines should assist the COP in reviewing the adequacy of the commitments. Separate guidelines are provided for national communications for non-Annex I parties.[7] In addition to assisting these par-

[4] The UNFCCC also promotes climate observation and monitoring. A primary component of this is parties' contribution to the Global Climate Observing System (GCOS) of the World Meteorological Society which was set up to provide comprehensive observations required for monitoring the climate system; for detecting and attributing climate change; for assessing the impacts of climate variability and change; and for supporting research towards improved understanding, modelling and prediction of the climate system. Parties are expected to report on their actions with regard to global climate observing systems.

[5] The issue of the timing and frequency of the developing countries' national communications has proved difficult to reconcile and was only resolved in May 2005.

[6] Annex I national communications are expected to include the following material: national circumstances relevant to greenhouse gas emissions and removals; greenhouse gas inventory information; policies and measures; projections and total effect of policies and measures; vulnerability assessment, climate change impacts and adaptation measures; financial resources and transfer of technology; research and systematic observation; education, training and public awareness.

[7] Non-Annex I national communications are expected to include the following material: national circumstances; the national greenhouse gas inventory; a general description of steps taken or envisaged to implement the convention; other information considered relevant to the achievement of the objective of the convention; constraints and gaps, and related financial, technical and capacity needs.

ties in reporting under the convention and encouraging the presentation of information in a consistent, transparent, and flexible manner, non-Annex I party guidelines are intended to facilitate the presentation of information on support required for the preparation and improvement of national communications. These guidelines should also ensure that the COP has sufficient information to carry out its responsibility for assessing the implementation of the convention. The secretariat has produced a user manual to assist non-Annex I parties in their usage of the guidelines. As noted above, funding is made available to certain countries to assist in their national communications preparation.

National greenhouse gas inventories are the basis of the UNFCCC's verification system. Inventories are essential for assessing the total and individual efforts made to address climate change and progress towards meeting the ultimate goal of the convention as well as compliance under the Kyoto Protocol. They are also needed for evaluating mitigation options, assessing the effectiveness of policies and measures, making long term emissions projections and providing the basis for emissions trading. Annex I parties must annually submit to the secretariat national inventories of their greenhouse gas emissions and removals for a period covering the base year, normally 1990,[8] up to the last year but one prior to submission. Non-Annex I parties are currently required to submit inventories with their national communications to the extent that their capacities permit. Annex I inventory submissions are comprised of two parts: the Common Reporting Format (CRF), which is a standardized electronic database; and the National Inventory Report (NIR) which contains information on how the inventory was compiled. Inventories should include enough documentation and data to enable understanding of the underlying assumptions and calculations of all emissions estimates [1]. The UNFCCC provides reporting guidelines for inventory preparation to help parties meet their commitments under the convention and the protocol. These guidelines are designed to assist the parties in meeting their reporting commitments as well as to facilitate the process of considering inventories and the preparation of the technical analysis and synthesis documentation and the verification, technical assessment and expert review of the inventory information (see following section). The inventories should be transparent, consistent, comparable, complete and accurate.[9]

Under the UNFCCC guidelines parties must use the Intergovernmental Panel on Climate Change (IPCC) guidelines[10] when compiling their inventories. The IPCC guidelines contain instructions and methodologies for estimating greenhouse gas emissions and removals. Parties may use national methodologies that they consider better able to reflect national circumstances as long as these methodologies are compatible with IPCC guidelines and guidance on

[8] Certain exceptions can apply whereby parties use a different base year.
[9] UNFCCC guidelines are available on the UNFCCC website, www.unfcccc.int.
[10] IPCC guidelines are available on the IPCC website, www.ipcc.ch.

good practice and are well documented. Furthermore, parties are encouraged to develop their own methodologies, including emission factors[11] and activity data, rather than to use IPCC default methodologies which may not always be appropriate for their national contexts, as long as these methodologies are developed in a manner consistent with IPCC good practice guidance.

The inventories provide both national totals and a breakdown of emissions by sector. The sectors included are Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land-Use Change and Forestry, and Waste. Each of these sectors is sub-divided into several categories. Most emissions estimation is derived from multiplying activity data by emission factors. Direct measurement of individual emission sources is also permitted under the guidelines but is comparatively rare in this particular system.[12]

The IPCC provides instructions for quality assurance and quality control (QA/QC) procedures and uncertainty management. Quality assurance is a system of routine technical activities to measure and control the quality of the inventory as it is being developed, for example, accuracy checks on data acquisition. Quality control activities include a planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process. The IPCC guidelines note that uncertainties[13] in emissions or removals estimates vary widely between different sources and sinks and between the different greenhouse gases as well as between states reporting the same gases and sources (depending on the approach and data used and the level of detail).

The IPCC provides information on certain specific verification procedures that parties can use to check the reliability of their emissions inventories, see Table 1. This information will be of use to the inventory compilation agencies, any independent inventory review arranged by parties in order to check and

[11] The IPCC guidelines define the term emission factor as a coefficient that relates the activity data to the amount of chemical compound which is the source of later emissions. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.

[12] This is because these systems may be inappropriate for certain sources, for instance mobile sources such as cars or wide area sources in agriculture. In addition, for those sources for which direct measurement is suitable (for instance, some industry and energy sources) direct measurement systems can be costly to install (though less costly if there is a pre-existing system which only has to be modified to measure another gas). Also, the systems need to be checked against certain standard criteria. Furthermore, direct measurement is not always more accurate than emissions calculation.

[13] IPCC guidelines note that uncertainties may be caused by, among other factors, differing interpretations of source or sink categories or by the use of simplified representations with 'averaged' values, especially emission factors and related assumptions to represent characteristics of a given population. Uncertainty in socio-economic activity data and in the understanding of the basic processes leading to emissions and removals may also affect estimates.

improve its inventory and for the expert review teams (see following section). Some parties have arranged bi-lateral inventory reviews in order to enhance checks on, and improvement of, their inventories.

The IPCC verification procedures should provide inputs to improve the inventory process, build confidence in emissions estimates and trends and help improve scientific understanding related to inventories. The tools available for inventory verification at the national level include comparison with other national emissions data, direct source testing, and comparison with national scientific publications. At the international level, inter-country comparisons for the same year can be made involving comparison of activity levels and aggregated emission factors as well as comparison of emissions trends or trends in input data. Estimated uncertainties and intensity indicators can also be compared between countries. Top down and bottom up estimates can be compared. An inventory can also be compared with other independently compiled international data sets.[14] However, the data sources used by the international datasets are often not completely independent of each other or from the data set used to calculate a national inventory. The IPCC notes that some of the comparison processes do not always provide verification of the actual data but rather the reliability of the data. However, inventory reviewers could use these techniques to identify inconsistencies or areas needing more detailed verification. The IPCC also notes that the amount of time that inventory agencies can spend on these independent verification activities will depend on resources available to them and an evaluation of the value of these activities compared to others ways of improving their inventory.

Other verification techniques suggested by the IPCC include comparison with atmospheric measurements at the local, regional or global scales. This may involve local and regional atmospheric sampling, continental plumes monitoring (which can provide an indication of emissions on a broad scale), satellite observations (which can allow quasi-continuous concentration profiles for part or all of the globe), and global dynamic approaches which measure trends in time in atmospheric concentrations of particular compounds indicating changes in the global balance between sources and sinks. Comparison of inventory estimates could also be made with international scientific publications for the purpose of checking the inventory quality. Comparisons of national inventories with independent global inventories and with global or regional emission levels when part of a comprehensive analysis could be used for updating global budgets or providing feedback to inventory developers, or both. Finally, global or regional totals could be compared against atmospheric concentrations, changes in concentrations, or against isotopic signature analysis. The use of remote sensing systems and atmospheric concentrations

[14] There are several other bodies that compile international emissions datasets including the International Energy Agency (IEA); the Carbon Dioxide Information Analysis Centre (CDIAC); the Global Emissions Inventory Activity (GEIA) Centre; and the Emission Database for Global Atmospheric Research (EDGAR).

measurement in relation to emissions inventories will be discussed in greater detail in Section 4.1.

The greater the level of detail and sectoral breakdown within an inventory the clearer the indication will be of what activities or entities are producing emissions and in what quantity. Greater detail also allows greater precision in formulating methods for reducing emissions. However, the difficulty of drawing up an inventory rises according to the level of detail required. Consequently the IPCC system, being global in scope, uses a tiered structure of increasing levels of detail and allows for both simple and more complex approaches, though countries are expected to use the most detailed methods that their capacity allows. Drawing up a national inventory is a complex task that requires significant financial resources as well as strong technical and institutional capacity. The IPCC has to cater for a diverse range of countries with different institutional, political, technical, geographical and economic circumstances. Some inventory systems, in particular those of states with high levels of capacity and experience in this field, can provide greater levels of detail than are required by international reporting rules. Nevertheless, the IPCC system is effective, extensive and also has the capacity to improve and evolve over time. This multilateral approach to emissions monitoring provided for under the UNFCCC means that states' emissions estimates are comparable since they must all use IPCC or IPCC compatible methodologies. The use of comparable methodologies (coupled with the formal review processes discussed in the following section) reduces the chance of intentional or unintentional under- or over- estimation and allows confidence to grow in the regime. Moreover, the sectoral tracking of man-made emissions included in the system can be used to assess more closely the effectiveness of policies.

2.3 The review process

Both national communications and inventories are subject to a formal and extensive review process. This review process is a key factor in making the UNFCCC and Kyoto Protocol verification systems effective and robust, especially in comparison with other treaties which lack this asset. The review process should both check reports for accuracy and adherence to UNFCCC guidelines and also improve their quality and comparability.

National communications are subject to an in-depth review by an international team of experts chosen from a roster and coordinated by the secretariat. The review, usually conducted by desk-based study and a country visit, results in an in-depth review report which facilitates assessment by the COP of a party's level of implementation of commitments. These reports should also make comparison of information between parties easier. In addition, the secretariat prepares a 'compilation and synthesis report' that summarizes the most important information in parties' national communications. Non-Annex I parties' national communications are not subject to in-depth review but information from them is drawn up into a compilation and synthesis report.

Table 1. IPCC guidelines for verification of a national inventory. Source: IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IGES, Japan

Verification of a national inventory

A. Checks:

- Check for discontinuities in emission trends from base year (usually 1990) to end year.

B. Comparisons of emissions and other such features:

- Compare the Reference Approach (see IPCC guidelines) for carbon dioxide emissions from fuel combustion with other approaches.
- Compare inventory emissions estimates by source category and gas against independently compiled national estimates from international databases.
- Compare activity data against independently compiled estimates and perhaps activity data from countries with similar source categories and sectors.
- Compare (implied) emission factors for source categories and gases with independent estimates and estimates from countries with similar source categories and sectors.
- Compare sector intensity estimates of selected source categories with estimates from other countries with similar source categories and sectors. If necessary, calculate emission intensity estimates based on international statistical compendia.

C. Comparisons of uncertainties:

- Compare uncertainty estimates with those from reports of other countries and the IPCC default values.

D. On-site measurements:

- Perform direct source testing on **key source** categories, if possible.

The national inventories of Annex I parties are subject to a review process that aims to provide a technical assessment of the inventory and to check its adherence to reporting guidelines. The review should ensure that the COP has adequate and reliable information on inventories and emissions trends and should provide the COP with an objective, consistent, transparent, thorough, and comprehensive technical assessment of the quantitative and qualitative inventory information. The review process is also meant to assist Annex I parties in improving the quality of their inventories. The review process includes an initial check for completeness and correct format, the synthesis and assessment of basic inventory information across parties and a preliminary assessment of individual parties' inventories including identification of potential problem areas. Finally, there is an individual review of each inventory by international expert review teams (ERTs). As of 2003, annual review of national inventories became mandatory. The individual review can be carried out in three ways: by in-country review, by centralized review (which takes place at the UNFCCC Secretariat) or by desk review (for which the experts work from their home countries). ERTs are meant to contain sufficient expertise to be able to cover all economic sectors and membership of the teams are balanced between Annex I and non-Annex I parties. The nomination of experts by parties coupled with geographically balanced representation helps to reassure parties that the review is objective. A code of practice was adopted at the Ninth Conference of Parties (COP 9), 2003, Milan, Italy, for the treatment of confidential information in the review process. The code covers reviewers' access to, and handling by the secretariat of, confidential information. In addition, reviewers must sign an agreement concerning, among other issues, appropriate conduct during the review. The code includes reference to conduct related to the protection of confidential information. An inventory review training scheme was introduced by the secretariat in 2004 to promote broader participation from parties and increase the number of experts. New experts who have been nominated must complete training and pass an examination before they can be invited to participate in a review. Inventories, national communications, review documents and guidelines are publicly available on the UNFCCC website.

The COP itself is mandated to review the implementation of the convention and also the adequacy of convention commitments for developed countries.[15] However, the convention's verification system, while expansive, is not coupled with a rigorous compliance system.

3 Verification provisions under the Kyoto Protocol

3.1 The Kyoto Protocol

The Kyoto Protocol was adopted in order to boost action on climate change. The protocol negotiations were fraught. The political and economic stakes concerning what type of, and how much action to take, are high because the problem of climate change is highly complex and anthropogenic contributions to climate change are made throughout a state's economy. Disagreement on how to tackle the problem has pervaded efforts to coordinate action, especially regarding stronger forms of commitments. Nevertheless, negotiations ended successfully with an agreement on a clear new set of measures to tackle climate change. The protocol came into force in 2005 but has not been ratified by all parties to the UNFCCC.

The Kyoto Protocol established fixed or 'absolute' emissions targets for Annex I parties defined in terms of change from an agreed base year. Each Annex I party[16] was given a quantified emission limitation or reduction target with a view to reducing their overall emissions by at least five per cent below 1990 levels by the end of the protocol's first commitment period, which runs from 2008-2012. These targets were arrived at by negotiation between parties with no specific logical basis used to differentiate commitments [3].

Under the protocol, parties must take domestic action to meet these targets but can also use the so-called flexible mechanisms set out under the

[15] The convention also contains provisions related to the settlement of disputes concerning the interpretation or application of the convention. Appeals can be made to the International Court of Justice (ICJ), but, according to [2], since proceedings can take a long time and are confrontational states are reluctant to pursue this route in multilateral environmental agreements.

[16] The European Union, as a regional economic integration organization, was also given an overall target (as well as each member state having its own specific target).

treaty which were established in order to lower the overall costs of meeting the emissions targets, see Table 2.

Table 2. The Kyoto Protocol's flexible mechanisms

• Clean development mechanism (CDM), under which Annex I parties can implement sustainable development projects that lead to emissions reductions in non-Annex I parties and thereby earn certified emissions reductions (CERs).
• Joint implementation, under which Annex I parties can implement emissions reduction projects in other Annex I parties and earn emissions reduction units (ERUs).
• Emissions trading, which permits Annex I parties to trade emissions units assigned amount units (AAUs) (see below), removal units (RMUs), CERs and ERUs with other Annex I parties.

The protocol also contains provisions relating to other general commitments (including promoting environmentally friendly technology transfer, research, and public awareness) and minimizing impacts on developing countries. It also sets out a list of policies and measures for tackling climate change relating to actions such as enhancing energy efficiency and promoting renewable energy. Phrasing related to commitments on policies and measures is largely non-binding, reflecting parties' unwillingness to take on obligations that would impinge on their choice of methods in how to tackle climate change [3].

The protocol demanded a verification and compliance system that built on and developed the convention's system in order to cope with its wider range of measures and more specific targets. The result is a system which is both complex and thorough: complex, since it must monitor compliance with emissions reduction targets and parties' participation in the 'flexible mechanisms', and thorough (though imperfect, see Section 3.5), since it not only needs to guarantee environmental integrity but also accurately and transparently regulate a new emissions trading system. Indeed, confidence in the quality of monitoring, reporting, review processes and compliance procedures, including their ability to identify and deal with problems, is critical to the validity of trading used for environmental management and the financial viability of the commodity to be bought and sold. Furthermore, comparability of data is crucial not only for comparing parties' levels of effort and compiling consistent data, but also because trading will mix states' inventories [4].

3.2 The monitoring and reporting processes

The Kyoto Protocol specifies that Annex I parties must have in place a 'national system' for estimating greenhouse gas emissions and removals at least one year before the start of the first commitment period. The national system must conform to strict criteria. National systems comprise all institutional, legal and procedural arrangements for estimating greenhouse gas emissions and removals. Parties must also establish a national registry (an electronic database) to account for their emissions trading units (ERUs, CERs, AAUs and RMUs).[17] The secretariat will run an independent transaction log to ensure the integrity of transactions by checking them against the trading conditions set out under the protocol. Parties must include additional information on these and other matters in their national communications and their annual greenhouse gas inventories. Parties also have to facilitate calculation of their 'assigned amount' by submission of the pre-commitment period report (see below). The assigned amount is the total amount of greenhouse gases a party can emit during a commitment period. The assigned amount is calculated using the party's quantified emission limitation or reduction commitment. Parties must fulfil monitoring and reporting requirements before they are eligible to participate in the flexible mechanisms.[18] There are also extensive provisions governing the use of each of the flexible mechanisms, in particular how they should be monitored.[19] Annex I parties should also submit a report by 2006 on demonstrable progress made towards meeting their commitments up till 2005.

3.3 The compliance system

In order to promote and assess parties' adherence to their emissions reduction commitments and the reporting requirements under the Kyoto Protocol an intricate compliance system was developed. This system augments the monitoring, reporting and review processes by formally determining and addressing adherence or non-adherence to the monitoring and reporting standards and

[17] Parties must keep a minimum level of units in the registry (know as the 'commitment period reserve') to prevent them from 'over-selling'. A different registry is used for issuance and distribution of CERs.

[18] The state is eligible if: it is a party to the Kyoto Protocol; its assigned amount has been calculated and recorded; it has in place its national system; it has in place its national registry; it has submitted annually the most recent required inventory; it submits certain supplementary information on its assigned amount.

[19] CDM projects must be approved by 'designated national authorities'. Participants must prepare a project design document that includes a description of the proposed monitoring methodology and baseline. The project must then be validated by an operational entity and registered by the relevant convention body. It must be monitored and a monitoring report must be submitted to the operational entity for verification that will then certify the emissions reductions. Parties involved in joint implementation projects must inform the UNFCCC secretariat of their national guidelines and procedures for approving these projects as well as monitoring and verification procedures. In order to fast track the process joint implementation projects can take place when a host party meets only some of the eligibility requirements. In this case project participants must submit a plan to an independent body (accredited by the relevant convention body) for evaluation and have established an appropriate baseline and a monitoring plan.

emissions reduction obligations set out under the treaty. Compared with most international environmental treaties the system is particularly elaborate.

Compliance theory

The options available to promote compliance with multilateral environmental agreements (MEAs) range from management (soft) to enforcement (hard) approaches [4,5]. Some commentators advocate management approaches based on a presumption that states are willing to comply with agreements and that non-compliance stems from a lack of capacity or unintentional or uncontrollable circumstances or ambiguity in the terms of an obligation [6]. Others advocate enforcement approaches presuming that a state will not necessarily comply with an international agreement unless it is more costly for a state not to comply. They argue that if levels of compliance with MEAs appear to be high it is because of the weakness of these agreements' obligations that demand little more action than states would have carried out in their absence. When more stringent obligations are introduced, harder enforcement measures are required [7,8,9].

Management approaches which can identify and address compliance problems include national reporting and review and verification processes, consultation and negotiation, mediation and conciliation. Beyond these approaches are those involving a 'carrots and sticks' approach including financial and/or technical support and issuing warnings or cautions. Enforcement approaches include making assistance funding conditional on compliance, the suspension of rights or privileges, financial or other penalties, trade measures or other economic sanctions [4].

The optimal means of ensuring compliance is a judicious balance between the approaches which fully takes into account parties' differing obligations and capabilities. Finding the correct balance of these approaches is vital for the development and implementation of a successful regime. Different methods are needed to respond to different types and levels of non-compliance. Transparency, facilitation, encouragement, and compliance assistance should be key elements in MEAs. The Kyoto Protocol monitoring, reporting, review and compliance system provides for a range of approaches to promote compliance including both 'soft' and 'harder' approaches.

Evolution of the compliance system

The concentration of effort on compliance issues has tended to be on the Kyoto Protocol rather than on the implementation of the convention. Although the convention demands emissions reductions and also includes reporting requirements, the lack of specificity of its obligations makes assessment of its implementation difficult. In 1998, it was suggested that a multilateral consultative committee (MCC) should be formed to give advice to parties concerning their implementation of the convention. However, the COP failed to agree on the MCC's composition and size so it never came into being [10]. Thus, while the COP is mandated to review the implementation of the convention, a systematic compliance system was not established. However, the obligations established under the Kyoto Protocol necessitated a clear compliance system. The protocol text only included the outline of the treaty, the details being left to later meetings to elaborate. Negotiation of the system was often turbulent. It was designed by the Joint Working Group (JWG) on Compliance (established in 1998) which received views from parties on what the composition of the compliance system should be and also heard suggestions from representatives from the secretariats of other international institutions and conventions, as well as from two non-governmental organizations (NGOs).[20] Negotiations at COP 6 part II, mid-2001, Bonn, Germany, had resulted in agreement on several elements of the Kyoto Protocol but divisions arose over the nature and strength of the compliance regime and several technical issues which were not settled by the end of the meeting. When parties resumed talks at COP 7, late-2001, Marrakech, Morocco, the divisions existed chiefly between the European Union (EU) and the G77/China, on the one hand, and the 'umbrella group'[21] on the other. On the important issue of compliance, the USA had sided with the EU and G77/China in wanting a strong compliance system rather than with its fellow members of the umbrella group. However, when the USA pulled out of the protocol in early 2001 not only did its departure reduce support for a strong compliance system but it gave the remaining members of the umbrella group a far stronger bargaining hand than they previously had because the protocol's entry into force had become dependent on their ratification [10,11,12]. Members of the umbrella group's objections concerned, among other issues, eligibility on use of the flexible mechanisms, reporting of sink data, and use of sink credits. The ability of one party to raise a question of implementation regarding another party was also objected to by members of the umbrella group. Following the fierce negotiations over these issues, a deal was reached at the end of the meeting which allowed the 'Marrakech Accords' to be adopted. These accords provide the detailed mechanisms for how the Kyoto Protocol should work in practice.

Other international environmental regimes focus on facilitative measures in relation to compliance. For instance, the ozone layer protection regime (including the 1985 Vienna Convention for Protection of the Ozone Layer and its 1987 Montreal Protocol on Substances that Deplete the Ozone Layer) provides for technical, financial and reporting assistance, issuing cautions, and suspension of treaty rights. It is the first two of these - softer measures - that have been preferred. However, this facilitative approach has been supported

[20] The organizations were the World Trade Organization and International Labour Organization while the treaties were the 1987 Montreal Protocol and the 1979 Convention on Long-Range Transboundary Air Pollution. The two NGOs were the Centre for International Environmental Law (CIEL) and the World Wide Fund for Nature (WWF) [10].

[21] Australia, Canada, Japan, New Zealand, Norway, Russia, Ukraine and the USA.

by firmer measures, as will be discussed in Section 3.5. Within the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) an assistance based approach to non-compliance has been used. Its Implementation Committee should examine progress in all protocols and can gradually increase pressure on non-compliant parties through a 'name and shame' policy. The explicitness of this naming procedure can in part be seen as the result of parties allowing more severe language to be used because they have reached a certain level of trust with each other in the regime. Indeed, there appears to be a trend in environmental treaties towards tougher review procedures in the form of more explicit naming and shaming, and tougher language being used by environmental convention bodies [13]. It may also be characteristic of environmental treaties that parties may invoke the compliance procedures themselves, in the expectation of receiving assistance and perhaps a more lenient response if enforcement procedures are applied.

The more facilitation and assistance that is provided the better the Kyoto Protocol will function in terms of progress towards its emissions reduction goals and in fostering a more cooperative atmosphere between parties. However, these elements should be backed up by credible use of the protocol's enforcement measures.

Kyoto Protocol compliance system

The Kyoto Protocol compliance system is concerned with determining and addressing both procedural (monitoring and reporting) and substantive (emissions reduction) commitments, and for providing facilitation. At the core of the Kyoto Protocol compliance system is the Compliance Committee which consists of a facilitative branch and an enforcement branch. Each branch has 10 members elected to it by the Conference of Parties serving as the Meeting of Parties to the Kyoto Protocol (COP/MOP). Membership of the Compliance Committee is balanced between Annex I and non-Annex I parties. The facilitative branch provides advice and assistance to parties in implementing the protocol and for promoting compliance by parties with their commitments taking into account the principle of common but differentiated responsibilities and respective capabilities. The facilitative branch provides 'early-warning' of non-compliance by parties and provides advice and facilitation concerning emissions reduction commitments and monitoring and reporting requirements. It can facilitate financial and technical assistance to any party concerned. The enforcement branch determines cases of non-compliance with emissions targets, reporting requirements and eligibility to participate in the flexible mechanisms. It can apply certain 'consequences' in cases of non-compliance. The compliance system contains due process safeguards. The Committee's mechanisms are triggered when it receives 'questions of implementation',[22] either

[22] A question of implementation is a problem pertaining to language of mandatory nature in the relevant UNFCCC guidelines influencing the fulfilment of commitments.

in reports by the ERTs, or from a party with respect to itself or from any party with respect to another party as long as it has corroborating information.[23] Each branch bases its work on information from several sources: ERT reports; the party itself; a party which has submitted a question of implementation regarding another party; reports of the COP, the COP/MOP and the COP subsidiary bodies; and from the other branch. Intergovernmental organizations and NGOs may also submit factual and technical information. Each branch may seek expert advice. In addition, subject to rules relating to confidentiality, information considered by the branch should be made available to the public. However, the branch may decide of its own accord or at the request of the party concerned, not to release information until its decision has become final. Any party about which a question of implementation is raised has the opportunity to represent itself through writing and at hearings.

The scenarios in which the Compliance Committee can apply consequences and the nature of these consequences are listed below:

- When a party fails to meet the monitoring and reporting requirements it must develop a compliance action plan.
- When a party fails to meet one or more of the eligibility requirements for the flexible mechanisms it will have its eligibility suspended in accordance with the relevant provisions.[24]
- When a party exceeds its assigned amount:
  1. A number of tonnes equal to 1.3 times the amount in tonnes of excess emissions can be deducted from the party's assigned amount for the second commitment period.
  2. A compliance action plan must be developed by the party.
  3. A party's eligibility to transfer quotas can be suspended.

In addition, ERTs can apply adjustments to inventory data (including base year data) if data is unavailable or if the inventory has not been prepared in accordance with the IPCC guidelines. If the party disagrees with the ERT decision the issue will be forwarded to the Compliance Committee to resolve.

Finally, parties can appeal to the COP/MOP on a decision of the enforcement branch but only if the party believes it has been denied due process. The COP/MOP can only overturn the decision of the enforcement branch with a 2/3 majority.

Compliance assessment takes place before, during and after the commitment period. As mentioned in the previous section, parties must have their national system and registry in place before the commitment period begins and both must be checked for suitability. They must also supply data needed to calculate their assigned amount and must have submitted their most recently

[23] The secretariat cannot raise questions of implementation. This was decided in order to preserve its neutrality.

[24] An expedited procedure exists for parties to have their eligibility restored.

required inventory. Furthermore, parties must submit a pre-commitment period report to the secretariat by 2007 to demonstrate adherence to the protocol's preconditions. During the commitment period ERTs will check inventories against the UNFCCC criteria. A party may lose eligibility with respect to the flexible mechanisms during the commitment period. After the commitment period there is an additional period of 100 days during which parties can make final transactions to bring themselves into compliance. Parties must submit a report on the additional period. Compliance assessment can only take place once the ERTs have access to all the commitment period inventories. Since there is a time-lag of two years in inventory preparation, compliance assessment for the first commitment period will not take place until 2015. The consequences can then be applied in cases of non-compliance.

3.4 Compliance system problems

Although the compliance system provided for in the Marrakech Accords is regarded as particularly innovative and elaborate, it could suffer from disagreement over its legal nature; problems inherent in its structure; parties' monitoring capacity; uncertainty over the future of the protocol; and a lack of enforcement provisions of sufficient strength.

Legal nature

Parties could not reach agreement on the legal nature of the climate regime. This decision has been deferred until the first COP/MOP. Article 18 of the Kyoto Protocol states that compliance procedures and mechanisms 'entailing binding consequences shall be adopted by means of an amendment to this Protocol'. The amendment would only bind parties that ratified it. Efforts were made to get round this problem and streamline procedures relating to compliance decisions. However, the withdrawal of the USA led to the disintegration of these efforts [10]. Instead of an amendment a COP decision could be taken on the issue, but this would not necessarily make the compliance regime consequences legally binding. Alternatively, a COP/MOP decision could initially be taken and a process started for an amendment. Another option is for the binding consequences to be included in a legal instrument that establishes commitments for the post-2012 regime.

While the emissions targets themselves can be considered legally binding, the binding nature of the compliance regime is as yet unresolved. It is encouraging that parties agreed to the details of the protocol's compliance mechanisms as this indicates a serious commitment to the principle of adhering to extensive verification and compliance procedures, consequently it would seem that parties may be less likely to consider free-riding. However, it is a matter of concern that the legally binding nature of the system has provoked such controversy. A speedy resolution of the matter would set the commitment period and the run up to it on a clearer and more solid foundation. It is important the compliance system is operationalized at the first COP/MOP (28 November to 9 December 2005) considering the proximity of this meeting to the beginning of the commitment period. The facilitative branch can then provide assistance to parties and the enforcement branch can enable full use of the flexible mechanisms.[25]

Credibility

Potentially, within the current structure of the system, lies a problem relating to the likelihood that the stipulated consequences allowed for under the compliance regime will be applied when a party has exceeded its target. The credibility of the threat to apply the consequences may be weakened when these penalties would also have a negative economic effect on the states from which the members of the enforcement branch are drawn. The imposition of the first and third consequences (deduction of 1.3 times excess emissions and suspension of eligibility to make transfers, respectively) on a given party will have different effects on the economies of complying parties in terms of the quota (trading units) price and on price differences between different fossil fuels and emissions intensive products. This could, though by no means necessarily would, lead to the possibility of strategic considerations on the part of members of the enforcement branch in deciding whether to apply consequences or not. Furthermore there is the possibility that a party may withdraw from the treaty when threatened, which could have a variety of economic effects on complying parties. Suggestions have been made as to how to improve the compliance mechanisms to eliminate this possibility. For instance, as an alternative to the third consequence, if a party is found to have exceeded its allowance then part of this allowance could be transferred to other parties. This alternative serves to overcome a situation where the enforcement branch is reluctant to punish non-compliance. However, since this alternative gives all compliant parties more allowances it may make the enforcement branch too eager to punish, thus the possibility of strategic behaviour is not eliminated. Another option is to define a penalty per unit of exceeded emissions independent of quota trading. However, while the emissions deduction penalty remains there is still a possibility of strategic voting, though it may be greatly reduced [14,15]. Of course, the problem of strategic behaviour will not arise if Compliance Committee members serve in their individual capacity as they are meant to and do not take national interests into account. The selection of the candidates for the enforcement branch should therefore be scrutinized carefully to avoid 'political' appointments.

Problems with uncertainties

It has been suggested that uncertainties in emissions estimation could present difficulties for making accurate judgements over whether parties have met

[25] At the time of writing this issue is as yet unresolved.

their emissions reduction targets or whether the overall Kyoto Protocol goal has been reached [16]. The presence of uncertainties means that parties' reported emissions could be different from their actual emissions, so while a party appears to demonstrate fulfilment of commitments, its actual emissions exceed its target. The level of uncertainties in emissions trends can be about equal to (or sometimes even more than) parties' typical emissions reduction obligations. When a party's obligations are met with a margin less than the level of uncertainty, judgement of whether a party has achieved its goal would appear to be problematic. However, the compliance procedures take this problem into account: if an inventory has been approved by an ERT uncertainties no longer feature in compliance assessment. Uncertainties are also unlikely to be a divisive issue concerning the overall emissions reduction goal. That is not to say that the presence of uncertainties is not important, rather that there are procedures in place for dealing with them so that the reporting and compliance systems can work efficiently and effectively. Furthermore, uncertainties will be reduced as parties improve their inventories and will be made easier to assess when uncertainty management systems are fully implemented. It will be important to target methodological problems when improving inventories from year to year in order to minimize disputes over non-compliance. It is important to note that difficulties in assessing compliance are most likely to occur over the quality and appropriateness of methodologies used by parties in emissions estimates.

External Factors

Factors external to the structure of, and capacity in, the verification system may take their toll on its efficacy. Since the emissions reduction penalty comes into effect after the end of the first commitment period, then increasing certainty over the post-2012 regime will increase the potency of this penalty's deterrent effect - as long as this regime is compatible with the compliance procedures. However, greater uncertainty surrounding the post-2012 regime will weaken its potency. In addition, an atmosphere of resignation may pervade compliance activities if it is widely believed that there will be no available process to carry out compliance assessment after 2012. Furthermore, uncertainty over the future of the climate change regime also affects confidence in the emissions trading market.

There are, however, positive external factors. Actors such as NGOs, stakeholders and the public can, and sometimes do, play a role in reviewing and promoting compliance in international environmental agreements. Within the UNFCCC and Kyoto Protocol processes, NGOs have been particularly active both in reviewing action by states and in attempting to influence the development of the regime. As discussed above in Section 3.3 there are opportunities for NGO involvement in compliance assessment within the formal compliance system. Furthermore, NGOs may try to promote compliance with the protocol through strategies external to the formal compliance procedures. Stakeholders and public pressure can also play their part in the promotion of compliance. The transparency generated by the reporting, review and compliance procedures greatly assists these forms of compliance promotion. A state's loss of reputation and international standing from non-compliance may well affect its resolve to comply. Other external actors such as international organizations also promote action and compliance by providing assistance.

Deeper Problems

Until the uncertainty over the future of the climate change regime is gone, compliance with the treaty will to a certain extent, rely on the goodwill of parties. However, a closer analysis of the treaty reveals that goodwill may be a key factor in compliance issues regardless of the fate of the current regime: it turns out that the compliance system appears to have blunter teeth than its elaborate consequences would suggest. Listed below are inherent weaknesses in the compliance system regarding enforcement.

- Punishment is forever delayed. If the enforcement branch applies the emissions deduction penalty, a state could conceivably put off the punishment repeatedly to each subsequent commitment period: a state could fail to comply with the penalty altogether.
- If a party believes that it will fall into non-compliance in the first period, it may attempt to negotiate a weak emissions limit in the next period to make up for any penalty that is applied.
- A party could simply withdraw from the treaty, or not ratify an amendment concerning compliance procedures, or make its participation conditional on being allowed a high emissions ceiling [2,10,17].

It may be possible to defend the emissions trading system against certain levels of non-compliance by preventing trading by ineligible parties through the registry system. In this case, the party itself does not have to be relied on to consent to carrying out action following the application of a penalty by the enforcement branch. Instead, the enforcement branch denies the ineligible party's trading privileges within the regime. The credibility and viability of the market would therefore only be at risk insofar as a state decides to disregard treaty obligations altogether.

Ultimately, the compliance system in the current climate change regime lacks any way of making determined non-compliance, withdrawal and non-participation more costly for a state than complying or participating. With its current provisions the regime is reliant on the willingness of states to comply or participate to preserve the integrity of the regime. One hopes that states that become parties to a treaty intend to fulfil their commitments. It would seem better not to sign and ratify than to undermine international law by flouting an agreement [18]. If, then, non-compliance results from a lack of capacity rather than an unwillingness to comply or from an uncontrollable change in circumstances, the early warning and assistance that the facilitative branch can provide will be most apposite. Other external actors such as international organizations also promote action and compliance by providing assistance. On the other hand, it is conceivable that parties may ratify and then subsequently see an advantage in non-compliance that overrides their concerns of adhering to international law on a particular issue. If non-compliance is indeed intentional then stronger enforcement measures may be necessary. With respect to non-participation, there are currently prominent examples (USA and Australia) demonstrating the option that states have to stay outside of the protocol.

When complying with treaty obligations is, or is perceived to be costly and when states want to ensure progress towards the goal of the treaty they may attempt to deter non-compliance and non-participation by using trade measures. This may occur either externally to the regime or through the development of such measures within the regime. The next section discusses the applicability of these options to the climate change regime.

Trade measures

Although trade measures would appear to be a powerful way of readjusting incentives both in order to encourage compliance by parties and to discourage non-participation, they are not included in the tool kit of the climate change regime compliance system. However, application of trade measures to compel a state to participate or to improve compliance levels could take place outside of the current climate change regime either unilaterally or by a coalition of states.

Possible trade measures include trade bans, tariffs or border tax adjustments. Trade measures are used within some international environmental treaties to promote participation and compliance. Two examples are the Montreal Protocol and 1973 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The threat of trade measures under the Montreal Protocol appears to have played a limited role as sanctions for non-compliance and increased participation [19]. In addition, trade measures have played a role in promoting compliance in CITES. However, in these cases the use of trade measures is limited to trade in the same areas that these treaties cover. While lessons can be learned from the experience of other treaties, each environmental problem presents its own particular set of economic, political, institutional and, of course, environmental factors to manage. Trade measures may be more suitable both in practical terms and in terms of creating incentives for certain treaties rather than others. Moreover, consideration of the use of trade measures must be set against the backdrop of the World Trade Organization (WTO). The WTO lays down certain principles relating to free trade that trade measures may impinge on. However, it also contains exceptions which permit trade measures on environmental grounds in certain cases.

Multilaterally coordinated trade measures, which are mandated or authorized by international agreements, are less vulnerable to challenge under international trade rules than unilateral action, particularly if the target state is a party to the agreement in question [20]. Indeed, trade measures in multilateral environmental agreements are unlikely to be challenged internationally. One reason for this is the undesirability of calling into question a treaty signed by many states [19]. It should also be noted that trade measures are asymmetrically available because their effectiveness depends on the size and diversity of the enforcer's and target state's economy and therefore they favour states that are more powerful [20]. In order for the threat to use trade measures to be credible it must either originate from a powerful state or a coalition of states with approximately the same incentives. Furthermore, when a powerful state believes that unilateral use of trade measures is in its interest, the threat to use such measures may be more credible than action involving a coalition since it does not depend on the consent of other countries. In a situation where trade measures are applied to increase participation or improve compliance in the Kyoto Protocol, the way in which the state applying the trade measures and its target are treated under international law would depend on whether the enforcer and target state are parties to either the WTO or the Kyoto Protocol or both or neither. Non-members of the WTO will receive the least legal protection while a non-complier with the Kyoto Protocol would be more shielded than a non-party to the Kyoto Protocol [20]. Hovi [21] argues that measures applied without the mandate of an international regime can enhance the deterrent effect of a regime but it may also operate to undermine the regime's legitimacy. Greater cooperation and coordination between international regimes, and in particular, between the climate change regime and the WTO could mitigate potential conflict between them.

There is likely to be growing debate in the international community over the use of external or internal trade measures to promote participation or compliance. There are already murmurs at the international level of a move towards the use, or at least threat to use, trade measures against non-parties to the Kyoto Protocol.[26] Such murmurs may grow since there is no other

[26] For instance, a Member of the European Parliament (MEP) recently argued that by refusing to ratify the Kyoto Protocol the USA is shielding its exporters from the costs of averting climate change, effectively handing them a state subsidy. The MEP called on the European Commission (EC) to raise the issue at the World Trade Organization (WTO) at the earliest opportunity and to demand authorisation to impose countervailing duties or border taxes on USA imports into the European Union (EU). However, the EC said it currently had no intention of imposing trade measures or raising trade distorting effects of Kyoto Protocol compliance at the WTO. On the other hand, the European Parliament Environment Committee in a recent draft motion for a resolution included a call for participants in the climate change talks held in May 2005 to explore the scope for imposition of WTO compatible trade sanctions against non-Parties to the Kyoto Protocol. Following this, the European Parliament adopted a resolution

equally powerful recourse currently provided for under the treaty. However, external measures for this purpose or to discourage non-compliance could lead to unintended consequences, such as a harder anti-treaty stance, being adopted. In particular, it is conceivable that such measures could weaken domestic action on climate change in non-participating countries which would in turn reduce the likelihood of the state participating in international action. Nevertheless, measures kept as a distant threat may serve to demonstrate the seriousness with which participating states take the issue and provide them with a tool to offset any competitive advantage enjoyed by producers in states which do not have emissions constraints.

While parties were previously reluctant to introduce stronger compliance measures into the regime that does not mean that they will remain so. Non-participation in the Kyoto Protocol is currently the primary area of concern for the international community. However, once the first commitment period is underway compliance problems may also cause difficulties. This could in turn lead to graver non-participation issues. It is conceivable that some states may consider it desirable, either due to their perception of the gravity of the climate change problem or for economic reasons, or both, for the future climate change regime to have more stringent penalties than it is currently equipped with to ensure that withdrawal or persistence in non-compliance is not in a party's interest. However, while trade measures may meet with success, overuse of such penalties could be damaging to the maintenance of a cooperative atmosphere within the regime by creating an antagonistic stance between states. Furthermore, incorporation of trade measures into the regime could be problematic. The high economic and political stakes in the climate change regime and the complexity of both the problem and breadth of action that must be taken to solve it coupled with the large number of types of product that could be controlled would require agreement on a particularly sophisticated and powerful sanction system to resolve the compliance and participation problem [4].[27] The difficulties associated with using trade measures heighten the value of facilitation in promoting compliance.

which included a call on the EC to take into account in any cost-benefit analyses of climate change policies the possibility to adopt border adjustment measures on trade in order to offset any competitive advantage producers in industrialized countries without carbon constraints might have [22,23,24].

[27] Barrett [17], for his part, argues that trade measures are unsuitable for enforcing the Kyoto Protocol and that the Montreal Protocol should not be seen as a precedent for the climate regime in this respect. According to Barrett, the Montreal Protocol is much easier for parties to implement and comply with and the adverse impacts from ozone depletion are more clearly perceived and the benefit-cost ratio of action in the Montreal Protocol is much higher than that of the climate change regime, consequently parties are more likely to participate and comply. Barrett further argues that sufficiently severe trade measures in the Kyoto Protocol are not credible, border tax adjustments impractical or ineffective and they may expose a tension between liberalized trade and environmental protection.

It should be noted that financial penalties and a compliance fund were considered as a means of preventing, or finding a remedy to, non-compliance [10]. However, without any stronger means of enforcement, these procedures would meet the same difficulties in terms of potential compliance avoidance by parties, as exist in the present compliance system.

Finally, it should be noted that a particularly challenging situation could arise concerning the application of the 1.3 emissions deduction penalty in the case of non-compliance by a party that is severely struggling to meet its target due to unavoidable factors (in other words, unintentionally) and when facilitation measures are proving to be insufficient.

4 Progress so far and improvement pathways

The current climate change verification system as described above is the result of more than a decade of intense negotiation, technical development and institutional capacity building within the UNFCCC, Kyoto Protocol and IPCC processes. The system, constantly evolving, forms the backbone of both the convention and the protocol.

Monitoring, reporting and reviewing the greenhouse gases and sectors under the Kyoto Protocol are formidable tasks. The level of difficulty in carrying out these tasks varies considerably between gases and sectors. Certain sectors, such as Land-Use, Land-Use Change and Forestry (LULUCF),[28] are particularly difficult to monitor accurately. However, difficulties in collecting activity data and use of appropriate emission factors affects the whole inventory compilation process. Nonetheless, Annex I parties have steadily improved both their annual inventories and also national communications with respect to the quality and timeliness of submissions. Timeliness of submission is a key factor in the verification system as delays can hinder the assessment of implementation and compliance.

Many Annex I parties' recent inventory submissions are of good quality. They are more complete than former ones were, both in terms of the explanations supporting submissions and the number of years for which estimates are available [25]. Furthermore, the number of parties making late submissions has decreased substantially. Parties have gained experience in running their national systems, though several still have some way to go in their development. Setting up and running national systems for effective national inventories is a complex process requiring a considerable amount of expertise and resources. The composition of, and arrangements for, each party's national system differ widely, based on factors such as the nature of its economy, the structure and size of its bureaucracy and the way in which political and bureaucratic

[28] Although earlier IPCC guidelines refer to Land-Use Change and Forestry, the term Land-Use, Land-Use Change and Forestry has now become the usual title for this sector.

authority is devolved within the state. Types of entities involved in preparing an inventory can include government departments and agencies and, in some cases, research facilities and private entities as well. The primary factors determining the difference in the levels of development between parties are the degree of experience in emissions monitoring a party has had, how well resourced and coordinated the relevant institutions are and the level of technical capacity and experience that personnel have. Some parties had a head start in this field as a result of previous domestic or regional monitoring activities.

The national systems and inventories of EIT parties tend to be less developed than those of other Annex I parties but have also improved greatly in recent years. However, they often require institutional improvements and sometimes lack a complete time series of data. Problems with completeness, transparency and the need to establish QA/QC procedures are also present. Furthermore, base year data[29] for some of these parties are currently deficient. Capacity building assistance would help to improve their inventories. In particular, they need greater technical expertise in personnel, institutional strengthening, and greater financial resources. While Annex II parties' national systems are more developed there is still room for improvement. Again, transparency is a principal problem area and the need to explain choice of methodologies when the methodologies differ from those of the IPCC and the use of emission factors. Implementation of QA/QC procedures and quantitative uncertainty analysis needs to be improved in varying degrees by all Annex I parties. With regard to inventory improvement, the degree to which Annex I parties specify clear improvement plans and implement their improvement plans or the ERT recommendations varies [26].

Inventory preparation can be an arduous task for non-Annex I parties. Inventory compilation problems lie in the unavailability, inaccessibility and/or quality of data in Energy, Agriculture, and Land-Use Change and Forestry sectors as well as the lack of disaggregated data required to apply the IPCC methodology. Data on land use and forest cover are often out of date. Problems with the activity data can result from inadequate data collection and or management systems. These parties need stronger institutional capacity and coordination for collection, archiving and management of data for preparing the inventory and for the systematization/standardization of activity data. Many parties expressed the need to improve and update their inventories but would require financial and technical assistance to carry this out. Almost all these parties received external support in preparing their inventories [27,28]. Herold [29] identifies several key problems for non-Annex I inventory preparation: the lack of a continuous inventory system resulting from inventory teams only working temporarily at a project basis; non-availability of activity data collected on a continuous basis in many sectors; lack of information on methods and data sources used (posing problems for time-series consistency if teams change and if the national communication itself does not provide

[29] Problems with base year data make calculation of assigned amounts difficult.

adequate guiding information); and the lack of individual review for these parties which means there is no targeted feedback for them to use to improve their inventories. However, Herold [29] also notes that non-Annex I participation in the ERTs and the ERT training programme will increase capacity for inventory preparation in those experts' home countries.

Indeed, the review processes provide a powerful means of improving the quality of emissions monitoring for all parties through the feedback from, and experience gained by, experts. However, their effectiveness is hampered by the large quantities of data and methodologies they have to examine in a limited time-span [30]. The more capacity that can be built into the roster of experts (through initiatives such as the training scheme) and other measures designed to strengthen the review process will go far to improve the quality of monitoring and reporting by parties as well as promoting more accurate review reports.

Monitoring and reporting standards should increase over time as experience and capacity grows. Experience from other air pollution conventions shows that an institutional warm-up period is needed. Reporting under CLRTAP was initially lacklustre but improved over time, partly as a result of the establishment of an Implementation Committee which focused on this problem. So too with the ozone regime which also suffered from teething troubles in its reporting system but later experienced steady improvement. In this case the ozone secretariat has assisted considerably in improving the standard of reporting [13]. It is clear that assistance and facilitation provided or coordinated by convention bodies or other organizations catalyzes the process of improvement. In addition to the UNFCCC review process, workshops are a source of assistance to Annex I parties. When the Compliance Committee begins its work, the facilitative branch can start to assist parties in their monitoring and reporting requirements leading up to the first commitment period. The UNFCCC Secretariat facilitates the provision of assistance to non-Annex I parties, including organization of workshops and collaboration with bilateral or multilateral support programmes. These parties should also receive, as mentioned in Section 2.2, financial assistance towards meeting their reporting commitments. In addition, a consultative group of experts (CGE), established by the COP, gives advice to non-Annex I parties on ways to improve their national communications. These efforts need to be maintained and expanded if a truly comprehensive and effective global monitoring system is to be established.

Annex I national communications have improved with each round of submissions. In particular, reporting on policies and measures has expanded, though problems relating to transparency, terminology and categorisation of information linger. Timing of national communications submission has also improved. It is difficult to assess progress in non-Annex I national communications since few parties have submitted their second report. However, the fact that a large number have submitted their first is encouraging.

National registries are presently under development. Parties are again at different levels of development. However, consultations held before UNFCCC meetings have shown that cooperation and the exchange of information and experience can help both states which are advanced in registry development and those that are in the early stages. The secretariat plays a primary role in facilitating registry development.

4.1 Remote sensing systems

A state's monitoring system can be improved in many ways, several of which have been outlined above. Remote sensing systems can offer an additional way to improve emissions monitoring.

Much of the activity in remote sensing related to climate change is directed towards earth observations involving the monitoring of many different indicators, for instance sea level rise and ice cover. However, remote sensing can also provide much needed information for the LULUCF sector. These systems can be used to identify land-use and land cover in 1990 to assist in base-line calculations and can be used to monitor afforestation, reforestation and deforestation (ARD) activities in the first commitment period and thereafter [31]. Rosenqvist et al [32] identify the provision of systematic observations of relevant land cover; support to the establishment of carbon stock baselines; detection and spatial quantification of change in land cover; quantification of above ground vegetation biomass stocks and associated changes; and mapping and monitoring of sources of anthropogenic methane as areas where remote sensing can be applied. Remote sensing data already provides some input to national inventory compilation for this sector and is permitted by the IPCC. Although the capacity to provide data for 1990 was limited there has since been a significant increase in capacity and this trend is likely to continue. Recently, there has been a surge in the number of earth observation activities geared towards specific end-uses, in particular (but not exclusively), in the number of satellites. Major efforts to coordinate earth observation monitoring systems have recently been launched which will further improve capacity in this field. In particular, the Group on Earth Observation (GEO) has drawn up a ten-year implementation plan for a Global Earth Observation System of Systems (GEOSS) which will coordinate land-, sea-, air- and space-based instruments.[30] Satellite data has the advantage of being independent, repeatable and comparable. However there is a need for states to agree on appropriate methodologies and standardization of practices to convert data into the required parameters [31]. This process has begun under the auspices of GEOSS.

While states can use earth observation systems to build up national activity data and to verify their own carbon stock estimate, formal, indepen-

[30] At COP 9, December 2005, Buenos Aires, a decision was taken calling for GCOS to collaborate with the ad hoc Group on Earth Observations to implement a plan for global climate observations. GCOS involves the use of many different types of land-, sea-, air- and space-based monitoring instruments.

dent verification of states' inventories using satellite data would be difficult to establish. Some states may feel this is too great an infringement on state sovereignty. There would also be several legal issues concerning use of remote sensing that would need to be examined. Remote sensing of this kind should be regarded as a support mechanism for the UNFCCC and Kyoto Protocol, at least for the moment [31,32].

Remote sensing can also be used for measuring atmospheric concentrations of emissions. There must be sufficient knowledge about the atmospheric transport of gases and about sink and loss processes in order to run models to estimate the locations and amounts of emissions. Given the difficulties associated with drawing up emissions inventories and reviewing them, it is worthwhile considering to what extent remote sensing, which can provide independent and objective measurements, can augment or could even replace the inventory compilation and compliance system.

Measuring atmospheric concentrations of emissions suffers from its own set of uncertainties which include complications caused by natural emissions and loss processes. Emissions of carbon dioxide, methane and nitrous oxide have a high level of uncertainty, especially regarding carbon dioxide from LULUCF activities and nitrous oxide from soils. On the other hand, uncertainties are lower for halogenated gases that do not have natural sources and have long lifespans in the atmosphere.

At the national level, the use of inverse modelling to make estimates based on measurements of atmospheric concentrations and numerical transport modelling suffers from several obstacles including insufficient measurement networks, inaccurate measurement techniques, lack of knowledge of natural sources and sinks, insufficient quality of meteorological data, and coarse representation of key transport processes in transport models. These obstacles give rise to uncertainties and a level of geographical resolution in the calculated distribution of emissions that prevent inverse modelling from being used either to replace inventories or for compliance assessment on its own [16,30]. Apart from these technical problems, there would be considerable difficulties - political, logistical, methodological and organizational - in agreeing on and establishing an atmospheric monitoring system which could, on its own, monitor emissions and be used to assess parties' compliance. The same is true for a regional emissions trading scheme. However, even though remote sensing systems cannot replace inventories or be used on their own for compliance assessment, they can perform verification of emissions in certain regions on a coarse spatial scale. Unrecognised emissions sources could also be identified using these systems. In the future, verification of emissions could take place on an increasingly finer resolution. However, the obstacles referred to above need to be overcome. In particular, more ground-based stations are needed as well as better network techniques and improved modelling. These stations can be used in combination with operations involving aircraft equipped with measuring instruments and satellite data [16,30].

The measurement of atmospheric concentrations at the global level is simpler than at the regional or national level since gas transport uncertainties are not an influencing factor. Remote sensing systems could therefore be used for assessing the overall effectiveness of the Kyoto Protocol regime as well as overall levels of implementation. These systems could consequently serve as a tool to support decision-making in negotiations over the regime's adequacy. If a specific atmospheric concentration level is set as a target in future climate negotiations such systems could be used to help determine both whether parties as a whole were on course to meeting this objective and, at the end of a specified time-period, whether the objective had been met. Remote sensing data of this type could also be used for exposing deficiencies in the reporting procedures [16,30].

The international community stands at a cross roads over coordinated action on climate change. There is a lively, wide-ranging debate over the future of the climate change regime among governments, research institutes, NGOs, and the business sector. The chief questions are: to what extent should the Kyoto Protocol format be kept and what would be the consequences in each different possible regime scenario? There are many different proposals on what form the future regime should take. The following sections examine some of the more prominent proposals, focusing on verification and compliance issues.

5 Verification and the future of the climate change regime

The Kyoto Protocol is sometimes criticised as having little environmental effect and for not involving developing countries in emissions reduction commitments. However, it should be noted that, first, the Kyoto Protocol was designed to be an iterative process: the 2008-2012 commitment period is meant to be only the first of many, during which commitments could be deepened (made more stringent). Second, UNFCCC Article 3 says that 'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.' The Kyoto Protocol reflects the requirement that developed countries should take the lead. This feature does not prevent other countries gradually participating more substantially according to the principle of common but differentiated responsibility and taking on suitable types of obligations when they are ready.

There have been many different proposals drawn up regarding the post-2012 period, ranging from keeping all the elements of the Kyoto Protocol to introducing a different structure. The key aim is to broaden (in terms of numbers of participating countries) and deepen the regime. Proposals typically attempt to address, in varying degrees, concerns related to, environmental effectiveness, economic efficiency, equity, acceptability and operationality.

Negotiators have so far followed the principle that mobilizing international efforts to tackle climate change requires absolute emissions reduction commitments regulated by a sound verification system. Different types of international agreement with different obligations would require verification and compliance systems tailored to their specific needs. Assessment is needed both of the role verification and compliance would play in the overall structure of a particular regime and how each specific instrument under it could be successfully monitored.

Innovation and developments in the business world will be key drivers of emissions reductions. A unifying theme binds many companies that are prepared to engage in action on climate change, namely a desire for certainty in the future structure of the climate change regime and homogeneity in regulatory and market structures so that they can make appropriate long-term investment plans.[31] The sooner consensus can be reached on an effective post-2012 climate change regime, the more stable the carbon market will be and the more time the international community will have for developing and implementing any new structures or elements in the regime.

The following sections do not give a definitive answer to the question of what the future regime or verification system should look like. Instead, they seek to shed light on what the verification issues involved in each proposal are and suggest what the preferable format might be. Other costs and benefits of the proposals will only be outlined briefly here.

5.1 Future climate change regime proposals

Proposals for the climate change regime usually consider one or both of the following elements depending on how broad their scope is: types of commitments and/or participation and differentiation criteria.

A long-term target?

The UNFCCC aims for stabilization of greenhouse gas concentrations at a level that prevents dangerous climate change occurring. However, it does not

[31] It should be noted that certain initiatives have recently been developed in response to the need for corporate greenhouse gas emissions reporting. These include the Greenhouse Gas Protocol of the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) and a new International Organization for Standardization (ISO) standard on greenhouse gas accounting and verification. In addition, domestic and regional emissions trading schemes require detailed emissions accounting and reporting by companies and verification of the reports.

specify what this concentration level should be. Nor does the Kyoto Protocol consider a long-term target. Indeed, there is currently no clear long-term target agreed on by the international community.

On the one hand, setting such a target could have many benefits. It might stimulate international negotiations. It would guide efforts and facilitate measurement and assessment of progress and facilitate evaluation of how much action is required. By setting a target the risks of climate change may be addressed more effectively. By providing a clear signal to markets, businesses would be given confidence and investment in clean technology could be stimulated. Finally, it could promote public awareness and participation. On the other hand, achieving international consensus on a long-term target could be difficult since opinions on many aspects of the climate change problem and perceptions of risk differ widely, as do states' national priorities. Attempts to negotiate such a target could conceivably stall negotiations and lead to inaction.

There are several different indicators that could be used to establish a long-term target including emissions, concentrations, radiative forcing, temperature levels, or impacts. Each indicator has its own set of advantages and disadvantages. Alternatives to internationally negotiated targets include hedging strategies or an informal target. Some analysts as well as several governments have proposed various targets using various indicators. In the absence of an internationally negotiated target it is possible that a target proposed by influential states could gradually become a guide for action [33].[32]

Types of target[33]

There are several different types of emissions targets. Each different type of target has its own benefits and costs. Fixed targets, such as those found in the Kyoto Protocol, allow for easier monitoring and compliance assessment. Their fixed nature provides greater certainty on emissions levels but may also result in greater cost uncertainty. Another option is for states to use dynamic targets, that is, targets indexed to a variable. Indexed targets may provide more cost certainty but with less certainty on emissions levels. Intensity targets, defined as a ratio of greenhouse gas emissions to gross domestic product (GDP), are a form of indexed target.[34] Targets of this type may present greater monitoring

[32] The EU has suggested a target of limiting global average temperature increase 2°C above pre-industrial levels and outlined the likelihood of meeting that target at various concentration levels [34,35].

[33] This section is based on Philibert and Pershing [36]; Aldy et al [37]; Philibert et al [38].

[34] Dudek and Golub [39] argue that intensity targets do not necessarily provide greater certainty about costs. They also argue intensity targets may raise the costs associated with a given emission level by making it harder to implement emissions trading, and finally that the introduction of variables such as gross domestic product (GDP) into the negotiations could potentially stall them.

and compliance problems than fixed targets since two variables have to be monitored rather than just one. Furthermore, measurement of GDP can be controversial and difficult in some developing countries [3,38]. Finally, while dynamic targets appear to be compatible with emissions trading they are unlikely to prove as simple as trading with fixed targets. Alternatively, a price cap could be used on a quantitative target - where supplementary permits are available in unlimited quantity at a fixed price. With this type of target high cost certainty is achieved but at the expense of certainty on emissions levels. Emissions trading may also be difficult to implement with this system. Another option would be to use a no-lose target. A no-lose target means that a state is able to sell onto an emissions trading scheme if its emissions are below a given target level but would not incur any penalties if its emissions go above that target.[35] Yet another option is the use of dual targets where states have two targets, one lower 'selling' target under which emissions units could be sold and one 'compliance' or 'buying' target above which target emissions units must be bought. There is a 'safe zone' between the two targets where no penalty applies but where a party cannot sell units. Dual targets can be applied to fixed or dynamic targets [40].

Alternatively, economic sectoral targets could be established and could include any of the quantitative instruments outlined above. While these kinds of targets can ease some competitiveness concerns they may raise others in their place. States also lose the flexibility to choose where to make emissions reductions. A sectoral approach raises several questions regarding monitoring, reporting, review and compliance procedures. If the sectoral targets were mandatory, national governments would have to be involved in order to ensure that targets were complied with in their own country and that data could be collected and assessed for veracity. CDM-style sectoral target proposals may present accounting and compliance assessment difficulties if emissions reductions are specifically linked to policy action.

Alternatives to targets

While the target-based approach is the focus of current efforts to tackle climate change, it is not the only option. One alternative is a 'policies and measures' format in which states could agree to implement certain policies in a 'pledge and review' system. However, even with a review system in place it may be difficult to compare states' efforts in this type of scheme. Technology agreements are another option. Such agreements face a number of potential problems related to technology choice and capture, international coordination problems linked with competitiveness concerns, negotiating complexity due to the vast number of different eligible technologies, and finally, inconsistency with market economics [3]. Indeed, technology agreements may be more costly than

[35] The emissions trading scheme would also have to involve states (developed countries) with firm targets in order to ensure there are buyers.

quantity-based or market-based instruments [38] and, on their own, may fail to stimulate the global market sufficiently rapidly [41]; see also [17]. A target-based approach is instead needed to galvanise innovation, development, and dispersion. The complexity of monitoring a technology agreement would depend on the number and type of industries or products under consideration and the number and type of standards agreed to. Technology agreements and 'policies and measures' approaches could, however, sit within a wider climate change regime framework. Other options include research and development commitments and internationally harmonized carbon taxes.

Emissions reduction targets and their alternatives vary in terms of their economic and environmental predictability and outcome. However, the degree to which these targets and the alternatives can be monitored and accounted for, and their suitability for compliance assessment also varies. There is currently a wide divergence in the level of states' capabilities to monitor and report emissions. A state must have sufficient capacity to monitor and report emissions accurately when taking on a target in order make compliance assessment and emissions trading possible and ensure the environmental integrity of the regime. Any other variables/indicators used must also be monitored and accounted for accurately. There must be effective international structures and processes in place to manage and regulate use of these targets.

It will be crucial to incorporate an assessment of the operationality of these proposals and an evaluation of the related implementation issues into the debate on the future of the climate change regime as early as possible so as to establish a rational and effective structure. Some targets may be technically more complex to negotiate than others but at the same time be more acceptable to certain parties. The need to tackle climate change based on the principle of common but differentiated responsibilities and respective capabilities means that industrialized parties should take the lead and accept and meet strong emissions targets while non-industrialized parties could gradually take on stronger obligations or targets as they develop.

Differentiation

If the climate change regime is to secure broad participation it must be seen to be fair. There are several different concepts of equity in relation to the climate change regime. These include responsibility for the problem; equal entitlements; capacity to act; basic needs fulfilment; comparability of effort; and consideration of future generations [37]. Differentiation of action between countries could be based on any one or several of these equity principles, and use a variety of indicators, for instance per capita GDP and per capita emissions, to order them into groups. Commitments or benefits which are appropriate to each group's characteristics and level of development can then be chosen and could include many of the above targets or alternatives. The provision or receipt of financial and technical assistance should also be included. Countries could move from one group to another by meeting certain economic and developmental graduation criteria. The criteria could include a specific level of per capita GDP or per capita emissions.

The UNFCCC and Kyoto Protocol differentiate between Annex II, Annex I and non-Annex I parties. Each group has its own particular set of obligations. However, as suggested above, it is possible to devise more elaborate criteria which would differentiate more subtly between parties. A staged approach offers a framework in which there can be many variants in altering stages, types and strength of target and participation thresholds. One such approach is the multi-stage proposal which provides for increasing participation of countries in different stages with stage-specific obligations. It offers an approach using stages of progressively stronger types of commitments for groups of parties. The differentiation criteria could be based on emissions per capita or another indicator such as GDP per capita. Countries could graduate from one stage to the next based on emissions per capita, GDP per capita or other indicators [42,43,44]. Another staged approach is the 'South-North Dialogue' in which Ott et al [45] suggest that states could be classed as newly industrialized countries, rapidly industrializing countries, other developing countries, least developed countries, and Annex I and Annex II. Each different group would have its own responsibilities, commitments and/or benefits. Differentiation between countries and for determining commitments would be based on a country's responsibility (measured from the year 1990 to 2000), capability (determined using GDP per capita and the Human Development Index) and the potential to mitigate (determined using emissions intensity, per capita emissions and emissions growth rate). Countries graduate when they pass over the threshold of each particular stage's criteria.

An alternative approach is the 'triptych' proposal which is sector and technology oriented and calculates quantified emission limitation objectives. It establishes different burden-sharing rules for different economic sectors: convergence of per capita emissions in the domestic sector, efficiency for energy intensive industry and carbon intensity targets for the power generation sector. Objectives can be adjusted to suit desired levels of carbon dioxide concentrations. National targets are calculated by adding together the sectoral targets. Compliance assessment is based on the national rather than sectoral targets. This approach is intended to reflect the concerns of equity, needs and circumstances of developing countries, cost effectiveness and sustainable development [46].[36] However, this system would be highly complex. Another proposal is 'contraction and convergence' [47]. This proposal establishes a global trajectory towards a specific concentration level of carbon dioxide. Under this proposal, all countries agree an annually reviewable target and then work out the rate at which emissions must contract in order to reach it. Allocations of carbon dioxide converge by a specific date from current emissions to allowances that are proportional to national populations (equal per capita

[36] The EU used a triptych approach to work out its burden sharing agreement of greenhouse gases.

emissions). The proposal is based on the principle of equal per capita emissions and is simple but does not specifically take national circumstances into account.[37]

The novel proposals for the future of the climate change regime vary in terms of complexity and operationality and their likelihood of being agreed on. A staged approach could turn out to be a moderately complex system. Many decisions on participation thresholds and on differing types and stringency of commitments would have to be taken. However, such an approach, which involves different types and stringency of obligation selected according to fairness and capability, and which allows for gradual participation of countries, would appear to be the preferable format since it may be the most likely to result in agreement among states [44]. This approach is compatible with the Kyoto Protocol in terms of reporting and mechanisms. Of course, in such an approach industrialized states have to take the lead by accepting and meeting strong emissions targets.

As noted above, in order to take on targets states should be able to monitor and report emissions accurately and any other variables/indicators used must also be monitored and accounted for accurately. Proposals with new graduation, differentiation and allocation schemes which include different types of obligation and target would have to ensure that each state in each stage or group meets an agreed standard of monitoring and reporting. This will make compliance assessment and emissions trading possible and ensure the environmental integrity of the regime. If, in addition to targets, other approaches are included in the regime, consideration will have to be given as to how they would integrate with the verification system.

Some of the indicators that could be used in these proposals, whether related to differentiation or certain types of target, may be contentious. The complexities involved in establishing a transparent and robust international system will increase with the number of indicators and types of target used and the degree to which they are measurable and contestable. The capacity to successfully implement and manage these systems would have to be rapidly built up in all states, especially in developing countries with financial and technical assistance from developed countries. New international monitoring, reporting, review and compliance structures may need to be developed and implemented to successfully manage and regulate these systems. The systems already in place under the UNFCCC and Kyoto Protocol can be built on to facilitate this process. However, while this task may be challenging, it will be worth the effort if the proposals are accepted by the parties and make action suitable and fair for each state and lead to broader participation and deeper emissions reductions.

---

[37] A similar approach is 'Common but Differentiated Convergence' (see [43].

6 Conclusion

An effective verification and compliance system is crucial for facilitating cooperative action between states and measuring and promoting progress towards treaty goals. The current UNFCCC and Kyoto Protocol verification and compliance system includes extensive monitoring, reporting, formalized review processes and compliance procedures. It is a thorough system which should be maintained and continuously improved.

The challenge facing the international community is to develop a climate change regime for the post-2012 period that is environmentally effective, economically efficient, equitable and workable. Participation needs to be broadened and commitments deepened. There are many proposals facing the international community for the post-2012 period, ranging from keeping all the elements of the Kyoto Protocol to introducing a different structure. The post-2012 structure could build on the strengths of the UNFCCC and Kyoto Protocol. These strengths include the verification and compliance system.

Since effective verification and compliance systems measure progress and promote action and cooperation as well as build confidence, there must be careful evaluation of their level of applicability to each proposal for the post-2012 regime.

The development and implementation of the current climate change regime verification and compliance system has already taken several years and the process is ongoing. Discussions and decisions over appropriate future structures, including new types of target and differentiation, allocation, and graduation procedures will have to take into account the time it would take to develop and implement verification and compliance systems, which could be considerable. Early consideration is required of what will be needed to develop the appropriate international systems to manage these processes. Early consideration is also required of the capacity of states to fulfil new monitoring and reporting requirements. The institutional, technical and resource base of all states will need to be carefully assessed when weighing up which approaches and particular elements are feasible and effective and what needs to be done in order to successfully and swiftly implement them.

Acknowledgements

I would like to thank Josef Aschbacher, Jan Corfee-Morlot and Cédric Philibert for their valuable comments on this chapter and all those who helped with the research. The views expressed herein are, of course, the author's, with whom responsibility for any errors or shortcomings rests.

References

1. UNFCCC (2003a): Counting emissions and removals: greenhouse gas inventories under the UNFCCC.

2. Wiser, G., and D. Goldberg (2000): Restoring the Balance: Using Remedial Measures to Avoid and Cure Non-Compliance under the Kyoto Protocol. Report prepared for the World Wildlife Fund.
3. Grubb, M. (2004) Kyoto and the Future of International Climate Change Responses: From Here to Where? In: *International Review for Environmental Strategies (2004)*, Vol. 5, No. 1. pp. 15-38, Institute for Global Environmental Strategies (IGES), Japan.
4. Corfee Morlot, J. (1998): Ensuring compliance with a global climate change agreement, *Organization for Economic Co-operation and Development (OECD) Information Paper*, ENV/EPOC(98)5/REV1.
5. Crossen, T. (2003): Multilateral Environmental Agreements and the Compliance Continuum, Berkley Electronic Press, www.law.bepress.com/expresso/eps/36.
6. Chayes, A. and A. Chayes (1995): *The New Sovereignty: Compliance with international regulatory agreements*, Harvard University Press, Cambridge and London.
7. Raustiala, K. and D.G. Victor (1998): Conclusions. In: *Victor, D.G., Raustiala, K. and E.B. Skolnikoff (eds) (1998): The Implementation and Effectiveness of International Environmental Commitments*: Theory and Practice, MIT Press, Cambridge.
8. Downs, G., Rocke, D. and P. Barsoom (1996): Is the good news about compliance good news about cooperation? *International Organization 50.*
9. Victor, D. (1999): Enforcing international law: implications for an effective global warming regime. Duke Environmental Law and Policy 10.
10. Wang, X and G. Wiser (2002): The Implementation and Compliance Regimes under the Climate Change Convention and its Kyoto Protocol. RECIEL 11 (2) 2002. Blackwell Publishers Ltd, Oxford, UK and Malden, USA.
11. Earth Negotiations Bulletin (2001a), Chasek, P. (ed.): *Summary of the resumed sixth session of the conference of parties to the UNFCCC: 16-27 July 2001.* International Institute of Sustainable Development (IISD), Vol.12, No.176.
12. Earth Negotiations Bulletin (2001b), Chasek, P. (ed.): Summary of the seventh conference of parties to the UNFCCC: 29 October-10 November 2001, IISD, Vol.12, No.189.
13. Wettestad, J. (2005), Enhancing Climate Compliance - What are the Lessons to Learn from Environmental Regimes and the EU? In: Stokke, O., Hovi, J. and G. Ulfstein (eds.) (2005): *Implementing the climate change regime: International Compliance*. Earthscan, London, pp.209-231.
14. Hagem, C., Kallbekken, S., Maestad, O. and H. Westskog (2003): Tough justice for small nations: How strategic behaviour can influence the enforcement of the Kyoto Protocol, *Center for International Climate and Environmental Research - Oslo (CICERO)* Working Paper, 2003:01.
15. Hagem, C. and H. Westskog (2005): Effective Enforcement and Double-edged Deterrents: How the Impacts of Sanctions also Affect Complying Parties. In: Stokke, O., Hovi, J. and G. Ulfstein (eds.) (2005): *Implementing the climate change regime: International Compliance*. Earthscan, London, pp. 107-120.
16. Berntsen, T., Fuglestvedt, J. and F. Stordal (2005): Reporting and Verification of Emissions and Removals of Greenhouse Gases. In: Stokke, O., Hovi, J. and G. Ulfstein (eds.) (2005): *Implementing the climate change regime: International Compliance*. Earthscan, London, pp. 85-105.
17. Barrett, S. (2003): *Environment and Statecraft*. Oxford University Press.

18. Grubb, M., Vrolijk, C. and D. Brack (1999): *The Kyoto Protocol: A Guide and Assessment*, Royal Institute of International Affairs and Earthscan, London.
19. OECD (2000): Trade Measures in Multilateral Environmental Agreements. OECD Industry, Services & Trade, 2000, Vol. 1999, No. 26.
20. Stokke, O. (2005): Trade Measures, WTO and Climate Compliance. In: Stokke, O., Hovi, J. and G. Ulfstein (eds.) (2005): *Implementing the climate change regime: International Compliance*. Earthscan, London, pp. 147-165.
21. Hovi, J. (2005): The Pros and Cons of External Enforcement. In: Stokke, O., Hovi, J and G. Ulfstein (eds.) (2005): *Implementing the climate change regime: International Compliance*. Earthscan, London, pp.129-145.
22. News Release from MEP Caroline Lucas, 9 March 2004, www.carolinelucasmep.org.uk.
23. European Parliament Committee on the Environment, Public Health and Food Safety (2005): Amendments 1-20, Draft motion for a resolution. The Seminar of Governmental Experts on Climate Change, PE 375.672v01-00, (PE 357.580v01-00).
24. European Parliament (2005): Resolution on the Seminar of Governmental Experts on Climate Change, $P6_TA - PROV$(2005)0177, PE 357.354.
25. UNFCCC (2004a): Issues relating to greenhouse gas inventories, FCCC/SBSTA/2004/L.17.
26. UNFCCC (2004b): Reports of the individual review of greenhouse gas inventories 2004 (Annex I parties) (see www.unfccc.int).
27. UNFCCC (2002): Fourth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention, FCCC/SBI/2002/8 & FCCC/SBI/2002/16.
28. UNFCCC (2003b): Fifth compilation and synthesis of national communications from Parties not included in Annex I to the Convention, FCCC/SBI/2003/13.
29. Herold, A. (2003): Current Status of National Inventory Preparation in Annex I Parties and Non-Annex I Parties, OECD/International Energy Agency (IEA), COM/ENV/EPOC/IEA/SLT(2003)7.
30. Rypdal, K., Stordal, F., Fuglestvedt, Jan S. and T. Berntsen (2003): Assessing compliance with the Kyoto Protocol: Expert reviews, inverse modelling, or both? *CICERO Working Paper*, 2003:07.
31. Aschbacher, J. (2002): Monitoring environmental treaties using earth observation. In: *Verification Yearbook 2002*, Verification Research, Training and Information Centre (VERTIC), 2002, London.
32. Rosenqvist, A., Imhoff, M., Milne, A. and C. Dobson (eds.) (1999): Remote sensing and the Kyoto Protocol: A Review of Available and Future Technology for Monitoring Treaty Compliance. Workshop Report. International Society for Photogrammetry and Remote Sensing (ISPRS), WG VII/5 and VII/6.
33. Torvanger, A., Twena, M. and J. Vevatne (2004): Climate policy beyond 2012: A survey of long-term targets and future frameworks. CICERO Report 2004:02.
34. EC Communication (2005): Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Winning the Battle Against Global Climate Change. SEC(2005) 180. Brussels, 9.2.2005 COM (2005) 35 Final.
35. European Council (2005): Presidency Conclusions. Brussels, 23 March 2005, 7619/1/05 REV 1.
36. Philibert, C. and J. Pershing (2002): Beyond Kyoto: Energy Dynamics and Climate Stabilisation. OECD/IEA, 2002, IEA Publications, Paris, France.

37. Aldy, J., Ashton, J., Baron, R., Bodansky, D., Charnovich, S., Diringer, E., Heller, T., Pershing, J., Shukla, P., Tubiana, L., Tudela, F. and X. Wang (2003): *Beyond Kyoto - Advancing the international effort against climate change.* Pew Centre on Global Climate Change, Arlington, USA.
38. Philibert, C., Pershing, J., Corfee Morlot, J. and S. Willems (2003): Evolution of Mitigation Commitments: Some Key Issues. OECD and IEA Information Paper.
39. Dudek, D. and A. Golub (2003): "Intensity" targets: pathway or roadblock to preventing climate change while enhancing economic growth? *Climate Policy*, Vol.3 (S2), 2003, S21-S28.
40. Kim, Y. and K. Baumert (2002): Reducing uncertainty through dual intensity targets. In: K. Baumert (ed.) (2002): *Building on the Kyoto Protocol, Options for protecting the climate*, World Resources Institute, Washington, USA.
41. Philibert, C. (2004): Lessons from the Kyoto Protocol: Implications for the Future. In: *International Review for Environmental Strategies (2004)*, Vol. 5, No. 1. pp. 311-322, IGES, Japan.
42. Höhne, N., Galleguillos, C., Blok, K., Harnisch, J. and D. Phylipsen (2003): Evolution of commitments under the UNFCCC: Involving newly industrialized countries and developing countries. ECOFYS GmbH on behalf of the Federal Environment Agency, Research Report 201 41 255 UBA-FB 000412, Berlin, Germany.
43. Höhne, N., Phylipsen, S. Ullrich, S., and K. Blok (2005): Options for the second commitment period of the Kyoto Protocol, Climate Change 02/05, prepared by Ecofys for the German Federal Environmental Agency, Berlin, Germany.
44. Blok, K., Höhne, N., Torvanger, A., and R. Janzic (2005): Towards a Post-2012 Climate Change Regime. Contracted by DG Environment, Directorate C - Air Quality, Climate Change, Chemicals and Biotechnology.
45. Ott, H., Winkler, H., Brouns, B., Kartha, S., Mace, M. J., Huq, S., Kameyama, Y., Sari, A., Pan, J., Sokona, Y., Bhandari, P., Kassenburg, A., Lbre La Rovere, E. and A. Atiq Rahman (2004): *South-North Dialogue on Equity in the Greenhouse. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH*, Eschborn, Germany.
46. Groenenberg, H., Blok, K. and J. van der Sluijs (2004): Global Triptych: a bottom-up approach for the differentiation of commitments under the Climate Convention. *Climate Policy*, Vol. 4, Number 2, (2004), pp.153-175.
47. Global Commons Institute website (2005): www.gci.org.uk.

III

Field Experience

Essential for the assessment of the effectiveness of treaties and their verification arrangements is the experience gained during the course of the implementation of treaties. This part contains some examples of operating experiences primarily in the nuclear field but also in the chemical and biological areas.

Experience and Challenges in Weapons of Mass Destruction Treaty Verification: A Comparative View

John Carlson

1 Introduction

The discovery of clandestine nuclear programs, first in Iraq following the Gulf War in the early 1990s, and more recently in Iran and Libya, together with the nuclear impasse with the Democratic Peoples Republic of Korea (DPRK) and that state's purported withdrawal from the Non-Proliferation Treaty (NPT), have led some to question whether multilateral approaches to Weapons of Mass Destruction (WMD) proliferation are effective. Do the WMD treaties only work with the committed, while doing little against the uncommitted? In particular, can treaty verification mechanisms be effective, or do they provide only false assurance?

These issues go to the heart of efforts to counter the proliferation of WMD. This article will discuss whether such criticisms are valid, and lessons learned from experience with the existing WMD treaty regimes.

While this article covers all the WMD regimes, nuclear verification - International Atomic Energy Agency (IAEA) safeguards - accounts for the greater part of the discussion. This reflects the central place of the Nuclear Non-Proliferation Treaty in international efforts against WMD proliferation, and the fact that IAEA safeguards are the longest-established, most developed and most universal of the WMD verification systems.

2 Multilateral Weapons of Mass Destruction treaties and verification

There are four multilateral WMD treaties:

- the NPT , which entered into force in 1970;
- the Biological and Toxin Weapons Convention (BWC), which entered into force in 1975;

- the Comprehensive Nuclear-Test-Ban Treaty (CTBT), concluded in 1996. As will be discussed, although the CTBT has not yet entered into force, substantial components of the Treaty's verification system are already in operation; and
- Chemical Weapons Convention the (CWC), which entered into force in 1997.

These treaties are of fundamental importance because they have established international norms of behaviour. One has only to think back to the pre-NPT period, when it was predicted there would be some 25 nuclear-armed states by the 1990s, to appreciate the value of the NPT to international peace and security. Even if it is true that treaties like the NPT only bind the committed, that is no mean achievement. The fact that there have been five NPT violators - Iraq, Romania, DPRK, Iran and Libya - is a matter of great concern, but without the NPT the international security situation would be far worse.

A key element in all these treaties, except the BWC, is the establishment of substantial treaty verification mechanisms. For most states the political commitment not to acquire WMD has been carefully made and is strongly held. Observance of their treaty obligations does not depend on verification. Nonetheless, it is an important maxim of international arms control to "trust, but verify". The establishment of a credible verification mechanism to provide confidence that all parties are honouring their treaty commitments plays a vital part in reinforcing these commitments.

In the case of the BWC the Parties have not been able to reach agreement on a Verification Protocol, because of differences about the likely effectiveness of BWC verification. A number of Parties (notably the former Soviet Union and Iraq) have had BW programs in violation of their BWC commitments. Regardless of views about the effectiveness of verification, the BWC experience shows the major limitations of a WMD treaty without verification.

Verification underpins the effectiveness of WMD treaties in a number of ways:

- the risk of detection deters non-compliance and reinforces the norms of behavior set out in the treaty;
- by constraining the use of declared facilities, verification increases the difficulties confronting the proliferator; and
- importantly, verification provides an objective mechanism for identifying non-compliance, so that if necessary enforcement action can be taken.

In practice, the degree to which verification reinforces treaty effectiveness depends on the technical effectiveness of the verification measures. If a would-be treaty violator assesses the risk of detection as low, the deterrent effect will be low, and this will impact on the effectiveness of the treaty. It is important to appreciate that deterrence does not depend solely on verification: the deterrent effect will be limited if the violator assesses that detection is not likely to result in agreement at the political level to take enforcement action.

This leads to a further point: while credible verification makes a vital contribution to the WMD treaty regimes, it is by no means the only determinant of effectiveness. The non-proliferation regime comprises complex interacting and mutually reinforcing elements. Verification is not the only barrier to proliferation, and treaty failures cannot be attributed wholly to shortcomings in verification.

3 Major treaty violations

What are the treaty violations that have led to misgivings about the effectiveness of verification? Did verification failures lie at the heart of these violations?

Mention has already been made of serious violations of the BWC. These were not a consequence of verification failures, but rather the absence of verification. In the case of Iraq's violations of the BWC, these were discovered through the verification activities of United Nations Special Commission (UNSCOM), established by the United Nations (UN) Security Council. Iraq's use of chemical weapons, a violation of the 1925 Geneva Protocol, predated the CWC. There are suspicions that a number of states are in violation of the CWC, but to date no violations have been proven, and the CWC's challenge inspection mechanism has not been invoked. The CWC's verification system is outlined in part 6 below.

The major treaty violations that have come to light and been proven conclusively through treaty verification measures have all involved the conduct of significant undeclared nuclear activities. These activities constituted a violation of the relevant safeguards agreement. Since Article III.1 of the NPT requires non-nuclear-weapon states to accept IAEA safeguards, and to follow safeguards procedures, for all nuclear material, they also constituted a violation of the NPT. The IAEA Board of Governors has found five states in non-compliance with safeguards obligations: Iraq, Romania, DPRK, Libya and Iran.

These NPT violations, and the implications for verification effectiveness, will be discussed in part 5.5.

4 Verification precepts

The NPT and the CWC establish inspection-based verification systems. Verification operates in the context that the treaty parties have materials and facilities that could possibly be used in a WMD program. Inspections are conducted to confirm this is not the case.

An inspection-based verification system typically includes the following major elements:

1. Definition of materials, facilities and activities subject to the treaty;

2. Establishment of a treaty inspectorate;
3. Requirement for parties to declare to the inspectorate relevant materials, facilities and activities;
4. Application by the inspectorate of technical measures - including regular on-site inspections and monitoring - to confirm parties' declarations;
5. Inspection procedures in case of suspected undeclared materials, facilities and activities; and
6. Procedures to deal with treaty breaches and non-compliance.

In addition, there may be measures applied by the inspectorate for the detection of possible undeclared activities, etc. This is not the same as point 5 above, which relates to resolution of suspicions once detection has occurred. As will be discussed, a significant difference between treaty regimes is whether the inspectorate actively seeks to detect undeclared materials/activities, or whether it is a matter for treaty parties to identify suspect locations for investigation by the inspectorate.

Another type of inspection, important to the CWC, is verification of disarmament - the destruction of proscribed materials and facilities (chemical weapons and agents, and related production facilities) declared to the inspectorate.

A verification system based on the elements outlined here was first developed for IAEA safeguards. Subsequently a broadly similar verification system was developed for the CWC. Negotiations for a Verification Protocol for the BWC also proceeded along these lines, but were inconclusive.

By contrast, a very different approach was taken to verification under the CTBT. There are no regular inspections: the focus is not on monitoring ongoing research and industrial activities, but on confirming the absence of a proscribed event, i.e. a nuclear explosion. Verification takes the form of monitoring to confirm that a nuclear explosion does not occur. The similarity with the other treaty regimes comes after a possible nuclear explosion has been detected. On-site inspection procedures - currently being negotiated - will apply to establish conclusively if the event detected was in fact a nuclear explosion.

5 The International Atomic Energy Agency safeguards system

Safeguards may be described as a system of technical measures (inspections, measurements, information analysis, etc) to verify the performance of legal commitments, namely, commitments given by states under international agreements - the principal agreement being the NPT - to use nuclear materials and facilities for exclusively peaceful purposes.

The IAEA safeguards system had its origins in bilateral inspection arrangements developed in the early years of the nuclear industry. These inspections were conducted by nuclear suppliers and were "item-specific", i.e. they applied only to the particular item supplied. Following the establishment of the IAEA in 1957, an IAEA inspectorate was developed and bilateral inspection activities were gradually replaced by IAEA inspections.

Item-specific safeguards remain for some items supplied to non-NPT states (India, Israel and Pakistan), and to a limited extent in nuclear-weapon states (NWS). Since the entry into force of the NPT in 1970, the most important function of the IAEA safeguards system is to act as the verification mechanism against horizontal proliferation (the spread of nuclear weapons to further states), through the application of the comprehensive safeguards required for all non-nuclear-weapon states (NNWS) under the Treaty.

IAEA safeguards closely follow the verification precepts outlined above. NNWS are required to declare all their nuclear material holdings and nuclear facilities to the IAEA, and to accept inspections and other verification measures, such as surveillance cameras and seals, at the locations concerned.

5.1 NPT comprehensive safeguards

The NPT recognizes the five NWS that existed at the time of the Treaty's negotiation: United States (US), Russia, United Kingdom (UK), France and China. The Treaty prohibits the acquisition of nuclear weapons by all other Parties (i.e. the NNWS) and requires the NNWS to accept IAEA safeguards on all existing and future nuclear material to verify it is being used for exclusively peaceful purposes. This requirement used to be known as "full scope" safeguards, and is now termed "comprehensive" safeguards.

5.2 Some factors influencing the operation of the safeguards system

Numbers and types of nuclear facilities under IAEA safeguards or containing safeguarded material are illustrated in Table 1.

There is a limited range of nuclear materials - principally uranium, plutonium and thorium - and these materials are used in a relatively small number (compared with other industrial activities) of specialized facilities. These materials are readily detectable and measurable, and lend themselves to mass balance accounting, i.e. materials can be accurately measured through all the processes and transformations they undergo. Accordingly, nuclear materials accountancy has been adopted as a primary verification tool. Other important tools include surveillance (e.g. camera systems) and containment (sealing systems to provide assurance that nuclear material has not been moved between inspections). More recently techniques such as environmental sampling, satellite imagery and information analysis are assuming increasing importance.

Very specific nuclear materials are used to produce nuclear weapons:

Table 1. IAEA safeguards statistics (2004)

Facility type	No of facilities	No of states (preliminary info)
Research reactors	149	54
Power reactors	200	27
Conversion plants	16	8
Enrichment plants	11	8
Fuel fabrication plants	41	21
Reprocessing plants	7	7
Other facilities	162	41
Locations outside facilities	337	63
Total	923	70

- High enriched uranium (HEU), typically enriched to 80% or more in the isotope U 235. This compares with low-enriched uranium (LEU) power reactor fuel which is typically in the range of 3% to 4% U-235; or
- unirradiated plutonium (i.e. plutonium separated from spent fuel or irradiated targets) - nuclear weapons are typically made from plutonium comprising more than 93% of the isotope Pu-239, produced in reactors designed and operated for this purpose, compared with normal power reactor fuel which contains plutonium comprising around 70% Pu-239.

In principle, safeguards could be limited to these materials, and to the facilities required to produce them, i.e. enrichment plants and reprocessing plants. In the future, if it were possible to achieve a sufficiently high level of confidence that a state has no undeclared enrichment or reprocessing facilities, routine safeguards activities could be substantially reduced. Meanwhile, until such confidence is achievable, safeguards are applied to all nuclear material, on the basis that the material could be diverted to be upgraded, either in an undeclared enrichment plant or an undeclared reprocessing plant (in the latter case possibly in conjunction with an undeclared reactor). As will be discussed, the problem of detecting undeclared nuclear activities has assumed central importance in the ongoing development of the safeguards system.

The intensity of safeguards measures (e.g. frequency of inspections, sample sizes measured, and so on) is based on the nature of the nuclear material involved. HEU and unirradiated plutonium are described as "direct-use materials", i.e. for safeguards implementation purposes it is assumed they could be used to produce nuclear weapons, and these materials have the most intensive safeguards - under the basic NPT safeguards system (termed "traditional" safeguards), monthly inspections. Materials that would require upgrading for weapons use are described as "indirect-use materials", and have lesser safeguards intensity: e.g. under traditional safeguards spent fuel is inspected every three months, and LEU and natural uranium are inspected annually.

5.3 Major safeguards violations

As mentioned in part 3 above, the NPT requires NNWS Parties to accept IAEA safeguards on all their nuclear material, and to follow IAEA safeguards procedures. There have been four cases, all involving undeclared plutonium separation (reprocessing) or uranium enrichment activities, where the IAEA Board of Governors has found that the state was in non-compliance with its safeguards agreement, and reported the non-compliance to the Security Council in accordance with the IAEA Statute: Iraq in 1991, Romania in 1992, DPRK in 1993, and Libya in 2004. The Board found Iran in non-compliance in September 2005, but at the time of writing (November 2005) had not decided on the terms and timing of its report to the Security Council.

Most of these cases involved undeclared nuclear activities that had not been detected by routine safeguards inspections. In the case of the DPRK, however, the undeclared activities had occurred before NPT safeguards inspections had commenced. As part of the verification of the "initial inventory" of nuclear material declared by the DPRK, the IAEA analysed declared plutonium and found anomalies indicating that the DPRK had separated plutonium at times other than those declared - and therefore that the DPRK had plutonium additional to that declared. The DPRK refused to allow further inspections to investigate this situation.

These cases shared a number of common features, very briefly outlined in the following paragraphs.

Reprocessing or enrichment experiments at declared (i.e. safeguarded) nuclear sites

The cases of Iraq, Romania, Libya and Iran all involved, inter alia, reprocessing experiments - fuel or targets had been irradiated in safeguarded research reactors, and hot cells used for plutonium separation were at declared sites. In some cases the material used had been exempted from safeguards by the IAEA at the state's request. Although the experiments were small-scale, they were significant because they indicated an intent to use the experience gained for more substantial unsafeguarded activities.

Reprocessing or enrichment activities at undeclared sites

Iraq, Libya and Iran were found, inter alia, to have undertaken uranium enrichment research and development (R&D) using undeclared nuclear material at undeclared sites. In addition, they had established, or were well advanced with, substantial enrichment capabilities at undeclared sites.

Obstruction of or refusal to cooperate with IAEA inspectors

Iraq and DPRK refused to cooperate with IAEA inspections, and Iran was found to have undertaken a program of "deception and denial" with respect to inspections.

5.4 Implications for safeguards effectiveness

What do these cases tell us about the effectiveness of IAEA safeguards? Does the failure to detect undeclared activities, which in some cases were part of a pattern of clandestine activities extending over as long as 20 years, suggest fundamental weaknesses in safeguards? These failures can be attributed to a number of factors existing at the time, including:

- restrictions on inspector access - under traditional safeguards IAEA inspectors could access only defined strategic points at declared nuclear facilities (and certain locations outside facilities). In all these cases some undeclared activities had been undertaken on safeguarded sites, but away from the strategic points where inspectors could go;
- lack of detection techniques - e.g. until the introduction of environmental sampling (see below) it was very difficult to detect activities such as small-scale plutonium separation;
- IAEA culture - a "checklist" approach to inspections had evolved, with inspectors not being trained to look beyond the obvious. This, combined with the access restrictions already mentioned, led to many inspectors having a narrow perception of their duties. One reflection of this was the approach taken to safeguards exemptions, since tightened up.

While the Iraq situation was a low point for the IAEA safeguards system, there were some positive aspects. The existence of clandestine enrichment was first revealed through detection and analysis of microscopic uranium particles on the clothing of hostages held by the Iraqis. Thus an important new verification tool - environmental sampling - was introduced to safeguards. Also in unravelling Iraq's nuclear program extensive use was made of satellite imagery. Environmental analysis and satellite imagery have since become well established safeguards techniques.

The DPRK case served to demonstrate the effectiveness of new analytical techniques, so from a technical perspective can be regarded as a success, though from a broader perspective the DPRK nuclear issue remains unresolved.

As outlined below, the discovery of Iraq's clandestine nuclear program led to an extensive program to strengthen IAEA safeguards, which has been underway since the early 1990s. The factors mentioned above are being addressed by this program.

It might be asked, if efforts to strengthen safeguards began in the 1990s, how was it that similar failures came to light a decade later, in the cases of

Iran and Libya? Mention might also be made of undeclared nuclear activities discovered in the Republic of Korea (ROK) and Egypt, which the IAEA Board of Governors considered in late 2004 and early 2005 but determined did not constitute non-compliance.

These cases show that the establishment of new detection techniques takes some time, and particularly that restrictions on inspector access continue to be a substantial impediment to effective safeguards in those states that have not concluded an **additional protocol** (see below). In the case of the ROK, environmental sampling revealed indicators of undeclared uranium enrichment and plutonium separation experiments, but these could not be fully investigated until the ROK's additional protocol came into effect. In the case of Egypt, undeclared activities were first revealed through the IAEA's information collection and analysis activities. Although regrettably Egypt refuses to conclude an additional protocol, Egyptian authorities cooperated with the IAEA in resolving the failures once they were detected.

5.5 Strengthening the safeguards system

The traditional safeguards system developed for the NPT was primarily focused on verifying declared nuclear materials and activities. It was assumed that development of fuel cycle capabilities independent of declared facilities would be beyond the resources of most states, and in any event would be readily detectable, and therefore if proliferation occurred it was likely to involve diversion of nuclear material from declared facilities. The discoveries made about Iraq's clandestine enrichment program demonstrated that these assumptions were no longer valid.

The program to strengthen safeguards is focusing particularly on establishing the technical capabilities and legal authority necessary for detection of undeclared nuclear activities. Central to these efforts is the effective use of information - involving collection and analysis of information that can enhance the IAEA's knowledge and understanding of nuclear programs - and providing more extensive rights of access to nuclear and nuclear-related locations, including for the resolution of questions arising from information analysis.

Areas of development include:

- detection methods for undeclared activities - including environmental sampling and analysis, and satellite imagery;
- safeguards procedures - particularly greater use of unpredictability in inspections (e.g. through unannounced or short-notice inspections);
- the "state level approach" - tailoring safeguards implementation to state-specific circumstances - moving from the uniformity of traditional safeguards, and basing safeguards intensity on information analysis and expert judgment taking account of all relevant circumstances.

Underpinning the program to strengthen safeguards is the Additional Protocol (AP) - a legal instrument complementary to safeguards agreements, which establishes the IAEA's rights to more extensive information and physical access. The Model Additional Protocol was agreed by the IAEA Board of Governors in 1997. Of the 63 NNWS NPT Parties with significant nuclear activities, to date (November 2005) 43 have APs in force and 12 have signed APs or had drafts approved by the Board of Governors - an uptake of almost 90% of such states. Clearly the combination of a comprehensive safeguards agreement and an AP has come to represent the contemporary standard for NPT safeguards. It is of serious concern that (at the time of writing) 8 NNWS NPT Parties with significant nuclear activities have yet to adopt the AP.

5.6 Integrated safeguards

An important development is the introduction of "integrated safeguards". This is not a new form of safeguards, but a rationalisation of safeguards activities under a combination of a comprehensive safeguards agreement and an additional protocol. The degree of redundancy between routine safeguards and AP measures (they provide different ways of covering similar acquisition paths) can be used to justify reductions in routine safeguards effort. Further rationalisation is possible through applying a state level approach. In the first instance introduction of integrated safeguards requires satisfactory implementation of the additional protocol.

More information on the program to strengthen safeguards, the additional protocol and integrated safeguards is provided in other chapters of this book.

5.7 Detection of undeclared nuclear activities

Undeclared activities at declared sites

An important measure to counter undeclared activities at declared sites has been the introduction of routine environmental sampling. This is most effective where an additional protocol is in place giving inspectors wider access rights, but even without a protocol environmental sampling is a powerful tool. For example, "swiping" of areas around hot cells will readily reveal undeclared reprocessing experiments. Another important measure is the regular re-verification of "design information", checking that facility designs have not been altered - and at the same time extending access through facilities.

Undeclared nuclear sites

Clearly detecting undeclared nuclear activities at undeclared sites is more difficult - this is the greatest challenge currently facing safeguards. While it is possible that indicators of undeclared nuclear activities could be detected through non-location-specific monitoring operations - such as wide area environmental monitoring (currently not considered sufficiently proven for deployment by the IAEA), or environmental analysis at a declared site fortuitously detecting emissions from another, undeclared, site - the fundamental problem here is identification of locations for investigation. Wider access rights are of limited practical value without leads on where to seek access. This requires information analysis - and is particularly dependent on information from states, whose information collection and analysis capabilities (including use of satellites and intelligence activities) are generally far greater than those of the IAEA.

The importance of information broader than that available from traditional safeguards activities can be illustrated by the Iranian and Libyan cases. In the case of Iran, there were long-running suspicions but, until relatively recently, no firm evidence. The extent of Iran's clandestine nuclear program started to be revealed after an Iranian dissident group identified specific locations that the IAEA was then able to ask to investigate. In the case of Libya, intelligence information enabled the interception of a shipment of centrifuge components bound for Libya. This led to the unravelling of an international illicit nuclear supply network, organized by the Pakistani AQ Khan, which was providing Libya with an entire centrifuge enrichment plant on a turn-key basis.

While states are an important source of information, it is also important that information available within the IAEA is used effectively. For example, it was disturbing to find that Libya's early work on uranium conversion and other areas relevant to the nuclear fuel cycle had been assisted under the IAEA's Technical Cooperation Program. There was no process for safeguards inspectors to follow up on the results of such assistance. This is an area that requires further attention.

5.8 Further steps in strengthening safeguards

Some further steps that can be taken in strengthening the safeguards system, and the non-proliferation regime more generally, are outlined in the following paragraphs.

Enhancing the IAEA's technical capabilities

The detection of undeclared nuclear activities presents a considerable challenge. For example, it is notable that undeclared centrifuge enrichment activities are a common denominator for most of the states found to have committed major safeguards violations. Because of the inherent characteristics of centrifuge enrichment - including relatively small physical scale, relative absence of physical indicators - detection presents substantial difficulties. It is essential for all states in a position to do so to assist the IAEA in developing the necessary capabilities and skills.

Increased sharing of information

The preparedness of governments to share national information with the IAEA is essential to an effective safeguards system. There are limits to what can be realistically expected of the IAEA, without the assistance of states, in the detection of undeclared nuclear activities. States need to contribute through the sharing of unclassified information and analyses, the sharing (under appropriate protection) of information from national intelligence sources, and assisting the IAEA in developing necessary information collection and analysis skills. Much has been done in these areas, but there is plenty of opportunity to do more.

Information-sharing with other verification agencies and secretariats can be improved, both within nuclear-related areas, such as the Nuclear Suppliers Group (NSG), the Zangger Committee, and the CTBT Organisation, and also with other WMD areas, such as the Chemical Weapons Convention and the Missile Technology Control Regime. Experience shows that a state pursuing one form of WMD is likely to be interested in others, as well as in suitable delivery systems. Often these states have used the same research institutions and front companies across different WMD areas. Thus knowledge of procurement efforts in other areas may be very useful for the IAEA, and vice versa.

Constraining the spread of proliferation-sensitive nuclear technology

Recent developments have highlighted that the spread of proliferation-sensitive technologies - uranium enrichment and reprocessing - jeopardizes the non-proliferation regime. The confidence that safeguards are intended to provide will be undermined if there is concern that states, in the guise of safeguarded "civil" programs, are developing nuclear weapons capabilities that will enable rapid break-out from non-proliferation commitments. Here, an issue that needs to be addressed effectively is the claim that the NPT gives states an unlimited right to pursue all nuclear technologies, regardless of the consequences for the Treaty's objectives.

6 Chemical Weapons Convention verification

The objective of the CWC (like the BWC) is the elimination of an entire class of weapon. The CWC inter alia bans the development and use of chemical weapons, and requires the destruction of all existing stocks of chemical weapons. Thus, CWC verification measures are aimed at both non-proliferation and disarmament.

The Convention vests the verification function in the Organization for the Prohibition of Chemical Weapons (OPCW). The OPCW, through its Technical Secretariat:

- monitors the destruction of existing stocks of chemical weapons and destruction or civil conversion of facilities used to produce chemical weapons; and
- inspects many research and industrial sites to confirm that chemical weapons are not being produced, and that other proscribed activities are not being undertaken.

The main verification processes follow the model outlined under the verification precepts outlined in part 4 above, and involve Parties making declarations to, and allowing inspections by, the OPCW. A notable transparency measure is that much of the declaration material and some summary inspection data are made available to CWC Parties.

A practical problem for verification is that a very wide range of chemicals, many in large-scale industrial use, are potentially suitable for production of chemical weapons. Chemicals that are subject to routine reporting and inspection arrangements are listed in Schedules to the Convention, or are included in the definition of "discrete organic chemicals". However, many chemicals, including some that are suited to CW production, are omitted from routine inspection coverage because they are too widely spread and inspections would not be practicable - chlorine is one example.

A major cause for concern with the CWC regime is that a number of states, some suspected of having chemical weapon programs, remain outside the Convention.

6.1 Routine inspections

For the chemicals that are subject to routine inspection, facilities are categorized by sensitivity of chemical. The more sensitive facilities are generally inspected annually, the less sensitive facilities are inspected randomly. The random inspections are based on a formula taking account of equitable geographic representation and the nature of the activities. There is a limit on the number of random inspections per state (the limit is 3 + 5% of the number of facilities in the state, up to a maximum of 20 inspections in a year).

The number of CWC routine ("industry") inspections is outlined in Table 2 (figures for June 2004). These figures do not include inspections at military sites for disarmament purposes, which as at June 2004 accounted for most inspection effort - some 84% of total inspector days. The balance of inspection effort is expected to change in favour of routine inspections in the longer term.

6.2 Challenge inspections

A major difference to IAEA safeguards is that the OPCW is not expected to look for undeclared activities in breach of the Convention, except as may

Table 2. CWC routine inspections (2004)

Chemical type	No of inspectable facilities worldwide	No of inspections planned for 2004	Inspection frequency
Schedule 1high risk to CWC Used or readily useable as CW	27	16	Usually annually (average 8 out of 10 years)
Schedule 2significant risk to CWC Not produced in large commercial quantities	156	42	All inspected initially, re-inspection depends on risk assessment
Schedule 3risk to CWC Produced in large commercial quantities	421	24	Randomly
Discrete organic chemicals	4440	80	Randomly

be revealed by a routine inspection. Instead, it is up to Parties, through national means, to identify locations that may be in use for prohibited activities. Another Party may request clarification from the suspected Party, and if appropriate may request a challenge inspection. A request for a challenge inspection is subject to a screening process - if the inspection proceeds it would be undertaken by OPCW inspectors. To date there have been no requests for a challenge inspection.

7 Comprehensive Nuclear Test-Ban Treaty verification

The CTBT prohibits nuclear weapon test explosions or any other nuclear explosions. CTBT verification, while technically sophisticated, has a relatively simple objective: the detection of a nuclear explosion. The Treaty has two verification mechanisms: the International Monitoring System (IMS), aimed at detecting possible nuclear explosions, and On-Site Inspections (OSI), which would be employed to investigate an explosion once detected.

The CTBT will not enter into force until it has been ratified by 44 named states - 11 of these have yet to do so. The CTBT specifies that the IMS must be capable of meeting the requirements of the Treaty when it does enter into force. Accordingly, although the Treaty is not in force, the IMS is in the process of being installed.

7.1 International Monitoring System

The IMS will comprise 321 seismic, radionuclide, infrasound and hydroacoustic monitoring stations and 16 radionuclide laboratories in 89 states. Approximately 55% of the IMS stations have been completed and are in operation. IMS stations are operated by national agencies under contract to the Preparatory Commission for the CTBT Organization (CTBTO PrepCom).

A feature of the CTBT verification arrangements is that data from the IMS stations are available to all Treaty Parties - data are transmitted to the Treaty's International Data Centre in Vienna, and may be accessed by any

Party. Any Party therefore is in a position to analyse IMS data and to call for an investigation, including an OSI.

7.2 On-Site Inspections

In contrast to verification under the NPT and CWC, where regular inspections are carried out by the treaty organization, inspections under the CTBT will be based only on a challenge mechanism. In the event that a suspected nuclear explosion has been detected by the IMS or by national technical means, any Party can request an OSI. Such an inspection would be regarded as a final verification measure which seeks to clarify whether a nuclear explosion had occurred in violation of the Treaty, and to gather evidence to assist in identifying the perpetrator.

OSIs would not be performed by a standing treaty inspectorate, but by inspection teams largely drawn from a list of experts nominated by the Parties to act as inspectors on an ad hoc basis. The detailed OSI arrangements are currently being negotiated, but the OSI provisions will not operate until the Treaty enters into force.

7.3 Effectiveness of CTBT verification

There have been claims that the CTBT cannot be effectively verified. Is this a valid criticism?

The IMS was designed to have a high probability of detecting explosions of one kiloton or more. An early trial of the IMS came with the Indian and Pakistani nuclear tests of 1998. Each said they had carried out two trials in which two or three nuclear devices were detonated simultaneously. Analysis of IMS and other seismic data identified three of these four events. In the fourth case, IMS data could not confirm Indian reports that it had simultaneously carried out explosions of 0.3 kt and 0.5 kt. It is possible that such small explosions, carried out in alluvium, were not well coupled, and thus were not visible to the nascent IMS.

The IMS has been developed considerably since then. Though still only partially installed, the performance of the IMS is proving to be remarkably capable of detecting even quite small explosions. A 100 tonnes conventional explosion carried out in Kazakhstan in 1999 for calibrating the IMS was readily detected by much of the IMS network installed at that time. An even smaller explosion, of about 12 tonnes, was used as part of an experimental OSI exercise in Kazakhstan in 2002. The quality of the IMS data analysis proved to be very good for both events.

Both of the small explosions mentioned here were carried out underground, and their energy release was well coupled to the surrounding geology. An often-cited evasion scenario involves conducting a nuclear test in a large underground cavity in a yielding medium (e.g. salt) to decouple much of the energy. While a well engineered cavity might offer the possibility of strong decoupling, it would be difficult for a proliferator to be assured that this would prevent detection by the IMS (or national technical means) of anything other than a very small nuclear explosion (e.g. < 0.5 kilotonne). Only an experienced NWS could have any confidence of conducting a successful test of this size, which practically eliminates the possibility that a new proliferator might test undetected. Such a threshold also makes unlikely undetected testing of significantly new designs by a NWS.

A further evasion scenario cited over the years has been the conduct of an atmospheric test over a remote ocean location. There is every chance that such an event would be detected by the IMS infrasound and/or radionuclide monitoring network. The issue then is one of attributing responsibility.

The IMS will not detect small-scale nuclear experiments - hydronuclear tests (i.e. sub-critical tests where a nuclear chain reaction is initiated but stopped at an early stage), or hydrodynamic tests (where non-fissile material is used, e.g. to test implosion systems). In addition, it would be possible to deploy an HEU-based "gun-assembly" weapon or a basic implosion weapon without testing, though a proliferator without nuclear weapon experience would be faced with uncertainty whether the weapon would work effectively, or even at all.

Thus for some specific cases the criticism about verifiability may be valid. However, a proliferator seeking to develop more advanced, "boosted" fission weapons, or thermonuclear weapons, would have to conduct large-scale (> 1 kilotonne) tests. This is also the case for an experienced weapon state developing significantly new weapon designs. Experience demonstrates explosions of this size are likely to be detected. Accordingly, the CTBT is an important complement to the NPT in limiting the proliferation of nuclear weapons.

8 Some issues common to the Weapons of Mass Destruction regimes

8.1 Detection of undeclared activities

As has been discussed, verification relates both to possible misuse of declared facilities, and to the possible existence of undeclared facilities. Regarding the misuse of declared nuclear facilities, or conduct of undeclared nuclear activities at declared sites, IAEA safeguards have had some failures, but the causes of these have been addressed and safeguards can now be considered highly effective in countering these possibilities.

The greatest challenge facing IAEA safeguards is detection of undeclared nuclear activities away from declared sites. Detection of small-scale experiments at undeclared sites will always be difficult. Detection is more likely where activities are of a scale sufficient to produce one or more nuclear weapons in a year. In the case of reprocessing, detectability is good, especially if an undeclared reactor is also involved. In the case of enrichment, detection of centrifuge enrichment plants presents a major challenge, but as greater R&D efforts are focused on this problem, detection capabilities can be expected to improve.

The IAEA's detection capability depends on the tools - legal and technical - at its disposal. Technical capabilities have been substantially improved, but the most effective use of these depends on states concluding additional protocols extending the access and information available to the IAEA. Many of the weaknesses in safeguards discussed here remain for states that have not concluded an additional protocol.

Ultimately, national intelligence has a vital role in the detection of undeclared nuclear activities - good results will very much depend on intelligence activities being well-targeted, and evidence being shared with the IAEA. The IAEA cannot be blamed for failures of national intelligence. And no alternative to IAEA safeguards has been devised that solves the basic problem of finding "actionable" information - information sufficiently specific to act on.

The CWC verification regime provides reasonable assurance that activities at declared "high-risk" facilities are consistent with declarations. However, for the wider chemical industry, the low number of inspections relative to the number of facilities (see Table 2), and the non-coverage by routine inspections of a number of toxic chemicals, means that inspections primarily serve a confidence-building function. The fact that a state has accepted inspections - assuming the inspections proceed satisfactorily - has a certain qualitative value, but the level of assurance is not comparable with that gained from safeguards inspections. Inspections aimed at possible undeclared facilities depend on the challenge inspection mechanism being initiated by a state.

8.2 The problem of non-state actors

This is now increasingly recognized as a major aspect of the problem of undeclared WMD activities. The conventional view is that if activities relating to WMD proliferation are occurring in a state, these will be carried out by or on behalf of the state concerned. However, recent events - such as discovery of the Khan nuclear network - have shown that proliferant activities are not exclusive to states. Non-state actors can also be very active in this area. A number of considerations follow:

- Traditionally, there is a potentially adversarial relationship between a treaty verification agency and the corresponding national authority - because the national authority is a state instrumentality, it has to be assumed that if proliferation is occurring the national authority is in collusion. But if proliferation is being carried out by non-state actors, the state may be genuinely unaware of this;

- States have a very serious interest here. Governments cannot assume that because they are committed to non-proliferation, all persons in their jurisdiction share this commitment. Exercising effective control over WMD-related activities is not only a matter of meeting treaty commitments and maintaining credibility within the international community, such activities could pose a threat to the security of the state itself;
- The most effective counter to non-state proliferation will be close cooperation between the treaty agency and the national authority. While care is needed to ensure the ability of the treaty agency to reach independent conclusions on state compliance, a partnership approach is needed in countering WMD proliferation by non-state actors.

8.3 How to focus verification effort to best effect

An important political aspect of the verification regimes is that they are non-discriminatory. In the IAEA, this led to uniformity in safeguards implementation, where safeguards effort was determined in a formulaic, facility-by-facility fashion. The end result was that in the 1990s some 60% of total safeguards effort was being expended in just three states - Canada, Germany and Japan - based on the size and complexity of their fuel cycles and the quantities of nuclear material held. Yet actual safeguards violations had demonstrated that the risk of proliferation lay elsewhere, in certain states which under a uniform approach received few inspections.

As part of the program to strengthen safeguards, and also to meet cost-efficiency objectives, IAEA safeguards are now moving from a uniform approach to one of differentiation, taking account of appropriate state-specific factors. Differentiation is not discriminatory provided the same technical objectives apply to all states. The further development of this "state-level approach", where the IAEA's evaluation of the state as a whole plays a key role, remains a work in progress.

The inutility of concentrating inspection effort in states simply because they have the largest number of facilities was also recognised in the CWC context. The CWC has approached this issue in a different way, through a formula which ensures geographic spread of inspection effort. This may be acceptable in a system that samples only a fraction of the total number of facilities, but has the disadvantage that inspection effort is determined mechanistically rather than as an outcome of state evaluation. There are moves by some CWC Parties to promote selection procedures for certain facility groupings that would redress this.

8.4 Transparency of the verification system

To be most effective in its confidence-building function, a verification system must have an appropriate degree of transparency. States must have sufficient knowledge of how the verification system works, including performance standards, quality assurance and decision-making processes, to have confidence in the credibility of conclusions reached under the system. A related issue is the extent to which information available to the verification system should be shared with states.

For the IAEA, it is a long-established practice, reflecting the wishes of Member States, for information provided to the Agency in the course of its verification activities to remain confidential. This is in contrast with more recently-established verification systems, under the CWC and the CTBT. In the case of the CWC, any Party is entitled to access to national declarations submitted by other Parties. Under the CTBT, data collected by the IMS are available to any Party. Under both of these treaties, therefore, Parties are in a position to cross-check the information available to the verification agency - to identify gaps in that information where they may be able to assist, and to reach an informed assessment on the operation of the verification system.

Of course, there will be some information - e.g. commercial matters, physical protection arrangements, national intelligence-sourced information - that must remain confidential, and the verification agency must also be mindful of not revealing information (or its lack thereof) that could be exploited by a proliferator. However, there is an extensive range of information where greater openness could be beneficial - this is an issue that warrants further study.

8.5 Compliance issues

An essential aspect of a WMD treaty's effectiveness is the preparedness of the international community to act to enforce compliance where necessary. If a proliferator assesses that enforcement is unlikely, then the risk of detection will have little deterrent effect. Consistency and predictability in the reaching of non-compliance findings are also very important.

Inevitably political as well as technical considerations come into play in dealing with non-compliance. It is essential however to avoid confusion between technical and political dimensions. Non-compliance as such involves technical judgments, and a non-compliance finding should be based primarily on technical grounds. Political factors will come to the fore in efforts to resolve the situation after a non-compliance finding has been reached. The distinction between technical and political aspects is reflected in the IAEA Statute, which requires non-compliance findings to be reported to the Security Council. The Statute also requires that the Security Council be notified of matters within its competence, pertaining to international peace and security. This is a clear indication that political decisions are the Security Council's responsibility.

In the Iranian case, concern about the consequences of a non-compliance finding - e.g. whether Iran would cease cooperation with the Agency, or even withdraw from the NPT, and whether in any event the Security Council could agree on a response - led to what amounted to plea-bargaining within the

IAEA Board of Governors, under which a non-compliance finding was withheld while Iran suspended uranium enrichment and reprocessing activities and efforts were made to negotiate a solution.

This may be seen as a pragmatic response to a very difficult situation, but the mixing of technical and political considerations could have damaging consequences for the integrity and credibility of the IAEA's processes. For example, it has led to some arguing that non-compliance ceases to be non-compliance with the passage of time - in effect, that a clandestine program becomes legitimate once it has been discovered and documented. At the time of writing, it was unclear how the Iranian issue would play out, but there are serious lessons to be learnt.

The possible deadlocking of the Security Council is itself a regrettable reflection on the politicization of compliance decisions. Considering that on a number of occasions, e.g. in Resolution 1540 of 28 April 2004, the Council has recognized that proliferation of WMD constitutes a threat to international peace and security, it is essential for the members of the Security Council - especially all five permanent members - to appreciate that combating WMD is a common cause, of far greater importance than the politics of the moment.

9 Conclusions

IAEA safeguards have proven effective for declared activities. Now that emphasis is being given to assurance of the absence of **undeclared** activities, safeguards are moving into an area where effectiveness involves more qualitative judgments. As safeguards become more qualitative, it is important not to lose the substantial advantages safeguards now have in terms of effectiveness for declared activities. In the further development of the safeguards system, care is required in rationalising effectiveness versus efficiency.

Compared with IAEA safeguards, CWC verification is fundamentally a qualitative system. Effectiveness is less certain for declared activities, particularly for less sensitive chemicals. To counter undeclared activities there is substantial reliance on state-initiated action. This less rigorous system is acceptable because of practical constraints - it is recognised that, with millions of tonnes of chemicals produced each year, it would be impossible to monitor all production, use, and transfers.

9.1 Centrality of the Treaty on the Non-Proliferation of Nuclear Weapons

The NPT is the most universal of the WMD treaties, and also has the most well-developed verification system. The NPT anticipates and recognises the contribution of the other WMD regimes - the nuclear disarmament provision, Article VI, links nuclear disarmament to a commitment on all Parties, NWS and NNWS alike, to pursue "a treaty on general and complete disarmament under strict and effective international control". The NPT negotiators recognised that nuclear disarmament cannot be viewed in isolation - it is unrealistic to expect the eventual elimination of nuclear arsenals without effective steps to address strategic imbalances in conventional forces, and particularly other WMD concerns.

This places considerable challenge on the WMD regimes generally - not only must the strengthening of IAEA safeguards progress further, and important complementary steps such as entry into force of the CTBT and negotiation of a fissile material cut-off treaty (FMCT) proceed, but the CWC and BWC regimes must be made more effective. Because it is not practical for CWC verification to emulate nuclear safeguards, attention may have to be given to developing compensatory measures to complement verification, such as greater transparency between states and various forms of regional confidence building measures (CBMs). The lack of verification for the BWC will also need to be addressed. Here too complementary measures are likely to be required, but it is difficult to imagine these will be sufficient without some form of verification.

9.2 Effectiveness of verification

There is no absolute standard of effectiveness. Whether a particular verification regime provides the degree of assurance required by states - hence is considered "effective" - is a matter for judgment, involving questions such as the verification objectives; the verification methods and standards; detection capabilities; quality assurance for verification activities and conclusions; related CBMs; other information (including intelligence) available to states; incentives/deterrents reinforcing compliance; and so on.

As to the risk of false assurance, this is a complex issue, involving the same questions as just outlined. It is essential to promote a realistic appreciation of what verification can deliver, and to avoid over-expectation. This comes back to the point that deterrence through risk of detection is just one of a number of influences on the behaviour of states. Verification alone cannot be expected to solve the proliferation problem - but makes a vital contribution to the response to this problem.

9.3 Multilateral and national collaboration

The arguments canvassed above have emerged as part of a wider debate about the relative contribution of multilateral and national actions in countering nuclear proliferation. In fact, effective action against proliferation cannot be wholly multilateral, nor wholly national - what is needed is a collaborative relationship between the two.

There is no substitute for the disciplined, ongoing and objective service which a multilateral verification system such as IAEA safeguards can provide. The advantages of IAEA safeguards over national capabilities include:

regular access in the state (the ability of inspectors to get "under the roof" at places of interest); a strong body of expertise in verification/investigation techniques; and impartiality - important to international confidence-building and to securing support for enforcement action.

However, national action is also essential - the best results will come from close collaboration. Only governments can address the motivations for proliferation, and ensure effective coordination and application of controls over proliferation-sensitive exports.

Proliferation is a political problem, and can be dealt with effectively only at the political level. We must seek a better understanding of why some states - fortunately only a handful - seek to proliferate, and how they can be persuaded to change course. Political negotiations, such as those aimed at resolving the DPRK and Iran nuclear issues, are an example of this. Technical measures - especially IAEA safeguards - and complementary measures such as export controls, development of proliferation-resistant technology, and establishment of a multilateral framework dealing with sensitive technology, make a vital contribution. But the success of the non-proliferation regime depends on political judgments about confidence and trust - where verification plays an important role - and ultimately on political resolve to uphold compliance, using incentives and if necessary sanctions.

A Concrete Experience: The Iraq Case

Jacques G. Baute

1 Introduction

Verification in Iraq under a United Nations Security Council (UNSC) mandate was a very specific case. It took place under unusual circumstances, beginning as the outcome of one war and terminated by the breakout of a second war. Its legal foundation was not that of a willingly accepted treaty commitment, but the verification of a cease-fire agreement and Chapter VII action by the Security Council. It was the first in a series of activities that raised public awareness of the International Atomic Energy Agency's (IAEA or Agency) anti-proliferation role from relative obscurity to headline news (and most recently, to heightened status as the winner of the 2005 Nobel Peace Price). And from a purely technological viewpoint, the Iraq verification approach evolved in a manner that reflected the broader progress in technology and information processing that has characterized all aspects of modern society.

Consequently, in the context of a book dealing with the 'new discipline' of treaty verification, it is perhaps natural that the most extensive and dramatic nuclear verification exercise to date would provide food for thought. Having devoted more than 13 years of my life to following the evolution of Iraq's nuclear weapons programme (11 at the IAEA, nearly six as the Leader of the IAEA's Iraq Team reporting to the Agency's Director General), I would be pleased if my experiences and viewpoints could make a modest contribution to the efforts of the international community to address modern proliferation and verification challenges.

With this article, I will try to highlight the generic aspects of the IAEA's Iraq experience. The various processes that led to the well-known achievements of the Agency will be addressed, from the discovery phase to the drawing of conclusions.

2 Legal basis and practical implementation

2.1 The United Nations Security Council mandate

The unveiling of Iraq's clandestine nuclear programme in 1991 was greatly facilitated by the adoption of resolution 687 by the United Nations Security Council on 3 April 1991. In this first Gulf War cease-fire resolution, the Agency was provided with 'dream conditions' for verification: unconditional access to any location, at any time, as well as to any individual, any documents and any technology that would help to strengthen the Agency's conclusions. The mission? To map out and neutralise Iraq's nuclear programme, and to ensure Iraq's compliance with its obligations through an ongoing monitoring and verification system. This marked the first movement of what would become a change of culture in nuclear verification: from accountancy of nuclear materials to broad technical investigations - a shift in thinking that would affect both the international community, in its policy-making judgments, and the Agency, where those judgments would be given technical implementation.

Under UNSC resolution 687, the IAEA Director General was requested - with the assistance and cooperation of the United Nations Special Commission (UNSCOM) established pursuant to the resolution:

- To carry out immediate on-site inspection of Iraq's nuclear capabilities based on Iraq's declarations and the designation of any additional locations by the Special Commission;
- To develop a plan (for submission to the Security Council within 45 days) calling for the destruction, removal, or rendering harmless as appropriate of all designated items (as listed in paragraph 12 of the resolution;
- To carry out the plan within 45 days following approval by the Security Council; and
- To develop a plan for the future ongoing monitoring and verification of Iraq's compliance with the relevant provisions of the resolution. This plan was to take into account Iraq's rights and obligations under the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). It was to include an inventory of all nuclear material in Iraq subject to the Agency's verification, and inspections to confirm that Agency safeguards continued to cover all relevant nuclear activities in Iraq. The plan was to be submitted to the Security Council for approval within 120 days of the resolution's passage.

Iraq, for its part, was invited to reaffirm unconditionally its NPT obligations, and was required to agree unconditionally:

- Not to acquire or develop nuclear weapons or nuclear-weapon-usable material (or any subsystems or components, or any research, development, support or related manufacturing facilities);
- To submit to the Secretary General and the IAEA Director General, within 15 days of the adoption of resolution 687, a declaration of the locations, amounts and types of all items specified;

- To place all of its nuclear-weapon-usable material under the exclusive control of the IAEA, for custody and removal with the assistance and cooperation of the Special Commission;
- To accept urgent on-site inspection and the destruction, removal or rendering harmless as appropriate of all items specified above; and
- To accept the plan for the future ongoing monitoring and verification (OMV) of its compliance with these undertakings.

While such far-reaching authority was certainly welcome to the Agency and appropriate to the situation, the implementation of these rights presented an enormous challenge for the Agency. It took a substantial period of time just to set up the modus operandi - and a few years to refine the overall approach - that led to what is today regarded as a remarkable achievement. The measure of that accomplishment is indicated, first, by the IAEA's success in totally dismantling Iraq's nuclear programme; and second, by the fact that none of the Agency's conclusions have been contradicted by any of the multiple investigations that followed - including the comprehensive efforts of the Coalition's inspectors after the March 2003 initiation of the second Gulf war.

2.2 The implementation mode and achievements

During the first months of the Security Council mandated inspections, Iraq's obvious objective was to hide as much as possible of its past programme. In the face of concealment actions such as Iraq's cleanup of enrichment facilities and its efforts to hide sensitive information from inspectors, intrusive unannounced inspections became a powerful tool that forced Iraq to readjust its approach, and to reveal some of its programme components by the summer of 1991. This inspection approach was augmented by several crucial features: the introduction of new technical tools, such as particle analysis of swipe samples (now often referred to as "environmental sampling", one of the most effective nuclear verification tools); the realization of Member States that sensitive information provided to the Agency can lead to dramatic discoveries; the right mix of selected staff; and the development of systematic and comprehensive analytical approaches, dealing in particular with understanding the depth of Iraq's procurement effort during the 1980's. The result was a robust inspection regime that was able to uncover to a broad extent Iraq's clandestine programme well before Iraq's more forthcoming declaration in 1995, after the defection of General Hussein Kamel (the Minister formerly in charge of the Weapons of Mass Destruction (WMD) programmes).

The Agency implemented its Security Council mandate by taking advantage of these far-reaching rights of access, optimising their use for both detection and deterrence. But the Agency's approach was also deliberately balanced. While using all available rights, we also kept in mind that no result can be reached without the cooperation of the country, and did what we could to respect the sensitivities of our counterparts without compromising the effectiveness. For some of the Agency's harshest critics, observing from a comfortable distance, this balance was grounds for projecting an image of the IAEA as being 'soft' on Iraq. In fact, this was a complete misinterpretation of a very pragmatic approach, focused on achieving the ultimate objective. It makes little sense to repeatedly kick at the closed front door when being able to get in by the back door reaches the heart of the problem.

The Agency's mandate under UNSCR 687 - to destroy, remove or render harmless Iraq's proscribed materials, equipment and facilities - was practically completed by early 1994, although not in 45 days as foreseen in UNSCR 687. The status of dismantling Iraq's programme could be expressed in clear, concrete terms: by that time, there was no nuclear-weapon-useable material (plutonium or uranium enriched to 20% or more in U-235 - high enriched uranium or HEU) left in the country; no 'single use' (that is, exclusively nuclear) equipment remained intact; and all buildings with dedicated nuclear features had been destroyed. Even pieces of 'dual use' equipment that had been uniquely linked to the prohibited programme had been destroyed. In some cases, this included facilities for which Iraq had yet to acknowledge this link, such as Al Atheer, the weaponisation centre, denied to be such until the summer of 1995.

2.3 "93 +2" and the Additional Protocol

Much is known in the nuclear verification community about the limitations of the early approach to safeguards and of the steps that were taken to correct them. The nature of the approach, previously thought by the international community to be adequate, had enough loopholes for Iraq to begin a clandestine nuclear weapons programme and remain undetected for a decade. It is unfortunate that, in some political arenas, in particular when politically convenient, some continue to portray the failure of the safeguards system in the 80's as an indicator of a current inability of the Agency to provide credible assurance of a State's adherence to its obligations under non-proliferation agreements. We should remember that, prior to 1991, the international community as a whole was convinced that States that had signed the NPT would remain committed to their engagements, and had thus decided that the Agency's role should be restricted to the verification of declared materials and installations. The mistake - or naivety - was to believe that verification could be meaningful without measures aimed at detecting whether a State is trying to deceive the system by conducting undeclared activities.

Addressing these loopholes - that is, developing the lessons learned from the initial discovery of Iraq's undeclared programme - was the main objective of the so-called "Programme 93 + 2" that led to the approval in 1997 of the Model Additional Protocol, meant to broaden the scope of information and access to be provided to the Agency in the context of nuclear safeguards verification. For instance, Iraq would not have been able to develop most of its clandestine activities in undeclared buildings at its Tuwaitha Nuclear Research

Centre had the Additional Protocol been in the Agency's tool kit prior to 1991. Had the Agency been able to put together and analyse information from an extended declaration provided by Iraq, drawing on open sources quite numerous in the late 80's about Iraq's apparent intentions, and supported by Members States with access to sensitive information, the world would not have had to wait for the invasion of Kuwait to address the issue of a clandestine nuclear programme in Iraq.

2.4 Relevance to other verification regimes

When looking at the Iraq case, it is important to avoid both of the following contrasting errors of judgment:

- Given the demonstrated success of the regime implemented by the Agency in Iraq, the IAEA experience could be generalised as a template for nuclear verification,
- Iraq was such a special case that little can be learned from the years of implementation of that mandate.

The first line of thought overlooks the fact that imposing such stringent verification conditions on any country would be nearly impossible, except in the extreme circumstance of cease-fire conditions. The 'anywhere-anytime' access, although certainly very effective, is perceived as so offensive to the sovereignty and security of a country that it is unlikely ever to be repeated.

On the other hand, in addition to the lessons learned during the "93+2" deliberations, many other insights - particularly with regard to the modus operandi of the verification team and methodologies implemented - were easily transferable. In all verification issues, the various phases the Agency went through with Iraq are broadly applicable: from the initial discovery phase to the drawing of conclusions; from the potential boredom during the suspension of inspections to the intense pressure and hype when they were resumed; and from the difficulties of managing communication effectively to finding and assembling the needed cadre of skilled inspectors.

3 The process of discovery

The challenge that the Agency faced in 1991 started with a learning phase: learning about Iraq's covert programme, including nuclear weapons development and its most sensitive aspects; learning how to make effective use of the extraordinary rights provided by the resolution; and learning how to work as a team with UNSCOM, tasked with a similar mandate for chemical and biological weapons and missiles and responsible for providing "assistance and cooperation to the Agency".

Implementing in-field measures that allow verification that a party to an agreement or treaty remains committed to its obligation is a conditio sine qua non for ensuring the credibility of the agreement. In this case, the Agency was charged with verifying Iraq's acceptance of the conditions of UNSC resolution 687 (the acceptance was a precondition for the cease-fire). As demonstrated during the years when the Security Council inspections in Iraq were suspended, verification activities certainly could not be effective without their in field component. However, there is a widely held misconception that verification activities are essentially limited to field activities, or inspections. Actually, no verification regime can be conclusive without a very significant amount of effort spent on the preparation, accompanying and follow up of field activities.

3.1 Setting up a team

Size and composition

Establishing the right organizational structure, in terms of size and composition, was certainly a challenge for the Agency in the case of Iraq and remains a challenge for each such "special case". Resource allocation must be shaped to make the most of the funding Member States provide, either through the regular budget or extra budgetary contributions. But what is the 'right' level of resources, for a body like the Agency, to address a special issue such as the one faced in Iraq? The distance between too scarce resources and overkill is actually not that wide.

The Agency's first response was to start with an Action Team consisting of three professionals reporting directly to the IAEA Director General, to rely additionally on the roster of inspectors from the Department of Safeguards, and to call on Member States to provide expertise not readily available in house. Was this too modest? It would certainly seem so, given that the team had by December 2002 grown to become the Iraq Nuclear Verification Office (INVO), with over 20 full time professional staff members, assisted at times by staff "borrowed" from other parts of the Agency, as well as outside experts, to meet the needs of identified challenges. But more importantly, having a sizeable team dedicated full time to a specific topic like Iraq, instead of on an intermittent basis, was an essential parameter to ensure the intensity of focus and appropriate follow up needed to reach the objectives set by the Security Council.

Through the years, that combination of thorough and experienced inspectors, skilled analysts, and experts with sharp knowledge in key areas was critical to the team's achievements. For example, the thoroughness inherited from the nuclear material accounting was an essential component of the inspection team culture that set the ground in the early days by inventorying all items of significance - thus providing both a starting point for understanding Iraq's past programme and an early basis for establishing a sensible monitoring system. In addition to accounting for nuclear materials, down to minute quantities, this inventorying included documents of all origins, sites, installations, personnel, observed activities, pieces of equipment and materials of significance, down to the last detail. The Agency staff, experienced in multicultural activities, was also able to use these early interactions to create a "communication line" with the counterpart, however difficult the situation.

Experts who were recruited temporarily to fill gaps in expertise were always included in teams led by permanent staff members. This approach was vital to making individual contributions effective within the most reasonable framework, reconciling in particular the naturally paranoid state of mind of the proliferation specialist and the dismissive superiority complex that was frequently characteristic of Western technicians (who, for example, might be unable to imagine that anything concrete could be achieved unless working conditions were equivalent to those found in the most advanced laboratories).

The process of discovery requires the perseverance of the 'permanently dissatisfied' investigator combined with a creativity that leads to exploring all imaginable scenarios to the end. For the organisation to be on the safe side, it is essential that multiple inputs be consolidated in order to develop the broadest coverage of assumptions. It is too easy to fall into the trap of developing a programme of actions that results in reinforcing a pre-established opinion and finally misses the reality. In retrospect, it may have even been quite beneficial for the Agency to have had to face the numerous accusations that were coming from its critics from the outset (starting with UNSCOM itself), because this led to the exploration of wider assumptions, rather than a more limited focus on the most technically sound assumptions.

No discussion of team composition should overlook the importance of having the technical experts assisted by dedicated support staff, from the administrative assistants that ensure adequate travel arrangements to the technicians who help them use unfamiliar tools, such as databases or detection devices. And no international verification can operate without the contribution of experienced lawyers; in the Iraq case, the legal contribution started with the very drafting of the OMV plan, and continued with the constant support provided to the technical experts for the interpretation of the official texts. It was also essential, together with that of the policy and public information advisers, to make the official reports understandable for the non-technician.

Time scale and its implications

Perhaps the biggest misconception at the outset of the UNSC mandate was the time the "Iraq file" was expected to remain open. The timeframe cited by the Security Council in UNSCR 687 was expressed in terms of days, as if the general expectation was that the entire exercise would not last more than a few months. We have, since then, learned that specific proliferation issues may span decades, and that continuity of knowledge turns out to be one of the key parameters in addressing these issues.

For instance, the Action Team went through a serious struggle when, at the end of 1993, a major turnover of personnel occurred, due in particular to more urgent priorities and natural career aspirations of key members, leaving only the Action Team Leader as a continuing figure. Newcomers had to not only build their individual understanding but actually rebuild institutional knowledge. The traditional paper trail (declarations, field reports, analytical studies, etc.), which seemed sufficient for building a team understanding when the actors remained the same, quickly appeared inadequate; the need for the new comers to digest cubic meters of reading material before being effective felt like a tremendous waste of time, particularly when the customers, i.e. both the Security Council and the Iraqi side, were presenting signs of impatience. In addition, it was extremely inefficient (not to mention irritating for the inspected party) to require repeated answers to the same questions because of a lack of institutional knowledge from the inspector side. (This of course should not be confused with the process of asking the same question recurrently because of a lack of credibility of former answers!)

Career turnover on the part of Member States was, if anything, even more of a problem. In both the diplomatic and technical areas (setting aside the political arena and the natural election-induced changes), the effects of this turnover became obvious, during the 12 years from 1991 and 2003. The time constants under which capitals interested in the "Iraq case" had to re-learn the full spectrum of issues was often a communication challenge for the Team. In fact, some of the trickiest scenarios occurred when 'old timers' returned, after years of other activity, and began with the mindset that nothing had changed since they last worked on the subject.

3.2 Field activities

I have already referred to the nature of the field activities implemented in Iraq. The numerous reports to the Security Council show how the mandate led to inspections at hundreds of different sites, the collection of thousands of samples of all kinds, and the sealing and tagging of hundreds of pieces of equipment.

Numerous articles can also be found on the technical components of the Agency's verification activities, from the strength of particle analysis of swipe samples to the effectiveness of hydrological environment monitoring.

3.3 Sources of information and its adequate processing

It was often heard, particularly during the most tumultuous months of the "Iraq file" before the second Gulf War, that the Agency's findings were essentially derived from information provided by defectors. While no one should deny the importance of the Agency being provided with such information, these leads represented only a fraction of the discovery process. Many sources of various natures actually contributed to the result obtained by the Agency in Iraq.

Declarations

Any verification process starts with the inspected party's declaration. In 1991, it was clear that Iraq's initial response did not match the expectation of transparency set by UNSCR 687. Iraq's declaration was simply to deny the existence of any undeclared activities, providing only a reasonably accurate listing of Iraq's known assets, which had previously been identified by Iraq as components of their declared peaceful nuclear programme. Eventually, the "Full, Final and Complete Declaration" (FFCD) required by UNSC resolution 707 (1991) expanded over the years to reach six volumes and about 1500 pages. By 1997, it had reached a level that the Agency assessed as being compatible with a "coherent picture".

Iraq was also requested, after the establishment of the OMV system in 1994, to provide semi-annual declarations on sites, buildings, materials, nuclear and non-nuclear materials, and equipment, as well as on radioactive sources and planned programmes. Although generally of low quality (the Agency regularly complained to the Iraqi counterpart and reported regularly to the Security Council), these declarations were a very useful tool, as Iraq was requested to provide regular updates on all items assessed to be of proliferation concern.

Beyond these two information sources, obligations under the relevant resolutions, written answers to focused questions, as well as recorded statements by counterparts, constituted a significant addition to the official declarations and provided another huge set of documents that had to be reviewed and analysed. It goes without saying that a certain number of those answers and statements varied with time, rendering the assessment always more painful than necessary.

Original Iraqi documents

The volume of original documents (i.e. documents which had been, contrary to Iraq's declarations, generated during the development of the clandestine programme for internal use or for communications with management, suppliers or other counterparts) grew to be colossal. The collection of a large amount of original Iraqi documents started with the famous IAEA 6 inspection and the associated "parking lot episode", during which, following a very credible intelligence tip, an inspection team managed to collect a large batch of documents demonstrating the extent of Iraq's programme, including its nuclear weapon objectives. Later on, in the second half of 1995, the documents volunteered by the counterpart after the defection of Gen. Kamel filled most of the gaps in the picture related to centrifuge enrichment and weaponisation, including high explosives development. This included numerous blueprints of various centrifuge models and lens components, as well as procurement related documents, such as 40,000 telexes used in communication between the Iraqi buyers and their potential suppliers.

These original documents were a gold mine for completing the uncovering of the entire nuclear programme, and as I will highlight later, the main basis for drawing indisputable conclusions. Moreover, having access to additional documents unrelated to the nuclear programme also contributed to the establishment of the conclusions, demonstrating for instance the conversion of numerous technical staff to non-prohibited activities.

Field operations results

The field results included the inspectors' observations, the results of meetings and interviews with numerous Iraqi technical staff, sample analysis, the results of hand-held, car-borne or heli-borne radiation surveys, hydrological surveys, etc.

After operating for three years on a campaign mode (sending teams of inspectors from Headquarters for inspections finite in time), in August 1994 we established a permanent presence in Baghdad. This helped to flesh out our comprehensive and detailed knowledge of the remaining industrial capabilities of the country. Unannounced inspections maintained the deterrence aspect. Interviews of Agency-selected Iraqi personnel rather than spokespersons proposed by the counterpart allowed us to develop both an understanding of the range of expertise available in the past programme and a detailed picture of the use of such expertise after 1991.

Samples collected in the field were subjected to a variety of laboratory techniques, ranging from particle analysis (to show, for instance, the level of enrichment reached in the clandestine installations) to impurities analysis. These analyses were used to determine the origin of all types of materials, nuclear and non-nuclear, thereby building up a definitive understanding of the material balance and flow of the entire programme.

Member State information

Many observers assign importance to the provision of intelligence information, often timidly referred to as "third party" or "independent" information. It is in fact true that some major steps forward in the discovery process were the result of intelligence tips, either derived from national technical means, such as satellite imagery, or from human intelligence (Humint). Among them, the major ones are:

- The discovery of Tarmiya, the main location for Electromagnetic Isotopic Separation (EMIS), during inspection IAEA 1; and
- The landing of the IAEA 6 inspection team at two locations where significant documentation was stored.

Humint often led to less spectacular findings, such as helping to clarify the nature of certain areas, or to confirm official Iraqi declarations - an important contribution overall.

On the other hand, one cannot ignore that Humint information can be as unreliable as that provided by a concealing State. Numerous inspections triggered by a defector's information ended up with no finding at all, and, in some cases, wasted considerable resources.

But not all information provided by Member States was intelligence-related. A key resource, for both the discovery and the subsequent comprehensive understanding of Iraq's past programme and remaining capabilities, was the exchange of detailed information with every State from which companies had exported relevant equipment and materials. The finding of every piece of equipment significant to Iraq's nuclear programme was followed up with questions to the exporting country, in order to identify the possible existence in Iraq of other types of similar capabilities.

Other independent Agency collection means

Overhead imagery was a permanent asset from the time the Security Council mandate was first put in place. Starting with the use of the high altitude plane U2, it continued with the use of high resolution satellite imagery after the end of 1999. In parallel, low altitude helicopter photography provided detailed technical documentation of facilities subject to monitoring.

Almost no inspection was conducted without preparation involving the thorough analysis of such imagery. Used first to derive site layout, such resources also helped to determine the priority of buildings to be inspected, access routes and, when appropriate, even gates that should be secured to prevent concealment actions. And of course, when inspections were suspended, satellite imagery allowed the maintenance of certain knowledge on the evolution of sites of interest, although little could be concluded with regard to the status of the installations or activities inside buildings.

Given the access to all sorts of other information, open sources were never a serious asset in the context of the UNSC resolution mandate in Iraq. In actuality, most of the time when information of apparent interest reached the media, it was of such low credibility that it had been previously turned down by any serious governmental organisation. In some cases, this involved pure nonsense, such as the report of an under lake nuclear test allegedly carried out in 1989 and the existence of a mobile nuclear reactor. And given the ability of the Agency teams to inspect research centres and the very limited number of publications by Iraqi scientists, scientific literature surveys were of no value.

However, since then, the collection of open source information has become one of the Agency's basic safeguards tools. Had the Agency had such capability in the late '80's, serious concerns could have been raised about Iraq's intentions, and verification follow up could have taken place. In the late 80's, news articles had started to be published about Iraq's covert actions aimed at jump starting a centrifuge enrichment programme. By contrast, given the secrecy surrounding the electromagnetic enrichment programme, nothing had come out on this matter before its discovery through inspections.

Following the adoption of Security Council resolution 1409 in May 2002, which required that the Agency review all contracts for the export of goods to Iraq, INVO was able to build considerable knowledge of commercial transactions in the context of the "Oil for Food" programme. At the same time, the export-import mechanism approved by resolution 1051 (1996) never took off, as most countries apparently considered that it was superseded by the comprehensive review taking place in the context of sanctions, first by the 661 Sanctions Committee, then by the Agency and UNMOVIC.

Information handling

From the rough list of sources provided above, one can quickly appreciate the tremendous challenge of deriving, out of so much data, the knowledge necessary for taking appropriate actions and ultimately drawing credible conclusions. In addition, as highlighted earlier, turnover undermined institutional knowledge. The inherent need to assess the credibility of data was an additional dimension (N.B.: for example, even hard technical data, such as the analytical results of a swipe sample, could be corrupted by cross-contamination). To fuse all these elements into a clear set of reliable information that would be used to define follow up actions, and finally to derive the final picture, drastic actions needed to be taken.

The traditional compartmentalisation of information could have added to the challenge. The Action Team developed a team approach, aimed at accelerating the internal circulation of information, that dramatically enhanced the effectiveness of the group. It was a modus operandi, established by the first Action Team Leader, Maurizio Zifferero, maintained by Garry Dillon and afterwards, in order to avoid any unnecessary restriction of information circulation, unless its sensitivity demanded that it be handled on a strict "need to know" basis, and, consequently, that a more limited number of persons be involved. After 1994, the Team put a major effort into securing electronically all vital information, first by digitising all of it and then rendering access to it as efficient as possible through advanced structured databases.

That methodology was certainly a critical factor in the effectiveness and efficiency of the Agency when it resumed, for a compressed three and a half months, its Security Council mandated inspections in November 2002. By then, staff turnover had once again led to a situation where the Director of INVO was almost the only survivor of the team of senior staff involved in the previous four years of inspections, 1994-1998. But a strong focus on knowledge management had allowed a decade's worth of information to be integrated, and had shaped it into the appropriate knowledge needed by each contributor to perform his or her investigative duties and to speedily deliver undisputable conclusions with regard to the absence of prohibited activities. Unfortunately, as is well known, the Agency was not given the few additional months that would have allowed it to draw a complete conclusion.

4 Drawing credible conclusions

After more than four years of the implementation of the Security Council mandate, the challenge faced by the Agency in Iraq in the second half of the 90's was to demonstrate its ability to draw conclusions with respect to two major aspects:

- The extent of its knowledge of Iraq's past nuclear programme; and
- The absence of ongoing prohibited activities, given that all past known Iraqi capabilities dedicated to prohibited activities had been destroyed, removed or rendered harmless.

At that time, Iraq had lost its credibility in the eyes of the international community, as a consequence of the pattern of concealment followed in the previous years. And when in August 1995, General Hussein Kamel, the President of Iraq's son-in-law and former Minister supervising all WMD programmes, left Iraq, the new transparency displayed by Iraq obviously appeared in an ambiguous light.

4.1 Patterns of behaviour

In August 1995, Iraq decided to anticipate what General Kamel could tell the Agency and came forward with additional declarations. This sudden enhanced but obviously forced transparency certainly shook again any confidence that the international community had developed from the absence of new revelations on Iraq's past activities.

Iraq provided details on its attempt to recover HEU from reactor fuel, and handed over large quantities of documents related to centrifuge enrichment and weaponisation. These new revelations did not dramatically alter the already well understood range of Iraq's programme, but displayed how much, in some areas, Iraq had been less than forthcoming. This included Iraq's systematic understating of its weaponisation effort, particularly in high explosives research and development, and its refusal to acknowledge that some sites had housed components of the programme, such as the Engineering Design Centre (so-called Rashdiya) dedicated to centrifuge developments, and the Al Atheer weaponisation centre. These four years of less than full transparency (from 1991 to 1995), together with Iraq's refusal to accept the resumption of inspections after December 1998, certainly contributed greatly to the suspicions of the international community in 2002, seven years later.

At the same time, our Iraqi counterparts started to demonstrate a significantly higher level of transparency compared to what had been observed for years before. Access to all relevant Iraqi personnel became possible, while, prior to August 1995, Iraq had tended to grant access only to a "spokesperson" in the relevant technical areas. Preventing access to the right individuals (who would have been able to deliver precise information on their actual work), and instead proposing designated counterparts (who will always be imperfectly briefed on technical matters), is certainly one of the most damaging actions an inspected country can take in terms of building confidence. It does not take long for an adequately trained inspector to identify the shortcomings of such behaviour.

In Iraq, face to face interviews became a key tool for refining the Agency's understanding of Iraq's past achievements and for identifying the remaining capabilities, including the evolution and status of residual nuclear-relevant expertise. Additionally, meetings with gatherings of technicians allowed inspectors to 'dig deeper' and identify major areas where internal conflicts had existed and miscommunication had been an impediment to success. A question soon developed: were we witnessing real weaknesses or was this a show just for us, to make us believe that the programme was suffering major dysfunctions? In retrospect, most of the problems identified through such meetings appear to have been real, a normal feature of human interactions anywhere, in activities where personal ambition and greed become counterproductive to the general interest, but are the basis for daily actions.

Another illustration of the difficulty associated with pattern of behaviour was in Iraq's provision of "original" documents. Contemporaneous documents, written for the internal needs of a programme, have a tremendously higher value than declarations made after the fact. However, while providing such documents, the Iraqi side had to face another issue of consistency: namely, that their descriptions to us of struggles and limited achievements contrasted sharply with the always upbeat official progress reports and announced perspectives. Once again, while this inconsistency made us more than a little suspicious, it was understandable: how often do we observe, in the professional world, that mostly good things are reported to management while mistakes and failures are covered up?

It is clear that the pattern of "pleasing the boss" was not only a challenge from the Iraqi side. Much has been said - after commissions and committees investigated the discrepancy between what was advertised of the Iraqi WMD threat and the actual absence of WMDs - with regard to the consequences of political pressures on threat assessments. In some ways, given that the Agency analyst has ultimately as many bosses as there are IAEA Member States, it was easier for us to be more objective than national experts: the only way to survive was be absolutely right, rather than seeking to please a given master or to support one line of thought that could ultimately be proven wrong.

Another key characteristic of the Agency's approach was courage. In the verification world, it is very easy to hide behind the uncertainties that will always exist and to delay the drawing of any conclusion until a political evolution takes one off the hook. The Agency was blessed that its two Directors General, Hans Blix, in 1997, and Mohamed ElBaradei, in 2003, both had enough courage and the necessary degree of confidence in their technical teams to tell the Council the fact-based findings, even when these results were not particularly welcomed by influential Member States.

4.2 The coherent picture of Iraq's nuclear programme

In the Director General's semi-annual report of October 1997, the Agency indicated that it had a coherent picture of Iraq's past clandestine nuclear programme:

"As a result of the IAEA's inspection activities a technically coherent picture of Iraq's clandestine nuclear programme has evolved - a programme aimed at the production of an arsenal of nuclear weapons, based on implosion technology, which had involved:

- *the acquisition of non-weapons-usable nuclear material through indigenous production and through overt and covert foreign procurement;*
- *research and development programmes into the full range of uranium enrichment technologies culminating in the industrialisation of EMIS and the demonstration of a proven prototype gas centrifuge;*
- *the development of metallurgical technologies necessary for the fabrication of the uranium components of a nuclear weapon;*
- *research and development activities related to the production of plutonium, including laboratory-scale reprocessing of irradiated nuclear material and reactor design studies;*
- *the development of nuclear weapon designs and weaponisation technologies for implosion devices and the establishment of industrial-scale facilities for their further development and production;*
- *research and development activities related to the integration of a nuclear weapon with a missile delivery system."*

The coherent picture as described in 1997 was permanently reassessed, and systematically challenged with additional analysis of all data accumulated since 1991 and new information that had come in after 1997. Although inspections had been suspended since December 1998, the Director General stated in his October 2001 semi-annual report to the Security Council:

"[This analysis] *has permitted the Agency to refine its technically coherent picture of Iraq's past clandestine nuclear programme and nuclear-related capabilities as of December 1998, but has not changed that picture.*"

As stated in his report to the Security Council of April 2003, *"As of March 2003, the IAEA had found no evidence or plausible indication of the revival of a nuclear programme in Iraq"*, nor had the IAEA found any additional information that contradicted its previously described coherent picture.

4.3 What is the meaning of 'coherent picture'?

A coherent picture is a technical understanding that has been developed using all possible legal and technical resources. These resources range from in-field activities to exhaustive analysis. The picture is coherent because all of the necessary program elements are visible; nothing is missing in the programme planning sense and all evidence available from all possible sources, including the engineering consistency of all the expected components and project timelines, is consistent.

The coherent picture that evolved is that the main characteristics of Iraq's clandestine nuclear programme were the following:

- It was very well funded;
- It was "prepared" in the 1970s, through the development of cooperation on civilian projects (reactors, reprocessing, and fuel fabrication) and training abroad of future key staff, although the Iraqi counterparts would insist that there was no intention to go clandestine at that time;
- It was implemented in the 1980s;
- There are no indications that Iraq had achieved its programme objective (i.e. to obtain a nuclear weapon);
- There are no indications that Iraq produced or otherwise acquired any meaningful amounts of weapons-usable nuclear material (other than the reactor fuel under Agency safeguards that was removed by the spring of 1994);
- There are clear indications that Iraq had made major progress in the direction of its objective; and
- There are clear indications that Iraq still had some major hurdles to overcome, even in the areas where the most effort had been expended.

The drawing of a coherent picture requires that all information reaching the analytical team is consistent. For Iraq, as explained earlier and as in most cases, data came from many sources and the challenge of analysis was to first assess the credibility or quality of the data, and then turn them into pieces of information that could either be actionable for follow up or would at least contribute to the team's overall developing knowledge. These data included:

- Field observations;
- Physical samples analysis and real time surveys;
- Interviews and meetings with Iraqi personnel;
- Iraqi declarations;
- Iraqi original documents and records;
- Procurement records;
- Imagery of many kinds (ground or overhead);
- Member State information;
- Media information, etc.

Through the years, the effectiveness of the inspection teams increased with experience, progress in technology and cooperation of the inspected party brought back from the field more and more refined data which filled in the blank zones of the picture and refined its resolution. The flow of information of all kinds from third parties increased drastically (after its virtual non-existence prior to 1991), allowing the Team to become confident that, as all sources of credible information were showing consistency and compatibility among each other - not only technically, but also in terms of chronology, underlying logic, etc. - we had developed an accurate detailed understanding of Iraq's past nuclear programme and remaining capabilities.

4.4 The power of all-sources advanced analysis

This now undisputed technically coherent picture was developed through an intensive effort of collecting, evaluating, structuring and, in due time, using of the knowledge derived from information accumulated through the years. The challenge was to be sure that we had done enough, that we were not missing some element of importance. As often said, in the verification game, the absence of evidence is not the evidence of absence. However, even if "we did not know what we did not know", we felt strong enough to report our technically coherent picture to the Council.

Because we had previously been able to fully understand Iraq's documentation procedures, we were able to convince the counterpart that providing the missing original reports was inescapable, and thereby to complete our collection of original Iraqi documents. This action culminated with the provision, in late 1995, of an optical disc containing most of the literature produced by Group 4, the group dedicated to weapons development. Contrary to what happened in September 1991 with the "parking lot event", this step forward was not related to any tips, but the result of a thorough analysis and understanding of Iraq's internal reporting procedures and the success of the Agency in convincing Iraq that no other possibility was left than filling the gaps identified in the reporting nomenclature. Gathering a near-comprehensive set of all reports published by Iraqi technicians was clearly a pillar of the credibility of the assessment.

The thoroughness of the inspectors' inventory of all pieces of relevant equipment found in the field, single use and dual use - when combined with procurement records, consolidated with testimonies of companies that had exported items to Iraq, and compared with any equipment listed in technical reports - provided the near certainty that no significant component of the programme was missing from the picture. The Agency even followed up on Iraq's most damaging concealment action - the unilateral destruction of equipment and documents in the summer of 1991 - and conducted a campaign of digging in the desert to recover and inventory what had been hidden. The support of technologies such as subsurface sensing and mapping equipment led, with the help of the counterpart, to effective determination of the locations of interest and the recovery of numerous concealed items. Ultimately, that action added a significant piece to the puzzle, confirming the reality and the spread of the unilateral destruction.

This permanent loop between data collection, information analysis and field operations led to the strengthening of our conviction that the picture was coherent. By 1996, none of our inspections, most of which were unannounced, was leading to the finding of additional prohibited activities or past programme vestiges. Comparing detailed sample analysis of nuclear and non-nuclear materials, operational laboratory and production logbooks, and supplier-provided information allowed us not only to reconstitute material balances but also to understand the details of the materials flow within the programme. By sampling large trees, for example, we were able to confirm with a fair degree of precision the timeframe during which Iraq worked with tritium for weapon development purposes, as documented in their internal reports. Gamma surveys, handheld, car-borne or heli-borne, did not detect prohibited activities, but located numerous contaminated areas and orphan sources worthy of follow up. In the same way, the monitoring of Iraq's waterways (sampling of water, sediment and vegetation) did not provide any indication of prohibited activities, but demonstrated its power through the detection of iodine used for medical applications.

Follow up on "humint" tips was always an interesting probe for establishing the existence or absence of remaining undisclosed parts of either the past programme or ongoing activities. As years went by, supporting Member States, through national organisations that had been working closely on the Iraq case, realised that we were strong in our technical approach and reliable in our handling of sensitive information. We had become the most knowledgeable organisation on Iraq's past programme and remaining capabilities, and were then able to reliably assess the value of information provided to us by national organisations, avoiding investing too much effort in low credibility tips.

The lesson of that period should have been as follows: provided that the inspection team is technically strong and thorough, and has a detailed level of documentation and access to all relevant personnel; provided that it is focused on issues of importance and remains politically independent (that is, relying on facts only, rather than bending to political pressure); provided that Member States are supportive of the team's action, both politically through the support of the Security Council and technically through the provision of information and expertise; and provided that the inspected State fulfils the requests of the verification body; the international community can be provided with an accurate and comprehensive appraisal of the situation, past and present. Although, the accuracy can never be 100%, the world was given a clear and coherent picture of Iraq's nuclear programme (as reported in S/1997/779 and S/1999/127).

5 Staying the course in calm or storm

5.1 When the international community is almost blind

The world has certainly not yet measured the broad consequences of the fact that, after operation Desert Fox in mid-December 1998, inspections did not resume in Iraq for nearly four years. In the absence of field operations, all possible speculations became possible, based on the most pessimistic interpretation of fuzzy intelligence or worst-case scenarios extrapolated from procurement attempts. The "feet on the ground" normally provided by field activities was no longer available. Four years without inspection was certainly of significance in the potential development of a nuclear programme, especially considering what Iraq was able to do in the four years between 1987 and 1990. On the other hand, it is clear that, contrary to what was possible during the 1980's and early 1990's, the sanctions in place were having an effect, and there was no comparison in Iraq's available assets at the end of 1986 and the situation at the end of 1998.

The Agency continued its effort, although reduced in size following staff turn over, with the clear anticipation that, one day, it would be given the opportunity to return and, hence, needed to be as ready as possible. Several activities continued at a pretty intense pace, although the traditional short-sighted perception I have already mentioned - that equates verification with inspections - was present in sarcastic assessments by external critics that the Action Team was "idle."

Imagery and its limitation

In the absence of inspections, high-resolution commercial satellite imagery provided the only real opportunity to remain in contact with the reality in the field. Overhead imagery had been utilized by the Agency in Iraq since 1991, in the form of photographs from a U2 plane. Unfortunately, while imagery allowed us to prepare well for inspections (and is now used extensively in the preparation of safeguards inspections worldwide), imagery also proved, as expected, to be far from sufficient to confirm the existence or absence of nuclear activities. The limits of "humint" appeared even greater, as sources with obvious agendas could broadcast unverifiable information. How many of the concerns raised by defectors' reports or as the result of imagery observations could have easily been resolved had inspectors been in the field?

Moreover, while it is difficult to define a measurement of the deterrence induced by an inspection regime, the broad conditions provided by UNSCR 687 and other resolutions, together with their implementation aimed at optimising inspection effectiveness, were providing a level of deterrence quite effective in preventing any prohibited activity of significant scale during the period when inspections were ongoing. That deterrence no longer existed in the absence of inspections.

Export-Import information analysis

While the Agency was not operating in the field, UNSCR 1409, adopted by the Security Council in May 2002, provided us with a new mandate, resulting in developing a new type of experience. The review of all contracts of exports of goods to Iraq (in order to identify what items might be of relevance for a hidden nuclear programme) would allow the Agency to build an understanding of procurement networks, reflect on what items would be 'choke points', and identify areas of possible concern based on the procurement of goods ostensibly for humanitarian or infrastructure rehabilitation purposes.

Since then, with the discovery of clandestine networks dedicated to the support of undeclared nuclear programme in countries such as Iran and Libya, that experience has proven to be of great value to filling the gaps in knowledge and competence. Until recently, nuclear proliferation was almost always seen as country-based, given the usual level of confidentiality associated with a clandestine programme. This view is certainly no longer valid. The weaknesses of export and cross-border controls - associated with the fact that money will always attract greed, be it to unlawfully sell drugs or nuclear technologies - have to be seen as a very serious contribution to proliferation threats.

Although only implemented to a limited extent, given that sanctions were in place, the import-export mechanism approved by resolution 1051 (adopted in 1996), as part of the OMV system, was actually another opportunity for the Agency to reflect on the advantage of access to information on ongoing or intended procurement as a tool for developing credible assurance about a country's adherence to its obligations. In that mechanism, notifications related to either single or dual use items are to be provided by both the exporting and the importing country. As part of its verification mandate, the Agency would then be in a position to verify the end-use of sensitive equipment and materials. In a context where proliferation is no longer considered restricted to indigenous efforts, this mechanism could be a starting point for reflection on the establishment of the practical modalities for an improved worldwide export control regime, but more practically, as a template for transfer of relevant information between Member States and the Agency.

Outreach

In retrospect, one of the key weaknesses in the Agency's traditional behaviour, unfortunately, was that its conduct of business and achievements remained largely unpublicised. Although the panel established in early 1999 by the Security Council, led by Ambassador Amorim of Brazil, explicitly recognised the value of the Agency's approach, recommending for what was going to be the successor of UNSCOM a format and modus operandi closer to the Agency's, only the small microcosm of individuals that had worked closely with us was fully aware of the effectiveness of our verification regime as implemented.

By 2002, after four years had passed, and after heavy turnover of the staff involved in the relevant files in most of the Member State capitals, it was clear that the promoters of the "inspections do not work" line could easily surf on the majority's memory, mostly focused on the problems faced by UNSCOM in its fruitless "concealment mechanism investigations".

The key lesson for the Agency was that successfully fulfilling its mandate was not enough. It was also necessary to deploy significant communication efforts, using the media more effectively, dealing on a regular basis with lawmakers, and building up public awareness - by, for instance, being more proactive in participating in teaching students or multidisciplinary seminars - to ensure in particular that its achievements and the means to reach them are conveyed to the public and, ultimately, to decision makers.

5.2 In the spotlight: inspections under world scrutiny

Other recent proliferation issues have shown that international security has become a topic that makes the headlines in the media. As a consequence, the serenity under which verification specialists were accustomed to work in the past, whether inspectors or analysts, policy makers or lawyers, may now only be a relic of the past.

Making the most of the period of apparent rest was the key pillar on which the Agency was able to base the effectiveness of its action in late 2003. Based on the current situation, it is clear that the ongoing "preparation" made during such periods will be the main asset for coping with periods of crisis.

Impatience and distortions of the modern communication world

The last period of Security Council mandated inspections, between November 2002 and March 2003, was of a dramatically different nature in terms of the world's attention and what seemed to be at stake: some saw war or peace resting on the shoulders of the IAEA and UNMOVIC (UNSCOM's replacement after 2000). From our perspective, it was clear that the decision would not be in the inspectors' hands, but in those of the Security Council members. Still, the Agency could not afford to allow such a decision to be made without having done its best to provide the Council with all possible facts and reliable conclusions in a timely fashion.

The rate at which the Council was expecting progress was certainly technically unreasonable. However, by 7 March 2003, the IAEA Director General told the Council that the Agency had found no evidence or plausible indication of the revival of a nuclear weapons programme in Iraq. Relying on our four years of preparation, including our comprehensive databases on sites, equipment and personnel, our refined coherent picture, and the former inspectors we called back to benefit from experience accumulated before December 1998, the Agency was able, within three months, to address most of the concerns raised by Member States, and without compromising the quality of the assessment. Of course, the Director General had to highlight the fact that more time was still needed for the Agency to complete its investigations.

The knowledge management challenge

The first knowledge management challenge is linked to the shortage in adequate expertise. The nuclear world has been facing continuity of knowledge problems for two reasons:

- Nuclear energy and its associated fuel cycle, popular at one time as a career choice, became far less attractive for a couple of decades, attracting less and less new professionals;
- At the same time, the long time experts who made what exist today have started to retire en masse.

The verification area is actually suffering an additional blow: the experts needed for effective assessment of proliferation threats (i.e. knowledgeable in the specificities of a beginning programme), are those who worked in the *early* days of today's mature nuclear programmes. Many of them are now retired or will be soon, leaving the community with big gaps of expertise and experience.

The second aspect to address is that, when field operations impose the daily schedule, it is difficult to set aside the resources needed to plan for the future. It is too easy to rely on the same limited individuals to ensure continuity of knowledge through a few years. But when an issue spreads beyond these few years, and sometimes over a decade, if specific measures to supplement this expertise are not taken, the weaknesses of the non-proliferation side is dramatically highlighted (whereas on the opposite side, the nuclear proliferators may maintain a steady effort for years to reach their goals).

The Agency was successful in Iraq because it maintained a significant effort for over 12 years, without giving up when the pressure to do so was high. In addition, we developed specific methodologies to address the continuity of organisational knowledge - the integrated information system certainly being one of the most concrete assets, as well as the systematic mix of old timers with new comers. Reflection should take place in Member States to address these issues internally as well as in the way priorities are assigned to verification bodies.

6 Conclusion

The results obtained by the IAEA in terms of annihilating the threat of nuclear proliferation in Iraq were the outcome of a combination of positive factors. Inspections worked, as a result of focussed efforts developed by the Agency, the international community's support and, even if variable with time, the co-operation of the inspected country. The methodologies developed in Iraq have served and could certainly serve in the future, as inspiration for developing more effective and efficient verification activities elsewhere. The definition by Member States of adequate authority commensurate with the problem being addressed, the reasonable use by the Agency of all rights provided by that authority, the search for any kind of information to be consolidated with inspection results in order to derive independent credible assessment, and the maintenance of a constructive dialogue with the inspected party, are preconditions for a successful verification regime.

The Agency, as the only technical arm of the international community for nuclear verification, will always have to make progress through, for instance, the continual refinement of internal modus operandi and the definition of processes adequate to secure the credibility of its conclusions. Such an approach is actually a mandatory survival condition for any organisation or company of the Agency's size and profile. It is also the Agency's management responsibility to promote the development of current staff for the efficient preservation of the continuity of knowledge and to generate the recruitment of new adequate staff, to adapt the organisation's response to the new challenges. The first tool of non-proliferation is human resources and their competence and experience, in areas as diverse as policy making, legal framework, inspections implementation or analysis.

However, a verification body cannot operate on its own or make unilateral progress. It is, first of all, the responsibility of its Member States to set the political and legal basis of the verification regime, establishing the authority that the Agency will have in its endeavour. As often mentioned by the Director General, this may require, in the case of the IAEA, making the Model Additional Protocol the global norm for nuclear verification, as well as providing the Agency with actionable information from an effective export control system, in addition to other information available to Member States. That support should not be limited to the political, diplomatic or information aspects but should include technical components such as the provision of expertise and technology, including through national efforts put into the research and development of new verification tools. Beyond that, educational efforts will be required to transfer the knowledge and develop specific skills to new generations.

The preservation of international security with regard to nuclear proliferation and associated threats is a serious challenge for the start of the 21st century. Hopefully, more reflection will take place to strengthen this new discipline called "nuclear verification". I would hope that, in the year of the 60th anniversary of the atomic explosions at Hiroshima and Nagasaki, the 2005 Nobel Peace Prize awarded to the IAEA and its Director General will keep the momentum aimed at preventing such future disasters.

Beyond Iraq: The New Challenges to the Nuclear Non Proliferation Regime

Michel Richard *

1 Introduction

The future of the nuclear non-proliferation regime is once again questioned. In the dawn of the 21st century the regime has to deal with new challenges which call for new answers. This is its second serious crisis in less than twenty years and the regime is in jeopardy. If the international community is unable to joint together and to agree to provide adequate strengthening to the non-proliferation regime, the cornerstone which balances the thrust between the "have" and the "have not" will fall dawn and the delicate equilibrium will collapse.

In ten years, the prospects have shifted from hope to pessimism. The discovery of the clandestine nuclear programmes in Iraq and North Korea in the early nineties raised serious questions about the credibility of the non proliferation regime. Following that crisis, the international community adopted a policy of seeking to curb nuclear proliferation at least for some time, through universal adherence to a set of multilateral instruments supported by ad hoc monitoring and verification.

In the beginning of the decade, the trend was to significantly strengthen the non-proliferation edifice globally, on the basis of the lessons gained from North Korean and Iraqi experiences. Regarding the cornerstone of the edifice, was indefinitely extended during The 1995 Nuclear Non-Proliferation Treaty (NPT) Review Conference extended indefinitely the NPT and took significant steps towards universality. Regarding the verification, in reaction to the discovery of Iraq clandestine nuclear programme, the International Atomic Energy Agency (IAEA or Agency) safeguards were strengthened in November 1991, followed by the adoption of the Additional Protocol (AP) to the safeguards agreements in May 1997; the AP greatly enhances the legal au-

* The views expressed herein are those of the author and do not necessarily reflect the views of the Commissariat à l'Energie Atomique (CEA) or the French Authorities.

thority of the IAEA and expands its verification responsibilities, giving the Agency extended legal and technical means to detect undeclared activities. Rules of the Nuclear Supplier Group (NSG) on export of nuclear items have been significantly reinforced to cover the transfer of dual use items (1992) and to make the Comprehensive Safeguards Agreement [1] with the IAEA a condition of supply of the "trigger list" items. The negotiations for a Comprehensive Test Ban Treaty (CTBT) were completed at the Conference on Disarmament (CD) and the treaty opened for signature in September 1996. In March 1994, the CD adopted a mandate for the negotiation of a cut-off treaty with the view to ban the production of fissile material for the manufacture of nuclear weapons

But now these hopes seem to have vanished. The horizon is getting blurred. The pace of implementation of the AP is very slow. 39 NPT countries have not yet concluded a Comprehensive Safeguards Agreement (CSA). The three countries outside the NPT, Israel, India and Pakistan are not expected to join it in a foreseeable future as Non-Nuclear-Weapon State (NNWS). The CTBT is not expected to enter into force any time soon; in 1998, India and Pakistan conducted nuclear tests. The negotiation of a cut-off treaty is still stalled at the CD.

At the same time, new disturbing challenges to the IAEA safeguards and the nuclear non-proliferation regime have sprang up. Clandestine nuclear programmes have been discovered in several NPT countries. After ten years of continuing argument with the IAEA and the international community, North Korea has broken the "agreed framework", thawed its nuclear programme, expelled the IAEA inspectors [2], withdrew from the NPT and resumed its past activities. North Korea is strongly suspected of producing both plutonium and high enriched uranium for the manufacture nuclear weapons while continuously improving its ballistic missile capabilities. Iran has been caught in serious violation of its obligations, is strongly suspected of concealing a nuclear weapon programme behind the cover of a civilian nuclear fuel cycle and is constantly improving its ballistic missile capabilities. Among these threatening black clouds which darken the horizon, some partial light come the case Libya. The good news is that Libya gave up forever any military nuclear and Weapons of Mass Destruction (WMD) ambition. On the other hand, there are also bad news unveiled by the inspections; the use of extended foreign assistance in building Libya's unsuspected uranium enrichment programme. Investigations on Libya's clandestine programme have revealed the existence of an international clandestine procurement network based on a wide nuclear black market of sensitive technologies headed and managed from Pakistan by A. Q. Khan. This unforeseen discovery highlighted the fact that there were still serious loopholes in the control of transfers of sensitive technologies. Moreover, instances of "negligence" in declarations of past activities and resistance to the IAEA Additional Protocol and strengthened safeguards implementation have shown up (South Korea, Brazil, and Egypt).

After the September 11 terrorist attack, the emergence of nuclear terrorism and the involvement of non-state actors which could use radioactive materials to build a radiological dispersion device (RDD) or fissile material for a crude improvised nuclear device (IND) or even, in a awesome but fortunately unlikely scenario, a stolen nuclear device, have shown up against the gloomy background of the crisis in the non-proliferation regime. The threat of "hyper terrorism" soon appeared to be a major one that needed to be specifically and globally addressed by the international community through new means.

Thus at the beginning of the XXIst Century, the question is raised on how these new fearsome challenges to the global nuclear non-proliferation regime and international security could be tackled. As complex issues, they should be addressed as a whole and globally. New bricks have been added to reinforce the edifice. Answers to some aspects of the issues have already been given by resolution 1540 of the United Nations (UN) Security Council, the G8 Global Partnership, the IAEA programme to protect against terrorism, the Proliferation Security Initiative (PSI)[2], the amendment of the Convention on the Suppression of Unlawful Act at Sea (SUA Convention)[3] convention and the Convention on the Physical Protection of Nuclear Material (CPPNM). However, an appropriate answer requires building a universal approach at political, diplomatic, legal and technical levels supported by efficient detection and verification processes. This global approach should definitely draw upon the lessons and experiences gained in dealing with some major events of the last decade such as dismantling of South Africa's nuclear programme, disarmament of Iraq, containment of North Korea's nuclear ambitions, protection of nuclear facilities and material in the Independent States of the former Soviet Union and in dealing with the recent crises involving North Korea again, Libya, Iran and the A. Q Khan network.

[2] The Proliferation Security Initiative (PSI) is a global effort that aims to stop shipments of WMD, their delivery systems, and related materials worldwide. Announced by President Bush on May 31, 2003, it stems from the National Strategy to Combat Weapons of Mass Destruction issued in December. UN Security Council Resolution 1540, adopted unanimously by the Security Council, called on all States to take cooperative action to prevent trafficking in WMD. The PSI is a positive way to take such cooperative action (source: U.S. Department of States, The Proliferation Security Initiative, Bureau of Non Proliferation, Washington, DC, May 26, 2005, http://www.state.gov/t/np/rls/other/46858.htm).

[3] The purpose of the SUA Convention is to ensure that appropriate action is taken against persons committing unlawful acts against ships. These acts include the seizure of ships by force: acts of violence against persons on board ships and the placing of devices on board a ship which are likely to destroy or damage it. The 2005 Conference considered the adoption of two Protocols incorporating substantial amendments aimed at strengthening the SUA treaties in order to provide an appropriate response to the increasing risks posed to maritime navigation by international terrorism (source - the International Maritime Organization (IMO) - is the UN specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships. http://www.imo.org/).

At the political and legal levels, it means that the international community, as a joint body, should:

- First, reinforce of the role of the Security Council;
- Second, build on the experience gained during previous crises and give the international organizations charged with implementing each treaty, the legal and technical means
  - to address all aspects of nuclear proliferation and terrorism, including the means of delivery of weapons of mass destruction;
  - to provide them with the capabilities to implement edge technique, by themselves or with the support of member states;
  - to allow them to be able to recruit highly specialized experts with the possibility of the creation of a new inspectorate corps;
- Third, build on information collected and analysed at national and international level to prevent the manufacture and dissemination of WMD and their use or threat of use by rogue states or terrorist groups.

This chapter addresses some technical and political aspects of the issues raised. It starts with the progress made since the birth of the nuclear non-proliferation regime and concentrates on the issues of concern raised by the recent crises. It provides a comprehensive review the events in Iraq, Iran, Libya, North Korea, Pakistan and other less important crises, the A. Q. Khan undercover procurement network, the nuclear terrorism and the action of sub-state groups. Following the review, it addresses the question of the new challenges that have arisen with the focus on deriving lessons at the technical, legal and diplomatic levels from the management of these crises. The lessons drawn from field experience in Iraq, the implementation of the resolutions of the United Nations Security Council Resolutions, the experiences with North Korea in the early nineties and the feedback from the implementation of these mechanisms should help overcome new challenges.

2 A look backward: A half century of progress

2.1 Awareness of an arms control and non proliferation policy

Since the fifties a great deal of work has been done by the international community to develop protection mechanisms against nuclear, chemical, biological and radiological weapons and their means of delivery and to prevent the proliferation of these weapons through arms control and disarmament agreements. In recent years and especially in the aftermath of the dramatic events of September 11, the international community has expanded its efforts to include protection from and to combat terrorism. A network of international, multilateral or bilateral instruments has been set up to control the spread of sensitive materials and technologies. All these instruments rely, more or less, on monitoring and verification processes to give assurances that sensitive materials and technologies are not diverted to the fabrication of weapons of mass destruction. The fear of nuclear weapons and their huge power of destruction identified the vital need to stop their proliferation and to control the spread of sensitive nuclear technologies and direct use fissile materials, without hindering the opportunities to expend civilian applications of nuclear energy. The awareness of this "fearful dilemma" [3] inspired the speech of President Eisenhower "Atom for Peace" fifty years ago (8 December 1953) and gave birth to the IAEA [4] (1957). The missile Cuban crisis (1962) when the world came within a hair's breadth of a nuclear war triggered the beginning of United States (US) - Soviet talks on nuclear arms controls and disarmament.

At the time the IAEA was created, the Member States [5] accepted only very light verification provisions. Safeguards arrangements were slightly strengthened during the first decade culminating with the INFIRC/66/rev.2 agreement (1968) to better cover the front and back ends of the nuclear fuel cycle [6]. It is worth noticing that this agreement remains the one governing the nuclear verification activities of the IAEA in the three States non-parties to the NPT, Israel, India and Pakistan.

2.2 The milestone of the NPT as the birth of verification

In the early sixties, it was expected that by the end of the 20^{th} century, more than 20, even 30, States would possess nuclear weapons. With respect to the risk of a nuclear war, the lessons from the Cuban missile crisis (1962) were decisive in inducing the United States and the Soviet Union to realize that only responsible states could manage the fearful power of destruction of the atom and how dangerous it would be to have an uncontrollable increase in the number of nuclear weapon states. Such a spread of nuclear weapons would increase dramatically the risk of a nuclear war, if nuclear weapons were to fall into irresponsible hands; war could be triggered by regional antagonism, ethnic rivalries or even religious crusades.

This danger leads the first three Nuclear Weapons States (NWS) to agree on a treaty, NPT, that limited the right to possess nuclear weapon only to the five States that had tested a nuclear weapon prior to the 1st January 1967. All others States, in joining the NPT would have to give up all nuclear weapons ambitions and to undertake "*not to seek to not manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices*" (article II) [7]. In return, the peaceful use of nuclear energy and the exchange of nuclear technologies should be promoted, particularly by the five NWSs (article IV). The separation in "States having" and "States not having" was confirmed with the indefinite extension of the NPT in 1995. For the first time in the history, by joining the treaty, States accept to be subjected to constraining verification. They have to conclude with the IAEA a comprehensive safeguards agreement (INFCIRC/153), the scope of which is much wider than the INFCIRC/66/Rev.2. The new agreement gives the Agency the right to verify all the declared fissile materials and the facilities which contain them.

2.3 Thirty years of progress in nuclear disarmament, arms control and non-proliferation

During the period stretching from the end of sixties to the collapse of the Soviet Union, the United States and the former Soviet Union shared the common objective to maintain the equilibrium between the two super powers through the reduction of their nuclear arsenals and missile capabilities, to prevent the proliferation of weapons of mass destruction and to build confidence between the States. To achieve that objective they signed treaties, conventions and agreements, multilateral and bilateral. This trend continued after the collapse of the Soviet Union and has resulted in additional agreements. Some of the agreements since World War II are:

- The Anti-Ballistic Missile Systems Treaty (ABM, 1972);
- The Treaty for the elimination of Intermediate-Range and Shorter-Range Missiles (INF, 1987);
- The Biological Weapons Convention (BWC, 1972);
- The nuclear testing treaties such as the Partial Test Ban Treaty banning nuclear weapon tests in the atmosphere, outer space and under water (PTBT 1963) and the Threshold Test Ban Treaty limiting the yield of underground nuclear testing to 150 kt (TTBT, 1974) [8];
- The Nuclear Weapons Free Zone treaties (NWFZ) banning nuclear weapons from wide areas over the globe: the Antarctic Treaty (1959), the Latin America NWFZ Tlatelolco Treaty (1967); The South pacific NWFZ, Rarotonga Treaty(1985), Bankok Treaty (1995).

With the exception of the BWC, these treaties incorporate verification as an essential element for their implementation in order to instil confidence in their performance. The IAEA Comprehensive Safeguards Agreements required by the NPT and the safeguards agreements concluded in the framework of the NWFZs are examples of instruments that rely on verification to give States parties assurances that all other States parties comply with their obligations

During that period, the jarring note came from India which carried out a nuclear weapon test in 1974 declaring it as a peaceful one; it was the first blow to the NPT, upsetting the delicate balance between military and peaceful uses of nuclear energy; since then, the NPT framework has not fully recovered. It is out of question that India will be accepted as a NWS and the prospect that it will join the NPT as a NNWS is unrealistic. The Indian explosion was the first outward manifestation of creeping proliferation of non-NPT parties seeking to acquire nuclear weapons others being Pakistan, Israel, Brazil, Taiwan or even NPT parties such as Argentina, North Korea, South Africa, Iraq, Iran, Libya and, perhaps, Algeria at some time.

India relied on nuclear technologies transfers from western countries to build its nuclear programme. In the early seventies, no compelling international instrument has been set up to implement article III.2 of the NPT. Only recommendations from the Zangger Committee which issued export control guidelines of nuclear items [9] covered loosely the export of nuclear technology. In reaction to the Indian test and the need to reinforce export control of sensitive materials, a Nuclear Suppliers Group convened in London to issue export guidelines and a list of controlled items wider and tougher than the Zangger one [10].

2.4 Early nineties: multilateral arm control disarmament and non-proliferation

In the post cold war area of non-proliferation policy which began in 1991 after the crisis following the discovery in the early nineties of the clandestine nuclear programmes of Iraq and North Korea raised serious questions about the credibility of the non-proliferation regime; the international community began to consider changes to the non-proliferation policy in order to reduce nuclear proliferation. The aim was to significantly strengthen the non-proliferation edifice globally on the basis of lessons drawn from recent crises and the resistance of the international community to verification measures that were considered too intrusive.

Regarding the NPT, its indefinite prorogation was decided by the 1995 Review and Extension Conference and its role as the cornerstone of the nuclear non-proliferation regime strongly reaffirmed. The division between "have" and "have not" has been made permanent in exchange for the commitment to implement three decisions and a resolution on Middle East[4]. Of particular significance is decision 2 on the principles and objectives for nuclear non-proliferation and disarmament which is a commitment by the "haves" to eliminate their nuclear arsenal and a resolution on Middle East[11]. At the time when the Non-Proliferation Treaty was indefinitely extended, significant steps towards universality were also taken, because several important States joined the treaty, bringing the number of States parties to 189; in particular:

- The two remaining nuclear-weapon States: China (March 1992) and France (August 1992);

[4] Resolution on the Middle East (NPT/CONF.1995/32/RES. 1)

1. Extension of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT/CONF.1995/32/DEC.3)
2. Principles and Objectives for Nuclear Non-Proliferation and Disarmament (NPT/CONF.1995/32/DEC.2)
3. Strengthening the Review Process for the Treaty (NPT/CONF.1995/32/DEC.1).

- The three former Soviet Republics as non-nuclear-weapon States: Belarus (1993), Kazakhstan (1994) and Ukraine (1994); they joined the NPT after all nuclear weapons on their territories where returned to Russia;
- A Former de facto nuclear-weapon State as a non-nuclear-weapon State: South Africa joined the NPT as a non-nuclear-weapon State (1991) and then unveiled that it has possessed several nuclear weapons and, subsequently, had dismantled its entire arsenal and related facilities (1993);
- Several States suspected of having developed or had intended to develop a nuclear weapon programme: Algeria (1995), Argentina (1995) and Brazil (1998).

During the same period, the Additional Protocol to the Safeguards agreements was adopted, in order to support a more efficient implementation of the NPT. It gives the IAEA extended legal and technical means to deal not only with the correctness of the State's declaration but also with its completeness, in particular, detection of undeclared materials and activities and to verify compliance of the States Parties with their obligations.

The disclosure of the extended Iraqi foreign procurement organisation provided valuable lessons regarding the application of export controls. The Nuclear Supplier Group reinforced the control rules governing the export of nuclear items to cover dual-use items and made the signing of a comprehensive safeguards agreement a condition for granting export licenses.

Regarding nuclear testing, the negotiations at the Conference on Disarmament led to the Comprehensive Nuclear-Test-Ban Treaty that includes a verification protocol. The treaty, adopted as a measure of nuclear disarmament (vertical proliferation) and non proliferation [12], was open to signature in 1996 [13]. It has not entered into force because a number of States which are essential for the treaty to enter into force have not yet ratified it [14].

In the area of arms control and international security, the United States and Russia signed the Strategic Arm (limitation and) Reduction Treaty START-I (1991) and START II (1993). An immediate and grave proliferation risk was posed by the lack of security of facilities and nuclear materials in Russia and the newly independent States of the former Soviet Union, the vast nuclear, chemical and biological arsenal, their means of delivery, and the accumulated technology and human expertise of the former Soviet military complex. To combat the threat posed by the weapons of mass destruction and to enhance the security level of sensitive facilities and the physical protection of fissile material, the United States and its international partners have initiated a programme known as the Nunn-Lugar Cooperative Threat Reduction programme. The actions taken under this programme have not been completed and are continuing with the label of the G8 Global Partnership programme (the 10+10 over 10 initiative)[5].

[5] The Global Partnership is a G8 initiative committed to preventing terrorists, or those that harbour them, from acquiring or developing nuclear, chemical, radiological or biological weapons, missiles, or related equipment and technology. The

Regarding the reduction of military fissile material stocks available for nuclear weapons manufacture, the United States and Russia have agreed to declare some stocks of high enriched uranium and weapon-grade plutonium in excess of their defence needs and to put a part of them under IAEA safeguards before final disposition or transfer to civilian uses in the framework of the trilateral initiative [15].

Regarding the production of fissile material for nuclear weapon manufacture, the Conference on Disarmament adopted a mandate for the negotiation of a Cut-off treaty (1994) with the view to cap the production of such fissile material.

Regarding other weapons of mass destruction, the CD negotiated the Convention on the Prohibition of Chemical Weapons which was open to signature in 1993 and entered into force in 1997. However, the negotiations at the CD for a verification protocol to the Biological Weapon Convention, after many years of work, failed in 2000.

Regarding conventional arms two treaties were adopted to enhance security between the western and the eastern blocks through mutual verification:

- The Treaty on Conventional Armed Forces in Europe (1992);
- The Open Sky Treaty (1992);

Theses treaties are still in force [16].

2.5 Iraq: the non proliferation regime challenged and strengthened

1992: A milestone for compliance monitoring and verification

In the early nineties, the discovery of the clandestine nuclear weapons programme of Iraq, the difficulties of the IAEA to verify the initial declaration of North Korea and the decision of South Africa to reveal and dismantle its nuclear weapon arsenal triggered a serious attempt to strengthen the non-proliferation regimes [17] and initiated discussions on the need for new legal multilateral instruments e.g. CTBT and Cut-Off Treaty to curb horizontal and vertical proliferation of nuclear weapons and other WMDs. Loopholes in the regimes that were designed to detect and thwart undercover nuclear activities and fissile materials, to prevent illicit trafficking of sensitive technologies and to stop clandestine nuclear weapon programme, have been identified. Improvements to strengthen the regime for the detection of undeclared nuclear activities and undercover technology transfers have been proposed. The main advances toward the goal reducing proliferation are the strengthening of the

---

G8 countries announced at the June 2002 Summit in Kananaskis, Canada, that they would pledge $20 billion (10 from the US and 10 from other countries) over the next 10 years to fund projects, initially in Russia, to achieve this goal (Source: G8 Research Group at the University of Toronto: g8info@library.utoronto.ca).

IAEA safeguards agreements with the Additional Protocol [18] and the implementation of measures already within the scope of Comprehensive Safeguards Agreement, with the establishment of the dual use items list of the Nuclear Supplier Group [19].

Building up on lessons drawn from the implantation of the monitoring and verification operations in Iraq implemented under the UN Security Council resolution used advanced technologies as satellite imaging, open information collection and analysis, State provided intelligence, State provided knowledge and training on nuclear fuel cycle, environmental sampling and ultra-trace identification methods and satellite imagery; on the basis the experience gained from these tools, remote monitoring and new approaches on safeguards implementation have been identified as necessary to fill gaps in monitoring and verification [20].

Value of the Iraqi and North Korean experience

As some time has passed since the United Nations Monitoring and Inspection Commission (UNMOVIC) and the IAEA/Iraq Nuclear Verification Office [21] (IAEA/INVO) were compelled to stop their monitoring and verification activities in Iraq, it can be concluded that for many organisations and bodies, Iraq was a real "test-bed" for their contributions to the elimination of the Iraqi WMD programme and the establishment of the on-going monitoring. From 1992 to 1998, Iraq was a country wide, open field laboratory where many advanced monitoring technologies as well as verification approaches were implemented allowing participating states and organisations to test new monitoring systems, new verification concepts and new technologies as well as to conclude new legal instruments; these proved valuable in dealing with the subsequent crises in Iran and Libya. Some examples are the Additional Protocol, the dual-use items export control, local and wide area environmental sampling techniques, the extensive use of overhead imagery, aerial and satellite (Figure 1), the development of open-source analysis and the use of third party information, the in-depth analysis of nuclear fuel cycle, the continuous (remote) monitoring of processes or equipments, and the development of new inspection techniques: radiation monitors, geophysical survey techniques (figures 2 & 12), interview of key personal, search for import-export information (see 4.2).

Important as the collection of techniques and methods was, the most important development, essential to forming a coherent picture of a clandestine complex and extended programme as a whole, was the analysis and fusion of all type of information. It was not only a technological advance; it was also a methodological one. In the framework of the extensive rights of verification provided by the Ongoing Monitoring and Verification (OMV) Plan [22], new inspection approaches were developed and applied. Very intrusive, the provisions contained in section E of the OMV Plan goes far beyond what could be accepted by a sovereign State under an internationally accepted strengthened safeguards agreement (anytime, anywhere, interview everybody, access any document, implement any technologies). Although the Iraqi experience was unique, it is worth noting that it can be used to derive from it valuable lessons and to translate them into manageable inspection practices, i.e. interview of key personals or visit to military sites, to allow the Agency to cope with very complex and difficult situations. Thus, in his last report to the Board of Governors during the September 2005 session on the implementation of NPT Safeguards Agreement in Iran, the Director General of the IAEA noted that, even with the verification resources given by the Additional Protocol "the Agency is not yet in a position to clarify some important outstanding issues after two and a half years of intensive inspections and investigation"; he requested that, given Iran's past concealment efforts over many years, such transparency measures should extend beyond the formal requirements of the Safeguards Agreement and Additional Protocol and include *access to individuals, documentation related to procurement, dual use equipment, certain military owned workshops and research and development locations* [23].

Fig. 1. Iraq/Overhead imagery. In the framework of the specific context of Iraq disarmament, the U2 plane of operation "Olive Branch" flew over Iraq under UN flag for a permanent survey of Iraqi sites and search for undeclared sites and activities. Source UNSCOM

3 Current situation and prospects

3.1 Dawn of the century: Resuming the challenges

In the middle of nineties, with the availability of the expanded range of verification instruments, the international community could have increased confidence on its ability to curb proliferation of nuclear weapons; instead, a few years later, in the aftermath of the Iraq and North Korean crises, the expanded hopes of stemming rapidly the proliferation of nuclear weapons have faded away. At the dawn of the 21st century, new crises appear that call for

Fig. 2. Iraq/Ground penetration radar testing. Fielded for a primary testing, a helicopter born ground-penetrating radar (antennas on each side) was deployed during UNSCOM operation "Cabbage Patch" to seek for buried SCUD missiles (1993). Source UNSCOM

urgent and new measures to protect international peace and security. First, following the terrorist attack of September 11^{th}, it was the emergence of multiform terrorist threats from sub-state groups supported by states of concern which host them; these groups could use weapons of mass destruction, chemical, biological and possibly nuclear or even radiological if they could lay their hands on radioactive material. In response to these new threats, actions have been given to enhance the protection of fissile and radioactive material by the adoption of the nuclear security programme of the IAEA, to establish national anti terrorism laws and develop cooperation between the States, and to negotiate the strengthening of the Convention on the Physical Protection of Nuclear Material [24].

Then, it was the crisis generated by the findings that Iran, North Korea and Libya had violated their international commitments exemplified by the unveiling, following the IAEA investigation, of a multinational nuclear black market headed by the well-known Pakistani scientist A. Q. Khan. One obvious lesson which came out from the analysis of the violations is the existence of a major risk that a State may have access to sensitive nuclear technology as party to the NPT parties and signatory to a Comprehensive Safeguards Agreement [25]; the State could learn know-how and acquire equipment which would allow it to develop a discreet hidden military programme and to withdraw from its non-proliferation commitments when the time is ripe to reveal its nuclear weapon program. This scenario generates conflict in the international community between the states that want to have free access to nuclear technologies (mostly developing ones) and those that want to restrict the access to sensitive technologies (mostly industrial western ones). This division was one cause for the inability of the 2005 NPT Review Conference to agree on measures to redress such a situation. As a result, the pace of implementation of instruments such as the Additional Protocol is very slow and rather disappointing.

3.2 Prospects: A blurred vision of the future

Following these developments, the outlook on the future of international security became blurred. The pace of implementing the Additional Protocol is slowed down. 37 NPT parties have not yet concluded a Comprehensive Safeguards Agreement with the Agency. The prospect of the three non-NPT countries joining the NPT in the foreseeable future is rather small. The CTBT will not enter into force in the coming years because there is no evidence that several States listed in the Annex 2, in particular the United States, China, India, Israel, Pakistan and North Korea will ratify it any time soon; ratification by the States listed in Annex 2 is a condition for the Treaty to enter into force. The Cut-off Treaty is still in limbo in the CD [26], because the CD does not have a concrete programme of work. The challenges to the IAEA safeguards and the nuclear non-proliferation regime created by the cases of Iran, Libya and North Korea and other lesser crises arising from resistance to the verification activities and disclosures of past breaches persist. If these challenges are not faced and the underlying issues are not resolved, they may undermine significantly confidence of the States in the capacity of the international community to maintain security by preventing the dissemination of nuclear weapons and nuclear and radioactive materials to States of concerns and sub-state groups.

3.3 Current situation: Overview of concerns

Iran, Iraq, Libya and North Korea have all joined the NPT, three of them soon after entry into force. Since the sixties, all these countries except Libya have developed or tried to do so, all steps of the nuclear fuel cycle to various degrees: uranium mines, concentration, conversion, isotope enrichment, reactors and plutonium extraction, often with foreign or international assistance. They have also taken advantage of the technical assistance programme and the weaknesses of the former IAEA safeguards system to investigate for undeclared activities designed to develop nuclear weapons. Iran has been caught in significant violations of its undertakings and is strongly suspected of concealing a nuclear weapon programme; Libya gave up its nuclear weapon ambition under US and UK diplomatic pressure and disclosed its unsuspected proliferating activities; in doing so, it unveiled a concealed multinational procurement network. The implementation of the Additional Protocol has brought into light examples of past negligent behaviour and resistance to inspections (e.g. South Korea, Brazil, and Egypt).

Iraq: no longer a proliferation threat, but?

The disarmament of Iraq, the dismantlement of its clandestine nuclear programme and the monitoring of its nuclear activities under United Nations Security Council Resolution 687 (UNSCR 687) [27] and following resolutions

(UNSCR 707, 715, 1051 and 1441) was a consequence of the Gulf war. Before 1991 Iraq was not subject to any particular monitoring and verification under its safeguards agreement and was able to develop unbothered its clandestine nuclear weapon programme.

From 1998 on, after seven years of extensive investigations, the IAEA acquired the total control of all Iraq's nuclear activities and in depth knowledge of its clandestine programme [28]. This knowledge has enabled the IAEA/Action Team to form a complete picture of the clandestine programme. Although the threat of Iraq is over, some points remain to be clarified; they became more important after the discovery of the A.Q. Khan network, in particular on foreign assistance, procurement and transfer of know-how of centrifuge technologies as well as on nuclear weapons design (Figures 3 & 4). Also, did the A.Q. Khan network provide Iraq with weapon design information as it did for Libya and possibly Iran [29]?The answer could be difficult to get for Iraq, because the archives were destroyed and the equipment was looted and removed. Today, the question remains: *What became of the sensitive equipment and the nuclear scientists?*

Fig. 3. Iraq/Al Atheer: weaponization site. Source IAEA

North Korea: The present threat?

The first crisis occurred in 1992 when the IAEA went to North Korea to verify the initial declaration under its safeguards agreement. With help of the US satellite imagery, the Agency discovered an undeclared plutonium separation facility at Yongbyon (Figure 5) and found inconsistencies in the declaration. North Korea refused to grant IAEA free access to its reprocessing and waste storage facilities. Then the breach of North Korea to its agreement was referred to the United Nations Security Council. In 1994 North Korea withdrew for the first time from the NPT. Then, after an agreement between the United States and North Korea, all suspicious nuclear activities were frozen [30]; the IAEA was put in charge of the verification of the effectiveness of the freeze. In 2002 after years of dispute between the IAEA and North Korea concerning

Fig. 4. Iraq/aluminium tubes suspected to be part of centrifuge but rocket body. Source IAEA

verification, a new crisis arose when the North Korea declared that it had the capability, already suspected, to enrich uranium.

Following that declaration, North Korea has broken the relation with the IAEA, expelled inspectors, and put an end to the "freeze" agreement, resuming operation of its 5MWe plutonium production reactor, declared to reprocess spent fuel under control (Figure 6) and withdrew from the NPT. It is estimated that, in the early nineties, North Korea had already separated enough plutonium for one or two nuclear weapons. These facts have been brought to the United Nations Security Council's attention since 2003. Six-party talk [31] hosted by China have been engaged in negotiations for a new agreement; the negotiations are stalled because Russia and China, pursuing their own interests, remaining too indulgent towards North Korea.

The pending questions on the North Korean nuclear capabilities are about:

- The plutonium and HEU production capacity and
- The stock of fissile material North Korea has at its disposal.
- The size of its nuclear arsenal.

These factors together with the fact that North Korea has ballistic capabilities as middle range ballistic missiles holder and missile technology provider make North Korea a present threat for the Far East. Nevertheless, the situation is ambiguous. On one hand, the dialog with North Korea will remain stalled as long as China will not put more pressure on its neighbour; on the other hand, China, in dealing with North Korea, has its own interests to protect and , will never allows it to destabilize the region.

Iran: the threat for years to come?

Following information from an opposition group, suspicions were raised in June and September 2003 about a secret uranium enrichment programme

Fig. 5. DPRK/Yongbyon reprocessing plant. Source ISIS

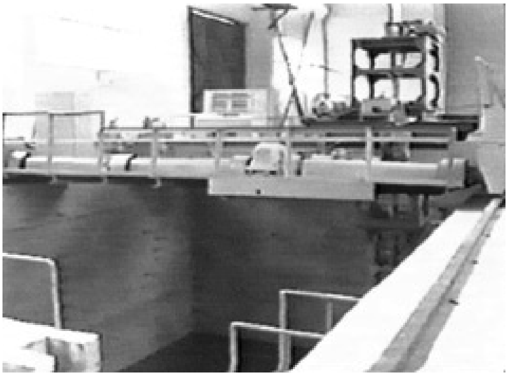


Fig. 6. DPRK/Yongbyon 5 MW_e reactor spent fuel pond. Source IAEA

developed by Iran. IAEA inspections showed that Iran had "*failed over an extended period of time (twenty years) to meet its obligations under the safeguards agreement with respect to the reporting of nuclear material, its processing and its use, as well as the declaration of facilities where such material has been processed and stored*" [32]. Failures included a long list of activities and materials, some very sensitive, such as centrifuge and laser enrichment, uranium metal production and polonium-210 production.

IAEA inspectors discovered a large gas centrifuge uranium enrichment programme including the construction of a large plant and a pilot plant at Natanz (Figure 7) and that the centrifuge technology was provided by the Pakistani A. Q. Khan network. Also they discovered that Iran was planning to construct an heavy water research reactor, well suited for plutonium production with the associate heavy water production plant, that it had imported an important stock of undeclared UF6 a part of which has been converted to uranium metal at Esfahan (Figure 8), that it had irradiated uranium metal targets and extracted some quantities of plutonium and bismuth targets to get polonium-210 which could be use as neutron trigger in a nuclear weapon. The presence of high enriched uranium particles on centrifuge parts has not yet been clearly explained but they could have come from contamination in Pakistan. Suspicion of undeclared activities has been raised for two sites, Parchin and Lavisan-shian (Figures 9 & 10); the Iranians are reluctant to grant access to those sites.

Not declaring these activities to the IAEA constitute serious violations of the safeguards agreement. The Iran case has been examined by the Board of Governors but, so far, it has not been referred to the United Nations Security Council; Iran continues to procrastinate and responds reluctantly to the IAEA requests even after it signed and implemented an Additional Protocol which is pending entry into force. Discussions between France, Germany and the United Kingdom (EU3) on one side and Iran have revolved around the suspension of the uranium enrichment activities by Iran in exchange for assurances of supplies and other commercial benefits; nevertheless, the construction of the heavy water reactor is still continuing and Iran has just resumed its conversion activities at Esfahan Research Centre.

Fig. 7. IRAN/NATANZ / Uranium Centrifuge Enrichment plant. Source ISIS

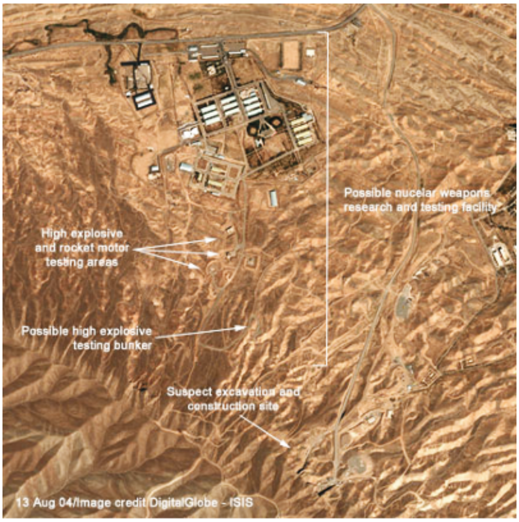
In spite of these efforts, the prospect of a successful resolution of the crisis seems unlikely. The Iranian case raises many questions about the capacity of the IAEA and the States intelligence services to detect concealed enrichment

Fig. 8. IRAN/ESFAHAN Research Centre & uranium conversion facility (UCF). Source AFP

Lavizan-Shian Site, Iran -- August 11, 2003

Lavizan-Shian Site, Iran -- May 10, 2004

Fig. 9. IRAN/LAVISAN: A site of concern. What kind of activities has been carried out before remediation? Source ISIS



Overview of select facilities within Parchin, possibly involved in nuclear weapons research, testing; and possibly production, and an area of suspicious excavation and construction whose purpose is a subject of debate.

Fig. 10. IRAN/PARCHIN missile and explosive test range, another site of concern. Source ISIS

activities, about the control of transfer of sensitive nuclear technologies, about the right for States to develop nuclear fuel cycle technologies under Article IV of the NPT and about the role and responsibilities of non-NPT States such as Pakistan in the fight against proliferation. Then, there is the most important question: Is Iran trying to gain time before withdrawing from the NPT as soon as it possesses nuclear weapons?

Libya: A success story?

In October 2003, Qadhafi decided to abandon his WMD programs and to allow experts from the United States and United Kingdom to visit his weapon facilities following the seizure of centrifuge components during sea transport. On December 2003, after two years of contacts and nine months of secret negotiations with American and British officials, Libya agreed to destroy all its WMD capabilities, nuclear, chemical and biological and to abide by the NPT, allowing immediate inspection and monitoring and concluding an Additional Protocol. It appeared that Libya had acquired know-how on uranium centrifuge enrichment technology and centrifuge components from the nuclear black market network headed by the Pakistani scientist A. Q. Khan and had developed mobile enrichment facilities. But more ominously, it also appears that Libya has acquired drawings of a Pakistani nuclear weapons design from the A.Q. Khan network. This discovery raises concerns about the exact extend of the transfer and about the number of other countries that could have benefited of the same type of information (Iran, North Korea, Iraq, Syria...?).

It is worth noting that the Libyan crisis was diffused through diplomatic means and through cooperation; also, in contrast to Iraq, the intelligence services had underestimated the extent of the proliferation.

Pakistan and the proliferation "bazaar"

While investigating the nuclear programme of Libya, the IAEA discovered that the international black market of sensitive items, centrifuge technology and know-how, centrifuge components, Pakistani, drawings of nuclear weapon design organized by the A. Q. Khan network extended over many continents, Africa, South Asia and Middle East and countries among which there were several European ones and involved individuals and companies. Moreover, there is well founded suspicion that not only Libya and Iran but also North Korea and possibly other countries have benefited from the network.

The network headed by A. Q. Khan is probably the most important proliferation issue of the beginning of the 21^{st} century. High priority should be given to resolving the problem because it is closely linked to the other problems. The overall extend of the ramifications of the existence of the network and the nature of the trafficked items is still unknown. A. Q. Khan confessed that centrifuge technology was transferred to North Korea, but in exchange of what? And did A. Q. Khan pass nuclear weapon files to countries other than Libya? And what about missile technology?

Other compliance problems: Korea, Brazil, Egypt

As consequence of the Additional Protocol and strengthened safeguards implementation, past undeclared activities, some very questionable, have come to light with the extended declaration; at the same time, increased resistance to more intrusive inspections developed. In 2004, Brazil refused to allow IAEA inspectors to access the cascade hall of its uranium enrichment facility at Resende to protect proprietary information. An arrangement has been found by which cascades remain hidden but this arrangement is not sufficient to resolve all ambiguities [33].

Also in 2004, the South Korean government confessed to the International Atomic Energy Agency that a group of scientists had produced without its knowledge, a small amount of near-weapons grade uranium using the AVLIS [34] enrichment technique. It also admitted to have separated a small quantity of plutonium. All these very sensitive activities had not been declared to the IAEA. Though the IAEA Board of Governors has concluded that it is satisfied with the declaration and explanation provided by South Korea, some doubts remain about the exact goal of these researches [35].

In December 2004, Egypt acknowledged that, between 1990 and 2003, it had conducted experiments involving the irradiation of small amounts of natural uranium in its reactors to test the production of fission product isotopes for medical purposes, and that it had not reported these experiments to the Agency [36]. In these two last cases, the use of open sources information analysis put the Agency in a better position to investigate these activities.

The threat of nuclear terrorism

In 2001, the September 11 terrorist attacks and the awareness of a pressing threat has accelerated the work on the prevention of terrorist acts and the mitigation of their consequences. Though the nuclear terrorist threat is not a new one, the September 11 attack and the development of sub state group activities in a context of regional crises (Afghanistan, Iraq, Iran, Chechnya, former Soviet Union Republics) have increased the importance of taking measures prevent terrorist actions. To this end, the international community has developed new instruments and strengthened existing ones. It should be expected that actions to combat nuclear terrorism would be closely linked to actions taken to combat nuclear proliferation. Thus, IAEA has set up a programme to help member States improve the security of their nuclear and radioactive materials and of the installations which contain them.

4 How to answer the new challenges?

To strengthen the nuclear non-proliferation regime to face the new challenges, the approach should be both a political one with the definition and implementation of new tools and a technological one to provide these tools with the best technologies in order to enable them to respond efficiently to these challenges. These developments should draw upon the experiences of the past (Iraq, North Korea) and the present (Iran, Libya).

4.1 New tools for nuclear security? Why and for what?

Addressing the proliferation of the nuclear weapons and the nuclear disarmament

To address effectively the proliferation of nuclear weapon and move toward nuclear disarmament, the international community needs to complete the legal framework it had started to set up ten years ago including the implementation of the NPT 1995 Conference decision 2, establishment of the Additional Protocol and the Comprehensive Safeguards Agreements as universal standards for non-nuclear-weapon States, the entry into force of the Comprehensive Test Ban Treaty, the negotiation and the adoption of a Fissile Material Cut-off Treaty and the strengthening of the nuclear export rules.

Addressing the traffic of sensitive technologies

The unveiling of the extension and range of activities of the A.Q. Khan multinational nuclear technology transfer network, prompted discussions on how to improve the export control rules as they apply in particular to dual-use items and guidelines in the Nuclear Suppliers Group and on how the IAEA and the safeguards system could better control the transfer of sensitive item by means of the Additional Protocol. International legislation has already been adopted to outlaw proliferation by implementing United Nations Security Council Resolution 1540 and to block the illicit trade with the implementation of Proliferation Security Initiative (PSI) by a group of concerned States and to amend the Suppression of Unlawful Acts at Sea Convention (SUA, see introduction) at United Nations International Maritime Organisation (IMO).

Addressing the Security of nuclear and radioactive materials

In the aftermath of the dramatic terrorist attack of September 11 event, international community became aware of the risk posed by the potential use of radionuclide materials as radioactive sources or spent fuel, not accounted for or not under adequate protection, for a radiological attack, in particular materials stored in the former Soviet Union. Actions have been taken in the framework of the G8 with the Global partnership, Global Threat reduction Initiative on radioactive sources, amendments to strengthen the Convention on the Physical Protection of Nuclear Material have been adopted, the IAEA is implementing a programme to combat nuclear terrorism and a code of conduct for the States on the safety and security of radioactive sources has been proposed.

Addressing the proliferation of means of delivery

The question of means of delivery, ballistic missiles, cruise missiles and other means such as unmanned aerial vehicle (UAV) needs to be dealt together with the question of nuclear weapon proliferation or the threat of terrorism. Iran, Iraq, North Korea and Libya, all have acquired or have developed various means of delivery adapted to their security environment. Delivery capabilities should be an important element in the evaluation of State proliferation potential "as a whole":

1. The possession by a proliferating state or a terrorist group of means of delivery able to carry nuclear weapons or chemical, biological or radioactive materials reinforces considerably the credibility level of the threatening capability.
2. Ballistic missiles have become exchange currency in the proliferation "bazaar". It is now assumed that North Korea (and possibly other countries) has exchanged missile technology for centrifuge technology with the A.Q. Khan network.

3. Instruments to prevent the illicit export of missile technology are only on a voluntary basis. The Missile Technology Control Regime (MTCR) should be strengthened to include new means of delivery and the adherence to the Hague Code of Conduct (HCoC) should be strongly promoted.

4.2 How advanced technologies can contribute to tackle the threats?

To be efficient and credible a non-proliferation or disarmament international instrument such as the NPT/IAEA Safeguards, CTBT, CWC, etc, should rely on efficient and credible verification tools that are capable of producing quick, un-ambiguous and reliable assessment of difficult situations (as it has arisen with the implementation of safeguards in Iran).

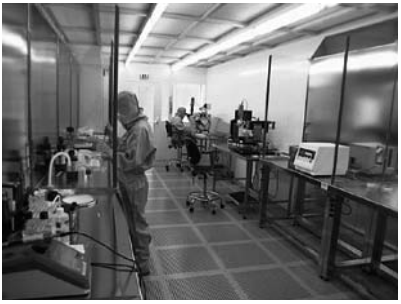


Fig. 11. Ultra-traces analysis of environmental samples at the DASE clean laboratory. Source CEA/DAM/DASE

Fig. 12. Geophysical survey /Ground Penetration Radar for DIV. Source CEA/DAM/DASE

Most of the time, investigation of suspicious activities has to be made in a hot political context and assessment of events has to be delivered within a short time period. The assessments have to be un-ambiguous, reliable, and trustworthy and, in cases of non-compliance, the evidence should be convincing; of course, efforts should be made to minimize the cost of the investigations.

An organisation in charge monitoring for and verifying compliance with the non-proliferation commitments needs to a "tool box" of the most sensitive and reliable technologies. It also needs the assistance of the member States and their strong support in research and development. The importance of technologies for IAEA safeguards implementation, on-site inspections in a future CTBT and other treaties discussed extensively by a number of contributors to this volume; some examples of applications of these technologies are shown in Figures 9 through 12: Satellite imaging for assessment of the Iran sites at Natanz, Parchin, Lavisan, Esfahan (Figures 9 & 10), environmental sampling and ultra-traces analysis for enriched uranium contamination of centrifuges parts in Libya, Iran and Pakistan (Figure 11), information collection and analysis for assessment undeclared past activities in Korea and Egypt, remote monitoring and advanced inspection equipment such as ground penetration radar to carry out design information verification (Figure 12). However, absent strong political commitments, even the best available technologies are practically useless.

4.3 A focus on nuclear fuel cycle and materials [37]

The discovery in the past few years that several non-nuclear-weapon States were able to conceal for decades research and development activities on sensitive technologies, the procurement or manufacture of related equipment (e.g., centrifuge components, laser enrichment parts), often through a clandestine procurement network of technology and know-how, and fissile material production activities, (as UF6, U metal, UHE, plutonium, Polonium) mainly related to uranium conversion and enrichment and reprocessing, have raised new concerns and call for new types of responses.

The findings of the IAEA have highlighted the possibility of a scenario where one non-nuclear-weapon State masters centrifuge enrichment technology or, less likely, laser enrichment technology and constructs and operates an enrichment facility for peaceful purpose under the umbrella of an IAEA comprehensive safeguards agreement and possibly with foreign open assistance; in parallel, the State constructs an undeclared facility at a concealed site, using the acquired know-how and operates this facility to manufacture nuclear weapons components (Figure 11). At a later time, the State may decide that the time is ripe to dismiss its commitments and to withdraw from the NPT with a three-month notice under the provisions of article X. The concern created by this possible scenario has generated several proposals to address the problem; among these are the proposal of President Bush to not allow access to sensitive technologies to States which do not already have a

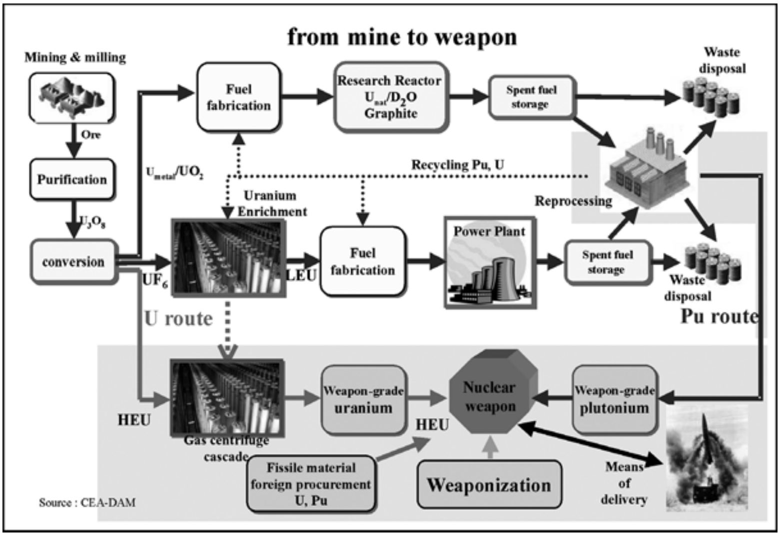


Fig. 13. Diversion of nuclear fuel cycle Sensitive Technologies

complete nuclear fuel cycle [38], the idea put forward by the Director General of IAEA that sensitive facilities must operate under international control [39], or the French proposal based on adherence to the additional protocol and several other criteria [40]. The French proposal also addressed the capacity of the IAEA and the member States to detect concealed sites with undeclared uranium enrichment activities and to develop adequate technological means for doing so.

4.4 An European Union security prospective

The European Defence and Security Policy has taken into account the threats of proliferation of weapons of mass destruction and hyper-terrorism. Following the Thessaloniki summit joint declaration, the European strategy has been spelt out in the document "A secure Europe in a better world". Actions on technologies research and development are outlined in the document "Preparatory Action in the field of Security Research and development (PARS) with the view to prepare the future European security capabilities and improve the support to international organisations [41].

5 Compliance is the key but how to enforce it?

5.1 Compliance

Notwithstanding the potential efficiency of the new instruments, the strengthening of the ones in force already agreed upon by the international community and the capabilities of the monitoring and verification technologies developed to support them, they will not be of much use, if there is no political will and means to redress non-compliance once evidence of it has been established. Following are some ideas on how to re-establish compliance.

5.2 Verifying compliance / the needed authority [42]

Compliance can only be verified effectively to the degree that States honour their political commitments. The organisation which is charged with the responsibility to verify compliance should be given the necessary authority from the international community to do so. For example, the IAEA in implementing the Comprehensive Safeguards Agreements and Additional Protocols should have the appropriate authority to be able to carry out verification activities at suspicious sites or facilities while respecting the sovereignty of the State.

5.3 Verifying compliance / the needed resources

The major challenge confronting organisations like the IAEA is how to monitor compliance of the States with their commitments and to evaluate how a State "as a whole" complies with them. The concept of "as a whole" encompasses the detection of undeclared material and activities and the detection of illegal transfers, imports and exports; for example, the development of a clandestine uranium enrichment capacity depending on transfers of know-how and technologies through an undercover network and the fabrication of sensitive equipment through delocalisation in a third country.

To answer this challenge, IAEA should rely on collected and supplied information and on advanced technologies such as remote monitoring and sensing, e.g., satellite imagery, environmental sampling for forensic investigation, modern inspection equipment, and so on. The IAEA should also be able to collect, process, fuse and analyse information from diverse sources, e.g., verification activities, open sources and "third party" sources, that to say from intelligence sources.

The IAEA and similar other international organisations (i.e. INVO, OPCW, UNMOVIC) is not a research and development institution and has no means to develop cutting edge technologies by itself or to know how advanced nuclear fuel cycle technologies work. Neither does it have the means to collect intelligence. It can only define and express needs. The organization will be able to discharge its responsibilities only if the member States are required to adequate know-how, equipment and training.

From that perspective and with the support of member States, the IAEA (and other similar organisations) should form highly specialized teams that deal with very specific subjects such as satellite imagery, information processing, advanced nuclear fuel cycle technologies, e.g., laser or centrifuge enrichment. The IAEA and similar organizations, in return for having access to highly specialized tools and information should establish more stringent rules to protect the confidentiality of sensitive information it receives; otherwise the non-proliferation regime would suffer serious damage. Though the management and protection of highly confidential information in the IAEA have been dramatically improved in the last fifteen years, progresses still remain to be done.

Regarding the handling of sensitive issues related to research, development and manufacture of nuclear weapons, the IAEA is bound by the Treaty for the Non Proliferation of Nuclear Weapons which prohibits any entities except the five Nuclear Weapon States to deal with them and by its statute which limits its objectives to peaceful use of nuclear energy (article II & III). Its capabilities of action in this area are also limited by the high confidentiality attached to any information related to nuclear weapons design, manufacture and testing. When the Agency has to deal with nuclear weapons related issues, it has to call for the support of P5 member States through ad hoc organizations like INVO (ex Action Team), or an ad hoc team, like for the nuclear disarmament of Iraq, the assessment of South Africa self nuclear weapon programme removal and the inspections on Libyan nuclear programme.

5.4 Enforcing compliance / a renewed role of the UN Security Council

All the efforts of the international community to patch loopholes and strengthen tools to stop proliferation and prevent nuclear terrorism would be for naught unless the States provide the appropriate means to utilize these instruments. First and foremost is the power and involvement of the United Nation Security Council to resolve crises. The role, composition and mandate of the Security Council should be revisited, extended, reinforced and backed by the leading States including the P5 and G8. The Security Council could also rely on a "body" of experts and inspectors to be able to be involved directly on all issues concerning weapons of mass destruction. In some situations, the intervention of external facilitators could also ease the political handling of sensitive cases as for example the action of the EU3 to secure a suspension of Iran's enrichment activities.

6 An attempt to a look forward

For the time being, considering the current situation, the prospects of stemming proliferation are not encouraging. Adherence to international instruments to strengthen the nuclear non-proliferation regime and stop the dissemination of nuclear weapons is proceeding at a slow pace. Given the urgent challenge the non-proliferation regime is facing, the outcome of the 2005 NPT Review Conference is particularly disheartening. Though the challenges were more clearly identified, States parties to the NPT were unable to agree on how to strengthen the implementation of the Treaty [43] and to prevent and punish breaches.

Proliferation issues are not on the way to being settled except for Libya and Iraq (this latter with still some reservation until the Security Council declares the disarmament of Iraq officially completed) most of the files are not anywhere near to being closed. North Korea has withdrawn from the NPT and is still a threat. The six-party talks have lingered and seem to be going nowhere. A new offer from North Korea to give up its nuclear weapon programme and return to the NPT in exchange for being supplied with nuclear power reactor may help to resolve the situation, though it is the look of "déjà vu". Nobody has yet a clear picture of the nuclear capabilities of North Korea; how large is the weapon-grade plutonium stockpile? How many nuclear weapons does it have now? Is it able to produce highly enriched uranium? If yes, how much is it able to produce? Meanwhile, North Korea continues to develop ballistic missiles able to carry WDM payload, possibly nuclear, at long distances and still has the capacity to trade missile technology for nuclear technology. Iran is obviously trying to save time before resuming conversion and enrichment activities and continuing its underground activities.

Finally the Indian-American joint statement of July 2005 raised the hope that a developing democratic country would get closer to the non-proliferation norms, in exchange for its participation in the international nuclear trade in the framework of a specific regime as a non-NPT state. However, such an exercise which is supported by most of developed countries and the IAEA will be delicate to carry out as it may undermine the non-proliferation regime as a whole.

7 Conclusion

In the beginning of the 21st Century, the international community has to tackle new threats that challenge the nuclear regime and call for appropriate responses. These threats are diverse but linked together: threats of clandestine nuclear weapon programme development under the umbrella of the NPT membership as for Iraq, Iran, Libya and North Korea; threats by the dissemination of sensitive technologies and nuclear material from non-NPT States such as Pakistan and the A. Q. Khan nuclear black market; threats of hyperterrorism from sub-state groups acquiring radioactive or fissile material for a radiological dispersion device or even a crude improvised nuclear weapon; threats also by the development and acquisition outside the international control regime by the same threatening entities of means of delivery, e.g., ballistic missiles or other means.

Loopholes in the current non-proliferation scheme and limitation of instruments have been identified. In this chapter we have put forward some possible ways to redress the situation and arrive at a more robust and effective nuclear non-proliferation regime by building upon the invaluable role of member

States in supporting the institutional framework as the United Nations Security Council and the IAEA and in providing them with advanced technological means. Ideas generated from field experience in managing past crises need to be implemented by responsible States and international organisations. These ideas have already given birth to new proposals and multilateral initiatives and agreements to strengthen the different aspects of the regime with focus: first on export controls and the prevention of illicit transfers; second on the prevention of the diversion of sensitive technologies of the nuclear fuel cycle, uranium enrichment, spent fuel reprocessing and storage, heavy water production, research reactor operation; third on the security of fissile and radioactive materials through strengthened physical protection measures to establish universal norms. National legal dispositions should outlaw proliferation related activities and trade as it is called for by United Nations Security Council Resolution 1540. The implementation of these initiatives and the operation of all the new tools should rely on the further development and use of advanced technologies both at the national level or international level as the experience gained from the field in Iraq, North Korea and now Iran and Libya demonstrates clearly.

The efforts of the international community to strengthen the mechanisms for stopping proliferation and preventing nuclear terrorism would be vain, if the States do not take the appropriate actions to do so. First they must seek universality **by promoting universal adherence** to an amended, strengthened and balanced non-proliferation regime. Second they must insist on enforcement of compliance enforcement; monitoring for compliance should be done by an appropriate **verification system based on the best technological means** and successful inspections under a strong mandate and support. Third, the States should provide **political and technical** support; past and field experiences from the IAEA demonstrate that nuclear verification and monitoring works best when backed by strong political and technical support. Fourth, there should be **enforcement of international law**; the role and involvement of the United Nation Security Council in the resolution of crises should be revisited, extended, reinforced and backed by a possible "body" of experts and skilled inspectors.

References

1. International Atomic Energy Agency (IAEA) (1972): Document INFCIRC/153 (corrected), *The Structure and Contents of Agreements between the Agency and States required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons* also known as Comprehensive Safeguards Agreement (also called "Full Scope Safeguards").
2. Agreed Framework between the USA and the Democratic People's Republic of Korea (1994): The agreed framework has been concluded between the North Korea and the USA in October 1994 and provided for the freeze of the operation or construction and eventually for the dismantling of all the north Korean critical

nuclear facilities including plutonium production reactors, reprocessing plant and fuel fabrication facility.

3. United States of America President Eisenhower (1953): "*Atom for Peace*" speech to the United Nations General Assembly on the 8^{th} December 1953 (http://www.iaea.or.at)
4. International Atomic Energy Agency (IAEA), (1956): Adoption of the IAEA statute on the 23^{rd} October 1956.
5. International Atomic Energy Agency (IAEA), (1961): Document INFCIRC/26 (1961) The Agency Safeguards System first type of agreement covering, only reactors rated less than 100 Mw_{th} then extended later to cover reactors of any sizes
6. International Atomic Energy Agency (IAEA), (1968): Document INFIRC/66/rev.2 1968, *The Agency's safeguards system, as approved by the Board of Governors in 1965, and provisionally extended in 1966 and 1968*, covers reactors of all size, reprocessing plants and fuel fabrication plants.
7. Treaty on Non-Proliferation of Nuclear Weapons (NPT), (1968): *Article II: Each non-nuclear-weapon State Party to the Treaty undertakes not to receive the transfer from any transferor whatsoever of nuclear weapons or other nuclear explosive devices or of control over such weapons or explosive devices directly, or indirectly; not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices; and not to seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices.*
8. Threshold Test Ban Treaty (TTBT), (1996): The Threshold Test Ban Treaty which prohibits nuclear explosion was the first agreement between USA and Soviet Union which was relying on mutual verification through on site-inspection.
9. International Atomic Energy Agency (IAEA): Zangger Committee guidelines and export control list has been published in IAEA document INFCIRC/209 (1974), *Communications of Received from Member States Regarding the Export of Nuclear Material and of Certain Categories of Equipment and Other Material* and revised in 2000 as IAEA/INFCIRC/209/Rev.2.
10. International Atomic Energy Agency (IAEA): Nuclear Supplier Group (NSG) guideline and export control list has been published in IAEA document INFCIRC/254 (1978): *Communication Received from Certain Member States Regarding Guidelines for the Export of Nuclear Material, Equipment or Technologies*. Revised after the discovery of Iraq nuclear weapon programme to be strengthened and include dual use material, equipment and related technologies as a trigger list published as IAEA/INFCIRC/254/Rev.1/Part 1 (1992) and a dual use items list has been published as INFCIRC/254/Rev.2/Part 1/Mod.1. (1996). Since, subsequent revisions has been made published as INFCIRC/254/Rev.7/Part 1 (2005) and INFCIRC/254/Rev.6/Part 2 (2005).
11. Treaty on Non-Proliferation of Nuclear Weapons (NPT), (1995): *Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons*,1995, the final document of the Conference has been published as NPT/CONF.1995/32 (Part I).
12. Comprehensive Test Ban Treaty (CTBT) (1996): The preamble of the CTBT states that *"The States Parties to this Treaty (hereinafter referred to as "the States Parties"), Recognizing that the cessation of all nuclear weapon test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons and ending the development of ad-*

vanced new types of nuclear weapons, constitutes an effective measure of nuclear disarmament and non-proliferation in all its aspects".

13. Comprehensive Test Ban Treaty (CTBT) and International Monitoring System (IMS): Information on the status of the CTBT and progress of the monitoring network are provided on the CTBTO PTS website: http://www.ctbto;org
14. Comprehensive Test Ban Treaty (CTBT) Entry into Force: The Entry into force of the CTBT requires the ratification of 44 states listed in Annex 2 of the Treaty. So far, 33 Annex 2 states have ratified but key states as United States, China, India, Israel, Pakistan, Iran, North Korea have not ratify it and do not seem willing to do it.
15. David Albright and Kimberley Kramer /ISIS (2004): "Fissile material: Stockpile still growing", *Bulletin of Atomic Scientist, November/December 2004*. Russia has declared 50 tonnes of military plutonium and 500 tonnes of HEU, 200 tonnes of which have already been down blended. United States have declared 52.5 tonnes of plutonium and 170 tonnes of HEU 50 tonnes of which have already been down blended. Among the 50 and 52.5 tonnes of plutonium, United States and Russia have agreed to dispose 34 tonnes each through irradiation as MOX fuel in nuclear civil reactors. Great Britain has declared 4.4 tonnes of military plutonium in excess.
16. Marc Zwilling, Chef de Bataillon, Unite Française de Vérification (2005): This volume, Treaty on Conventional Forces in Europe (CFE).
17. Jill Cooley (1998): "The Programme to strengthen the Effectiveness and Improve the Efficiency of Safeguards", *International Seminar on the 1998 preparatory Committee for the 2000 NPT Review Conference, ANNECY, France, 27 02 - 01 03 1998. "The discovery of a clandestine nuclear weapons programme in Iraq, the continuing difficulty in verifying the initial report of the Democratic People's Republic of Korea (DPRK) upon entry into force of their safeguards agreement and the decision of the South African Government to give up its nuclear weapons programme and join the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) have all played a role in an ambitious effort by International Atomic Energy Agency (IAEA) Member States and the Secretariat to strengthen the safeguards system".*
18. International Atomic Energy Agency (IAEA), (1997): *Model Protocol Additional to the Agreement(s) Between States and the International Atomic Energy Agency for the Application of Safeguards.* IAEA/INFCIRC/540 (corrected).
19. See ref. 10.
20. Pierre Goldschmidt (1999): "The IAEA system moves into the 21st century", *Supplement to the IAEA bulletin, Vol. 41, N. 4/December 1999*, International Atomic Energy Agency (IAEA), Department of safeguards: For more information see http://www.iaea.org/
21. United Nations Monitoring Verification and Inspection Commission (UNMOVIC ex UNSCOM/United Nations Special Commission) and: Iraq Nuclear Verification Office (INVO, ex Action Team)
22. United Nations Security Council (1991): *"Plan for future Ongoing Monitoring and Verification (OMV) of Iraq's compliance with paragraph 12 of part C of UNSCR Resolution 687 and with the requirements of paragraphs 3 and 5 of resolution 707"* adopted under UNSCR 715 (1991). Cote S/22872/Rev.1
23. Iran Watch (February 2005): *"IAEA reports and other documents 09-02-05 - Director General's Report: Implementation of the NPT Safe-*

guards Agreement in the Islamic Republic of Iran (GOV/2005/67)". http://www.iranwatch.org/international/index-iaea.html.

24. International Atomic Energy Agency (IAEA), (2005): *"The Convention on the Physical Protection of Nuclear Material (CPPMN)" published as IAEA/INFCIRC/274/Rev.1, May 1980. The new strengthened Convention binds States parties to protect nuclear facilities and material in peaceful domestic use, storage as well as transport and provide for expended cooperation between and among states regarding measures to locate and recover stolen and smuggled nuclear material, mitigate any radiological consequences of sabotage and prevent and combat related offences. The original CPPMN applied only to nuclear material in international transport"* (IEAE press release 2005/03).
25. Comprehensive Safeguards Agreements (CSA): see [1]
26. Conference on Disarmament (CD): *"The question one could raise about the Conference on Disarmament stalled since eight years a sleeping beauty fallen asleep after a bright youth : NPT, CWC, CTBT, an old lady in the winter of its life or in irreversible coma? as pointed out by some, she has already been in this state in the past, so let's be patient!"*
27. United Nations Security Council (1991): UNSC in article 12 of Resolution 687 *"Decides that Iraq shall unconditionally agree not to acquire or develop nuclear weapons or nuclear -weapons-usable material or any subsystems or components or any research, development, support or manufacturing facilities related to the above;.... to place all of its nuclear-weapons-usable materials under the exclusive control, for custody and removal, of the International Atomic Energy Agency, to accept urgent on-site inspection and the destruction, removal or rendering harmless as appropriate of all items specified above; and to accept the plan discussed in paragraph 13 below for the future ongoing monitoring and verification of its compliance with these undertakings"*.
28. International Atomic Energy Agency (IAEA), (1997): *"Iraq's lack of cooperation has required the IAEA to follow a protracted and painstaking process involving on site inspections, collection and analysis of procurement information and follow-up of other information provided by member state. The results of the IAEA's investigation have over many years yielded a technically coherent picture of Iraq clandestine programme."*, GOV/INF/827 part. Two, para. 76, 19 November 1997.
29. IAEA: Iraq Nuclear Verification Office (INVO) / ex Action Team: A memorandum about talks between Iraq and Pakistan on possible supply of nuclear weapons related information was found in 1995 at Hussein Kamel's Chicken Farm.
30. Agreed Framework between the United States of America and the Democratic People's Republic of Korea (1994): The Agreed Framework provides for the supply of heavy fuel and the construction of two non proliferating light water reactor under the KEDO supervision.
31. The six States involved in the six parties talks are North Korea, United States, Russia, China, South Korea, Japan.
32. IRAN WATCH-IAEA report, (2004): *"Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran, Report by the Director General"*. GOV/2004/83, 15 November 2004.
33. Peter Slevin (2004): *"Brazil shielding uranium facility. Nation seeks to keep its proprietary data from U.N. inspectors"*, The Washington Post, April 4 2004.

34. Atomic Vapour Laser Isotope Separation (AVLIS) is a very advanced enrichment technique which was thought to be within the reach of and mastered by only few countries. Inspection in South Korea and Iran have demonstrated that this idea should be discarded
35. David E. Sanger and William J. Broad (2004): *"South Koreans Say Secret Work Refined Uranium"*, Washington Post , September 3, 2004,
36. International Atomic Energy Agency (IAEA), (2005): *"Implementation of the NPT Safeguards Agreement in the Arab Republic of Egypt"*, Report by the Director General, document GOV/2005/9, 14 February 2005.
37. Pierre Goldschmidt (2004): Statements of M. Pierre Goldschmidt, Deputy Director General head of Safeguards Department of the IAEA, *"The Proliferation Challenge of the Nuclear Fuel Cycle in Non-Nuclear Weapon States"*, Institut Franais des Relations Internationales on,26 April 2004, Paris, France and *"Strengthening the Nuclear Non-Proliferation Regime: The Need For Broad Information and Access Rights"*, Carnegie International Non Proliferation Conference on 22 June 2004, Washington, USA.
38. United States of America President G. W. Bush: Remarks by the President on Weapons of Mass Destruction Proliferation, National Defence University, Fort Lesley, 23 March 2004.
39. International Atomic Energy Agency (IAEA), (2005): *Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency* INFCIRC/640 (Date: 22 February 2005).
40. Treaty on Non-Proliferation of Nuclear Weapons (NPT), (2004): Working paper submitted by France at the third Preparatory Committee for the 2005 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, 4 May 2004, NPT/CONF.2005/PC.III/WP.22.
41. Roland Schenkel (2005): "Nuclear Security at the JRC" presentation of Roland Schenkel, European Commission Director General of the Joint Research Centre:. ESARDA Symposium: 10-12 May 2005, London.
42. Pierre Goldschmidt (2003): Statement of Pierre Goldschmidt, IAEA, Deputy Director General, head of Safeguards Department on 25 September 2003, *Workshop on PCM&A best practices.*
43. International Atomic Energy Agency (IAEA), (2005): *"Introductory statement of IAEA Director General to the Board of Governors"*, IAEA, Vienna, 14 June 2005.

IV

Formal Models of Verification

The allocation of inspection resources and the assessment of the effectiveness of verification systems require a quantitative framework. Game theoretical tools have been shown to be appropriate for offering solutions of these crucial problems.

Formal Models of Verification

Rudolf Avenhaus and Morton Canty

1 Introduction

Inspection regimes for arms control and disarmament provide good examples of potential conflict situations that are subject to quantitative analysis. The inspected party, in this case a sovereign State, may have some incentive to violate its commitments deliberately and in a clandestine way, a possibility that necessitates the regime's verification measures. The Inspectorate, acting on behalf of a community of participating States (e.g. the United Nations), will wish to deter such illegal activity and, should that illegal activity nevertheless take place, detect it with the highest possible probability and speed. The potential violator knows that, by virtue of the inspection regime, a violation risks detection and may incur punishment in the form of sanctions or even military intervention. Therefore, if a State chooses illegal behavior, it will wish to avoid detection with the highest possible probability or at least delay detection for as long as possible.

It is because the preferences and strategic alternatives of the protagonists may be stereotyped in this way that routine inspection activities can, in principle at least, be treated quantitatively. It is possible to calculate and optimize the effectiveness of inspections and to quantify the idea of deterrence. The underlying concept is that of non-cooperative game theory together with its "solution", the so-called Nash equilibrium. This concept was formulated by the American Nobel laureate John Nash in the early 1950s [1]. It proposes that protagonists in a conflict situation will choose their strategies so that neither has an incentive to deviate unilaterally from his or her choice. This deceptively simple definition is the foundation of non-cooperative game theory and is recognized as a necessary condition for rational behavior.

Of course one might object that verification regimes are largely cooperative in nature, serving to bolster mutual international trust through voluntary submission to external scrutiny. But non-cooperative game theory, despite its name, by no means excludes cooperative behavior. For example in the famous *prisoners' dilemma*, see e.g. Myerson [2] there exists a mutually preferable, cooperative alternative, which however, because it violates Nash's rationality condition, is unfortunately not acceptable. In a "verification game" on the other hand, one quite generally observes the situation in which the Inspectorate carries out some inspection plan and the State, acting upon its own best interests, behaves legally. This cooperative behavior may be reached even if the State has some real incentive not to cooperate, and if it is, we have a formal definition of deterrence: a Nash equilibrium in an inspection regime in which the State's equilibrium strategy is to behave legally [3].

In the following we illustrate the application of formal models to verification problems at what we call the *conceptual*, *structural* and *operational* levels. The conceptual illustration treats the problem of arms control and disarmament in a very general way, providing insight into the nature (and necessity) of verification. The structural example demonstrates how sensibly the best inspection strategies depend on specific assumptions. The operational application provides an inspector with concrete advice as to how to spend his allotted inspection time most effectively.

2 A conceptual model: To sign or not to sign?

It is a commonplace among people of good will that arms control and disarmament (ACD) agreements among sovereign States are "good". Generally, independent verification of such agreements is also seen to be "good", although inspected States may in some cases resent the implication that they might violate their legal commitments through non-compliance. In any case, if we wish to understand the prevailing norm, in which States both sign ACD agreements and submit to verification under them in good faith, we must consider deviations from that norm. This is because in doing so, we can examine the conditions under which "good" behavior in the above sense is also rational and in a State's best interests, i.e. a Nash equilibrium. Deviations can involve a simple refusal to sign an agreement, or even acquiescence followed by clandestine violation. Both these strategies have of course been observed in the case of the Nuclear Non-proliferation Treaty (NPT).

Our analysis is based on the assumption that there are two dominating considerations for a State contemplating entering into an ACD agreement, namely

prestige (abbreviated p) - to be seen to be conforming to the accepted norm and

security (abbreviated s) - invulnerability to military force.

Thus we assume self-interest, rather than morality or honesty, to be the motivating force. Moreover we assume that the outcome

- not signing the agreement is bad for p and good for s,
- signing with compliance is good for p and bad for s,
- signing and undetected violation is good for p and good for s and

- signing and detected violation is bad both for p and for s.

These considerations of course must really be considered on a case-by-case basis. Becoming a signatory to an ACD can mean a loss of prestige in the third world if the impression is given that it is a concession to western powers. Similarly not entering into an agreement might invite preventative action and thus be very bad for military security.

To proceed quantitatively we must now assign the State's *utilities* to the above outcomes. These are numbers whose magnitudes reflect the order of preference:

- not sign: d_1
- sign with compliance: d_2
- sign and undetected violation d_3
- sign and detected violation: $-b$.

where, in view of the above considerations, we have

$$d_3 > \max(d_2, d_1, 0), \quad b > 0. \tag{1}$$

Implicit in the above is the *strategy set* for the State:

$$\{\text{not sign, sign and comply, sign and violate}\}.$$

Next we require the utilities for the other protagonist, namely the International Community (IC), represented by the Treaty Authority and, eventually, its Inspectorate. They are

- not sign: $-e$,
- sign with compliance: 0,
- sign and detected violation: $-a$ and
- sign and undetected violation $-c$,

where we assume

$$0 < a < c, \quad 0 < e, \tag{2}$$

reflecting the fact that the primary wish of the IC is to *deter* the State from non-compliance to a signed agreement.

It may appear that the IC has no strategic alternatives in this model, i.e. it simply "inspects". To be as general as possible, however, let us assume that the IC's strategy set is in fact

$$\{\text{not verify, verify}\}.$$

The first strategy models the situation for the Biological Weapons Convention, for example, for which no verification regime was specified. (In a more refined model, "not verify" could mean that inspections are performed on a random basis, implying that some locations or items are not verified.)

Now let us take the probability of detecting a clandestine violation to be $1-\beta$ in the event of verification, and exclude the possibility of false accusation (false alarm) for the time being. This introduces an element of chance into the model, and we can now only speak of *expected* utilities. For the State the utilities are, for all possible strategy combinations of both parties,

d_1 - not sign
d_2 - sign and comply
$-b(1-\beta)+d_3\beta$ - verify, sign and violate
d_3 - not verify, sign and violate.

(Here one might challenge the assumption that agreement and compliance will have the same utilities whether the IC verifies or not. It was the explicit desire to have its compliance confirmed by inspection that induced Germany to accept the NPT and its verification regime in 1968.)

For the Inspectorate the utilities are accordingly

$-e$ - not sign
0 - sign and comply
$-a(1-\beta)-c\beta$ - verify, sign and violate
$-c$ - not verify, sign and violate.

The strategic situation is depicted graphically in Fig. 1 as a so-called *non-cooperative game in extensive.*

The game representation in this figure is self-explanatory. The non-terminal nodes (open and closed circles) of the tree represent decision points for the protagonists, and the terminal nodes correspond to the five possible outcomes. The game is said to be one of perfect information because each player knows the precise situation that has been reached in the game when required to make a decision. The extensive form is a fundamental and complete way of representing a non-cooperative game. The equilibria of games of perfect information, when represented in this way, can always be determined, at least in principle and in our particular case, by *backward induction.* Let us proceed to do so.

Case 1. $d_2 < -b(1-\beta)+d_3\beta$

This is equivalent to assuming that the non-detection probability β is larger than some threshold value,

$$\beta > \frac{d_2+b}{d_3+b}. \tag{3}$$

In view of (1), if the State is at its lower rightmost decision point in Fig. 1, it will violate. Suppose that the State finds itself at its lower left hand decision point. Then it will again be in its interest to violate, by virtue of (3). Therefore we can "back up" the game tree, as shown in Fig. 2.

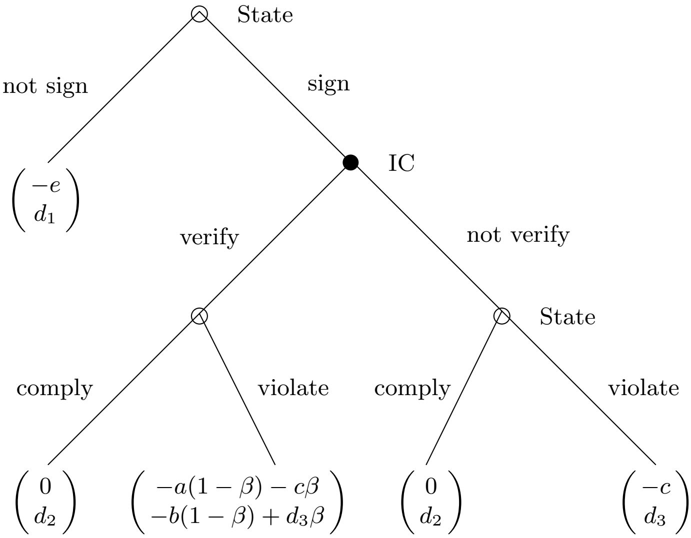


Fig. 1. The International Community (IC) - State game in extensive form

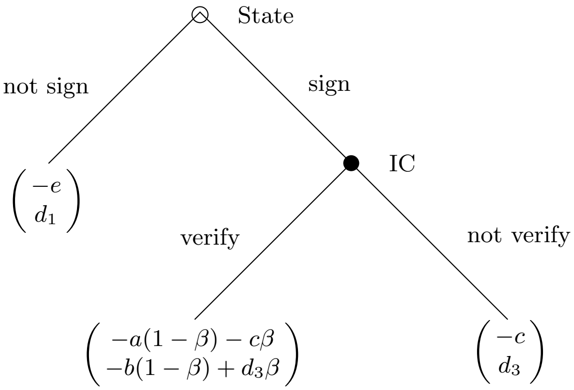


Fig. 2. Reduced form of the IC - State game

But now, since $c > a$ according to (2), the IC will of course wish to verify the agreement, leading to the lower left hand outcome. The choice that the State makes at its topmost decision point, i.e. to sign or not to sign, will again depend on its utilities and on the detection probability.

Case 1.1 $d_1 < -b(1-\beta) + d_3\beta$

This is equivalent to

$$\beta > \frac{d_1 + b}{d_3 + b} \tag{4}$$

and a Nash equilibrium {verify, sign and violate}.

Case 1.2 $d_1 > -b(1-\beta) + d_3\beta$

This is equivalent to

$$\beta < \frac{d_1 + b}{d_3 + b} \tag{5}$$

and a Nash equilibrium {verify, not sign}. Of course the IC strategy "verify" is never actually realized, since the State refuses to sign the agreement.

Case 2. $d_2 > -b(1-\beta) + d_3\beta$

This is equivalent to assuming that the non-detection probability is smaller than some threshold value

$$\beta < \frac{d_2 + b}{d_3 + b}, \tag{6}$$

and using similar reasoning we can back up the game tree as shown in Fig. 3.

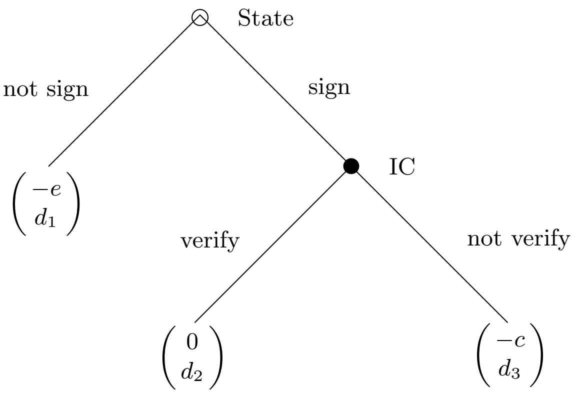


Fig. 3. Second reduced form of the IC - State game

Case 2.1 $d_1 > d_2$

Nash equilibrium is {verify, not sign}.

Case 2.2 $d_1 < d_2$

Nash equilibrium is {verify, sign and comply }.

Since "not verify" is never an equilibrium strategy for the IC, we need not consider it further. We have, then, the following equilibria for the State, depending on the values of the utility parameters:

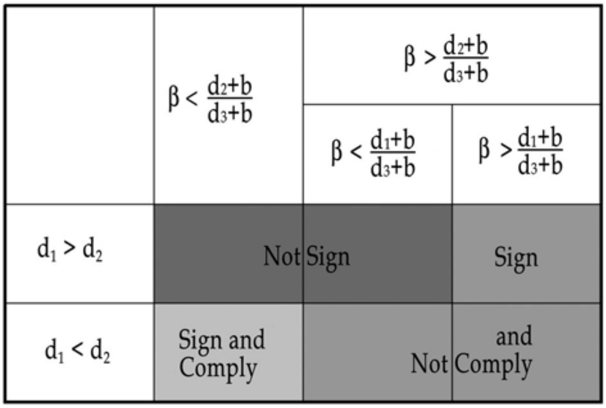


Fig. 4. Summary of the equilibria of the IC-State game. Note that from $d_1 < d_2$ and $\beta > (d_2 + b)/(d_3 + b)$ it follows that $\beta > (d_1 + b)/d_3 + b)$. Thus the subdivision between $\beta < (d_1 + b)/d_3 + b)$ and $\beta > (d_1 + b)/d_3 + b)$ refers only to the row $d_1 < d_2$

$$\text{No agreement: } d_2 < d_1, \quad \beta < \frac{d_1 + b}{d_3 + b}$$
$$\text{Agreement, Non-compliance: } \beta > \max\left(\frac{d_1 + b}{d_3 + b}, \frac{d_2 + b}{d_3 + b}\right)$$
$$\text{Agreement, Compliance: } d_1 < d_2, \quad \beta < \frac{d_2 + b}{d_3 + b},$$

see Fig. 4. These conditions depend only on the ratios of d and b. In fact we could have chosen $b = 1$. Moreover only the utilities of the State are used explicitly.

Most importantly, agreement and compliance constitutes an equilibrium strategy for the State if and only if $d_1 < d_2$, i.e. security with loss of prestige is judged by the State to be worse that prestige accompanied by a loss of security and, furthermore, the probability of detecting non-compliance is sufficiently large, that is $1-\beta > 1-(d_2+b)/(d_3+b)$. This result is hardly a surprising one, but we have demonstrated that self-serving, rational (i.e. Nash equilibrium) strategies on the part of the protagonists IC and State correspond to common sense behavior. In addition, we have quantified the intensity of verification needed for this behavior to occur.

It is interesting to note that, if the State does not know whether or not verification takes place (as might be the case for random sampling of inspected locations), we get the same equilibria as above.

As a special case, define the utilities p for prestige, $-p$ for no prestige, s for security and $-s$ for no security. Then the utilities of the State are

$$\begin{aligned} d_1 &= -p + s \\ d_2 &= p - s \\ d_3 &= p + s = b, \end{aligned}$$

and the threshold values for the non-detection probability are

$$\begin{aligned} \frac{d_1 + b}{d_3 + b} &= \frac{s}{p + s} \\ \frac{d_2 + b}{d_3 + b} &= \frac{p}{p + s}. \end{aligned}$$

Then agreement and compliance is a Nash equilibrium if and only if

$$s/p < 1 \quad \text{and} \quad \beta < \frac{1}{1 + s/p} \left(> \frac{1}{2} \right);$$

we see that the smaller the ratio s/p, the less strict the requirement on the non-detection probability β. In any case β need not be smaller that 1/2.

3 Structural models: Randomized unannounced inspections

An often-discussed proposal to reduce routine inspection effort while maintaining the timeliness of an inspection regime is to replace scheduled inspections with a smaller number of randomly chosen, unannounced inspections. The unpredictability aspect of such measures is appealing, as they would seem to place the potential violator in a permanent state of uncertainty and thus serve to deter illegal activity. In the context of routine verification under the Nuclear Weapons Non-Proliferation Treaty, Sanborn [4] contrasts the intuitive attractiveness of unannounced, random inspections with the substantial practical difficulties of implementing them and with the burden to the inspected party in trying to accommodate them. The problem therefore arises as to the true effectiveness of randomized inspections, a problem which we can analyze with the aid of non-cooperative game theory.

There are various ways to model the timeliness capability of routine inspection regimes. For instance one can choose objective functions which are dependent on the time between the beginning of illegal activity and its detection, or ones which are simple dichotomies based on some imposed critical detection time goal. One can assume unobservable inspections such as might be associated with instrumental or remote surveillance or, alternatively, that the inspections are observable so that the inspectee can make his actions conditional on those of the inspector. Furthermore, statistical error probabilities may or may not be taken into account.

The inspection games that we analyze in this Section are intended to describe on-site (and thus observable) inspections [5, 6]. Non-detection (second kind error) probabilities and associated false alarm (first kind error) probabilities are included. The inspectee can react flexibly to the observed activity of the inspector, choosing illegal or legal behavior according to his own perceived self-interests. We seek rational behavior, i.e. the Nash equilibria of the games.

3.1 Meeting timeliness goals

Consider a single inspected object, for example a nuclear or chemical facility subject to verification in the framework of an international treaty, and a reference period of one time unit (e.g. one calendar year). Let us assume that the required detection time goal is $t = 1/2$. By this we mean the maximum time available to the inspector for detection of an illegal activity. Suppose that due to resource restrictions, the inspector can perform only a single inspection, either at $t = 1/2$ or at $t = 1$. The inspectee either behaves legally or carries out an activity in violation of commitments precisely once during the reference interval. Clearly the inspectee, if he decides to behave illegally, will do so either at the beginning of the period ($t = 0$) or immediately after $t = 1/2$.

If no illegal behavior and no false alarm occurs (see below), both players receive by definition payoff nil; this is also the best result for the inspector and implies that inspection costs are not part of the inspector's payoff. If illegal behavior occurs and is detected by an inspection within time t, then detection is timely. The inspectee's payoff upon detection is $-b < 0$, and that of the inspector is $-a < 0$, since this is only his second best outcome. Otherwise, detection is not timely; the inspectee then receives maximum payoff, $d > 0$, and the inspector minimum payoff, $-c < -a$. If illegal behavior and inspection time points exactly coincide, we adopt the convention that detection can only occur at the next inspection.

In general, quantitative measurements are made at the inspection, so that errors of the first and second kind can occur. We characterize their probabilities with α (the false alarm probability) and β (the non-detection probability already used in the preceding section), respectively. Both probabilities depend on each other. In general, β is a monotonically decreasing function of α with boundaries $\beta = 1$ for $\alpha = 0$ and $\beta = 0$ for $\alpha = 1$. In practical terms and for given measurement systems this means that one of the two probabilities can be made small only at the expense of the other.

A false alarm incurs penalty $-e$ to the inspector and costs $-f$ to the inspectee. We shall assume throughout that $a > e$, $b > f$. The *expected* payoffs to the inspector as player 1 and to the inspectee as player 2 are

$$\begin{aligned} (-a(1-\beta) - c\beta, -b(1-\beta) + d\beta) &\text{ for timely detection of illegal action} \\ (-e\alpha, -f\alpha) &\text{ for legal behavior by the inspectee.} \end{aligned} \tag{7}$$

Define for convenience the quantities

$$A = (b + d)(1 - \beta) > 0, \quad B = (c - a)(1 - \beta) > 0. \tag{8}$$

We assume furthermore that the inspector's decision whether or not to call an alarm is based on an *unbiased test procedure*, i.e., if $1 - \alpha - \beta > 0$, which implies, because of $f < b$,

$$A - f\alpha > 0. \tag{9}$$

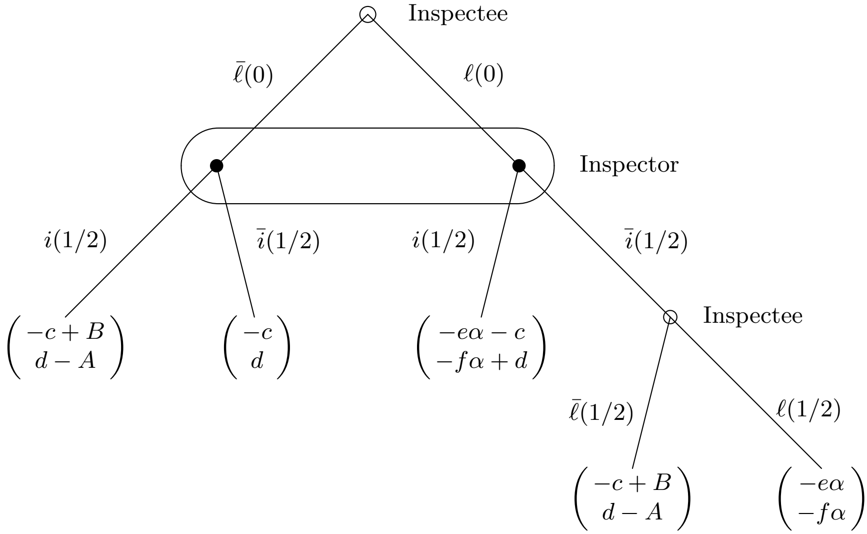


Fig. 5. Extensive form of the critical time inspection game. $\ell(t)$ denotes legal behavior, $\bar{\ell}(t)$ illegal behavior at time t, $i(t)$ and $\bar{i}(t)$ denotes inspection resp. no inspection at time t

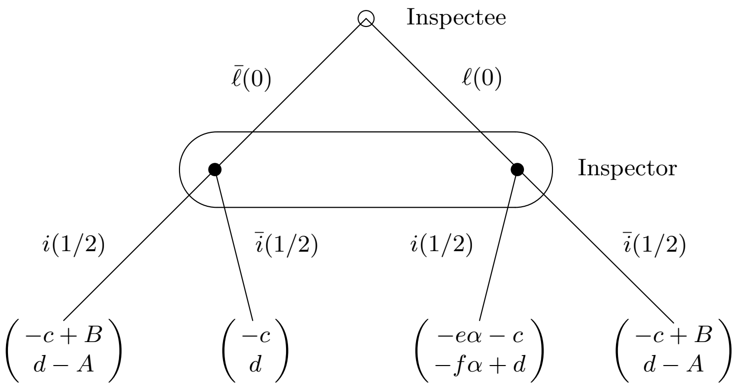


Fig. 6. Reduced extensive form of the critical time game for $d - A > -f\alpha$

The game is shown in extensive form in Fig. 5. The oval denotes the inspector's *information set* at time $t = 1/2$. It represents the fact that she must choose whether or not to inspect in ignorance of whether or not the inspectee behaved illegally at $t = 0$. Formally this is called a game of *imperfect information* and it means that a complete solution with backward induction, as in Section 2, is no longer possible.

However we can at least back up the inspectee's rightmost node, leading to two cases.

Case 1 $d - A > -f\alpha$, Fig. 6.

A simple indifference argument leads to the Nash equilibrium: the inspectee will behave illegally at time $t = 0$ (strategy $\bar{\ell}(0)$) with a probability q^* which makes the inspector indifferent as to inspecting at $t = 1/2$ (strategy $i(1/2)$) or at $t = 1$ (strategy $\bar{i}(1/2)$). Similarly the inspector will inspect at time $t = 1/2$ with a probability p^* so as to make the inspector indifferent to violating at time $t = 0$ or at time $t = 1/2$. Thus, we get two equations determining the equilibrium strategies p^* and q^* of the two "players":

$$q^*(-c+B) + (1-q^*)(-e\alpha - c) = q^*(-c) + (1-q^*)(-c+B) =: V^*$$
$$p^*(d-A) + (1-p^*)d = p^*(-f\alpha + d) + (1-p^*)(d-A) =: W^*$$

Explicitly, these equilibrium strategies are given by

$$p^* = \frac{A}{2A - f\alpha}$$
$$q^* = \frac{B + e\alpha}{2B + e\alpha}$$

and the corresponding payoffs are

$$V^* = -c + \frac{B^2}{2B + e\alpha}$$
$$W^* = d - \frac{A^2}{2A - f\alpha}.$$

Case 2 $d - A < -f\alpha$, Fig. 7.

By the same argument the equilibrium strategies are

$$p^* = \frac{d + f\alpha}{d + A}$$
$$q^* = \frac{c}{c + B}$$

and the corresponding payoffs are

$$V^* = -c + B \cdot \frac{c - e\alpha}{c + B}$$
$$W^* = d - A \cdot \frac{d + f\alpha}{d + A}.$$

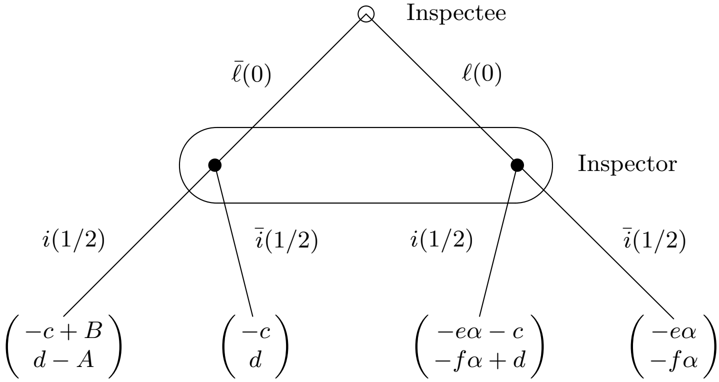


Fig. 7. Reduced extensive form of the critical time game for $d - A < -f\alpha$

There is therefore no situation in which the inspectee behaves legally with probability one, and both inspector and inspectee play *randomized strategies.*

The situation does not depend on the value of the false alarm probability α. The inspector may choose that value which maximizes his payoff, but the latter remains smaller than for the case of legal behavior, namely $-e\alpha$.

3.2 Minimizing time to detection

Let us consider once again a single inspected object and a reference period of one calendar year. Unlike the preceding model, the inspector's goal is now to reduce the time to detection of any illegal activity to an absolute minimum, irrespective of any predefined timeliness goals. An illegally behaving inspectee will wish to maximize that detection time, so that the protagonists may be said to be "playing for time". In order to separate the timeliness aspect of routine inspection from the overall goal of detecting illegal activity, we will assume that a thorough and unambiguous inspection takes place at the end of the reference period which will detect an illegal activity with certainty if one has occurred. This might be, for example, the mandatory physical inventory verification (PIV) inspection required under Nuclear Safeguards agreements. In addition there is, as before, a less intensive and strategically placed "interim" inspection which is intended to reduce the time to detection as much as possible. Again we ask the question, when should this inspection occur?

The utilities of the protagonists (inspector, inspectee) are taken to be as follows:

$(0, 0)$ for legal behavior over the reference time, and no false alarm,

$(-e, -f)$ legal behavior over the reference time, and a false alarm,

$(-a\Delta t, d\Delta t - b)$ for detection of illegal activity after elapsed time $\Delta t \geq 0$, where

$$0 < e < a, \quad 0 < f < b < d. \tag{10}$$

Thus the utilities are again normalized to zero for legal behavior without a false alarm, and the loss(profit) to the inspector(inspectee) grows proportionally with the time elapsed to detection of an illegal action. A false alarm is resolved unambiguously with time independent costs $-e$ to the inspector and $-f$ to the inspectee. The quantity b is the cost to the inspectee of immediate detection. Note that, if $b > d$, the inspectee will behave legally even if there is no interim inspection at all. Since the interim inspection introduces with a certain probability false alarm costs for both parties, there would be no point in performing it. Note also that the preferred outcome from the inspector's point of view is once again legal behavior: her primary aim is to deter the inspectee from behaving illegally. The extensive form of the game is shown in Fig. 8.

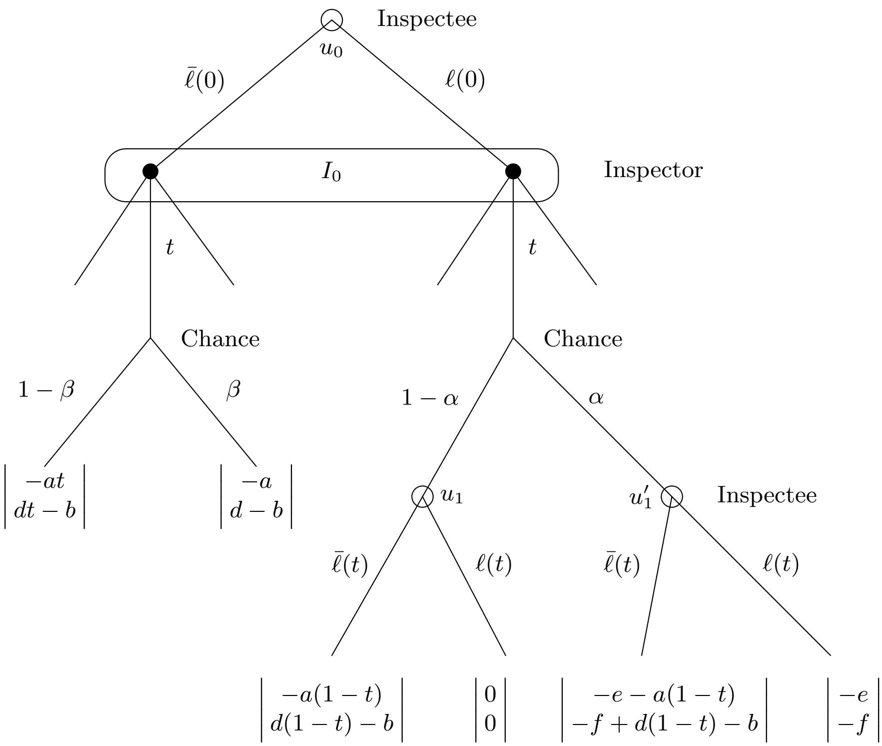


Fig. 8. Extensive form of the sequential inspection game with one interim inspection. $\ell(t)$ denotes legal behavior, $\bar{\ell}(t)$ illegal behavior at time t

The subgames beginning at the chance nodes can be simplified easily. In particular, the situations at the inspectee's decision points labelled u_1 and u_1'

are equivalent, since all payoffs following u_1' are reduced by the same amounts e resp. f relative to u_1. We obtain the reduced extensive form game shown in Fig. 9.

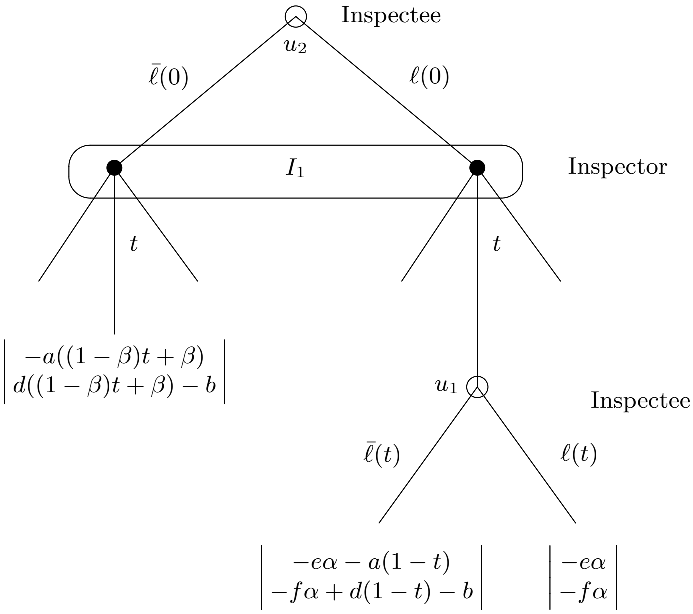


Fig. 9. Reduced extensive form of the sequential inspection game with one interim inspection

Since the interim inspection is observable, the inspectee will either act illegally at the beginning of the reference period, in which case a false alarm is excluded, or delay his decision until the interim inspection at time t. In the former case, the expected payoffs are

$$(-a((1-\beta)t+\beta),\ d((1-\beta)t+\beta)-b). \tag{11}$$

If he waits for the interim inspection at t and then acts illegally immediately afterward, the expected payoffs are

$$(-e\alpha-a(1-t),\ -f\alpha+d(1-t)-b). \tag{12}$$

Finally, he can behave legally at time t as well, with expected payoffs $(-e\alpha,\ -f\alpha)$.

If we assume that the inspectee will always choose to behave illegally, a simple indifference argument will once again solve the game: The inspector should choose her inspection time t^* so as to make the inspectee indifferent to violating at $t = 0$ or at t^*. The inspectee should violate at $t = 0$ with a probability q^* such that the inspector is indifferent as to her choice of t. Thus t^* is the solution of the following equation,

$$d((1-\beta)t^* + \beta) - b = -f\alpha + d(1-t^*) - b =: W^*$$

and the expression

$$q^*[-a((1-\beta)t - \beta)] + (1 - q^*[-e\alpha - a(1-t)] =: V^*$$

must be independent of t. We obtain at once the equilibrium strategies

$$\begin{aligned} t^* &= \frac{1-\beta}{2-\beta}\left(1 - \frac{f}{d}\frac{\alpha}{1-\beta}\right) \\ q^* &= \frac{1}{2-\beta} \end{aligned} \tag{13}$$

and the corresponding equilibrium payoffs

$$\begin{aligned} V^* &= -\frac{a}{2-\beta}(1 + \frac{e\alpha}{a}(1-\beta)) \\ W^* &= +\frac{d}{2-\beta}(1 - \frac{f\alpha}{d}(1-\beta)) - b. \end{aligned} \tag{14}$$

Since we must have $t^* \geq 0$, the solution (13) is valid only for f satisfying

$$\frac{f}{d} \leq \frac{1-\beta}{\alpha}. \tag{15}$$

As in the preceding section we assume our inspection procedures to be unbiased, i.e. $1 - \beta > \alpha$. Therefore (15) will always be satisfied provided $f < d$, that is, provided the cost of a false alarm never exceeds the maximum payoff for illegal behavior, see (10).

The inspectee again plays a random strategy, but unlike the game of Section 3.1, the equilibrium inspection strategy for the inspector is *deterministic*.

The inspectee will choose legal behavior with probability one when his payoff in (14) W^* is less than the cost of a false alarm, i.e. when

$$\frac{d}{2-\beta}(1 - \frac{f\alpha}{d}(1-\beta)) - b < -f\alpha$$

or equivalently when

$$\beta < 2 - \frac{d + f\alpha}{b} =: g(\alpha). \tag{16}$$

With (10) there exists α such that this inequality is satisfied iff

$$1 < \frac{d}{b} < 2 - \frac{f}{b},$$

see Figure 10. Given that this condition is fulfilled, the inspector should choose the smallest possible false alarm probability for which (16) is still satisfied in order to maximize her payoff $-e\alpha$.

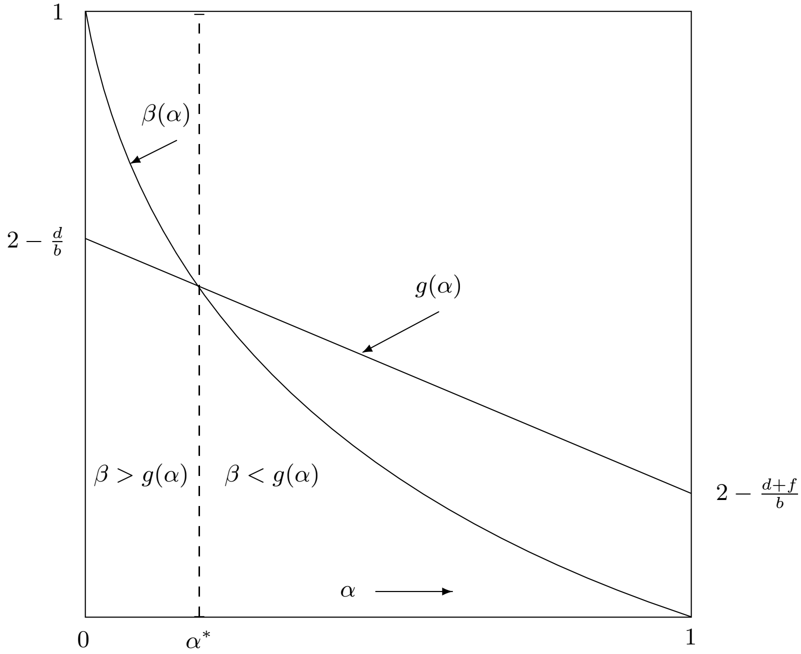


Fig. 10. Determination of the optimal false alarm probability α^*

4 An operational model: Stratified random sampling

Consider the situation in which an inspectee has reported a set of data, the inspector verifies a randomly chosen subset of those data by independent observation, and that for each data pair, reported and verified, an unambiguous statement can be made whether or not the values are consistent. "Unambiguous" means that the probability of raising a false alarm or missing a real inconsistency is exactly zero. This is referred to as *attributes sampling.*

4.1 One class of data

A single class of reported data consists, let us say, of N similar items, r of which have been falsified, where $0 \leq r \leq N$. *Drawing without replacement* describes the procedure of sampling the class randomly such that no single item is chosen more than once. Denote the event of choosing an unfalsified item from the class with the letter A, and of choosing a falsified item with $\bar{A}$. For a random choice of $n = 1$ item, clearly the probabilities of these events occurring are

$$\Pr(A) = \frac{N-r}{N}, \quad \Pr(\bar{A}) = \frac{r}{N}.$$

For a sample of $n = 2$ there are four possible events:

$$A_1 A_2, \quad A_1 \bar{A}_2, \quad \bar{A}_1 A_2, \quad \bar{A}_1 \bar{A}_2$$

whose probabilities are equally easy to write down. For example the probability of no falsifications in the sample is

$$\Pr(A_1 A_2) = \Pr(A_1) \cdot \Pr(A_2 \mid A_1)$$

where $\Pr(A_2 \mid A_1)$ is the probability of event A_2 conditional on event A_1 having preceded it. This is just $\frac{N-r-1}{N-1}$ and therefore, introducing the binomial coefficients

$$\binom{a}{b} = \frac{a!}{b!(a-b)!},$$

we can write

$$\Pr(A_1 A_2) = \frac{N-r}{N} \cdot \frac{N-r-1}{N-1} = \frac{\binom{N-r}{2}}{\binom{N}{2}}.$$

Generalizing from 2 to n samples, the probability of finding no falsifications is

$$\beta = \frac{\binom{N-r}{n}}{\binom{N}{n}}.$$

Expanding the binomial coefficients, the non-detection probability β can be written as follows,

$$\beta = \frac{\frac{(N-n)!}{(N-n-r)!}}{\frac{N!}{(N-r)!}} = \frac{N-n}{N} \cdot \frac{N-n-1}{N-1} \cdot \ldots \cdot \frac{N-n-r+1}{N-r+1}, \tag{17}$$

or, equivalently,

$$\beta = (1 - \frac{n}{N})(1 - \frac{n}{N-1}) \cdots (1 - \frac{n}{N-r+1}) = \prod_{i=0}^{r-1} (1 - \frac{n}{N-i}).$$

If the number r of falsifications is much smaller than the total number of items N, β can be approximated as

$$\beta \approx \prod_{i=0}^{r-1} (1 - \frac{n}{N}) = (1 - \frac{n}{N})^r. \tag{18}$$

On the other hand, because of the symmetry of (17) in n and r we can write

$$\beta = \prod_{i=1}^{n-1} \left(1 - \frac{r}{N-i}\right). \tag{19}$$

Thus if the sample size n is much smaller than the total number of items N, β can be approximated by

$$\beta \approx \left(1 - \frac{r}{N}\right)^n \tag{20}$$

which is just the exact formula for the non-detection probability for *drawing with replacement*, as can be seen directly.

Now, what does this mean for the inspector. In the final section we will talk about *bureaucratic* solutions, meaning that the sample size should be determined by some pre-ordained probability β of not detecting a falsification or r units. For instance with (20) we get the sample size

$$n = \frac{\ln \beta}{\ln(1 - r/N)}. \tag{21}$$

But what is the rationale for such a choice? A better solution is to choose β such that the inspectee is *induced to behave legally.* To this end we again introduce utilities: d for the incentive to violate and $-b$ for detection of violation. Certainly we can say $(b, d) > (0, 0)$. The expected gain for the inspectee, for a given non-detection probability β and illegal behavior, is then the weighted sum

$$-b(1 - \beta) + d \cdot \beta.$$

For legal behavior, the expected gain is nil, so legal behavior is induced if β is chosen so as to make the inspectee's expected gain less than zero,

$$\beta < \frac{1}{1 + d/b}. \tag{22}$$

For simplicity, suppose that (21) is valid. Then the sample size n which, if announced to the inspectee in advance, would make him think twice about falsifying his data, is given by

$$n > \frac{N}{r} \ln(1 + d/b). \tag{23}$$

Not surprisingly, it has turned out to be a lot easier to set *ad hoc* values for β or n than to agree on the ratio d/b for the inspectee. Their relationship should be kept in mind, however. For example, (22) says that requiring a detection probability of 90% is tantamount to saying that the fruits d of undetected falsification are 9 times sweeter than the consequences of detection b are dire.

4.2 Several classes of data

Now consider the case of several classes. The inspector is presented with, say, K populations of reported data N_i, $i = 1 \ldots K$, each characterized additionally by the size μ_i^{max} of a typical item, by the techniques of generating the data for a given class, and the effort ϵ_i that would be involved in verifying one item of the ith class.

If the verification procedures are open and negotiated, ϵ_i is common knowledge. Given furthermore an upper limit ϵ on the total amount of inspection effort that can be expended (set either by mutual agreement or imposed by resource restrictions), we can write

$$\sum_{i=1}^{K} \epsilon_i n_i = \epsilon, \tag{24}$$

where n_i is the sample size for the ith class.

Next we have to make an assumption as to how the inspectee, if he chooses illegal behavior, will falsify his reported data. Suppose that falsification is class-specific (by which is meant that those item in a class chosen for falsification are falsified by the same amount) and given by μ_i. Given that μ_i^{max} is also common knowledge, the falsification obviously cannot exceed it:

$$\mu_i \leq \mu_i^{max}, \quad i = 1 \dots K. \tag{25}$$

For r_i falsifications in the ith class, the overall falsification is then

$$\sum_{i=1}^{K} \mu_i r_i = \mu. \tag{26}$$

It is convenient to treat both the total verification effort ϵ and the total falsification μ as parameters which are known to both inspector and inspectee: they are determined externally. For ϵ this is reasonable since the total effort will, as already mentioned, generally be fixed in some way. "Natural" values for μ on the other hand are hard to come by, with the notable exception of the critical mass in the verification of nuclear non-proliferation undertakings. Generally, values must be defined externally and agreed upon as reasonable inspection goals that represent an acceptable compromise between the assurance to be provided by verification and technical feasibility.

The problem then is to determine, from the inspector's viewpoint, the best distribution of the total inspection effort among the K classes.

Both adversaries have well defined *sets of strategies*: The inspector's set, X_ϵ, is the set of distributions $\boldsymbol{n} = (n_1, \dots, n_K)$ of class sample sizes which fulfill the constraint (24), which in vector notation is

$$X_\epsilon = \{\boldsymbol{n} \mid \boldsymbol{n} \cdot \boldsymbol{\epsilon} = \epsilon\}. \tag{27}$$

Similarly, the inspectee's strategy set Y_μ is the set of distributions $\boldsymbol{r} = (r_1, \dots, r_K)$ of falsified data subject to the boundary condition (20):

$$Y_\mu = \{\boldsymbol{r} \mid \boldsymbol{r} \cdot \boldsymbol{\mu} = \mu\}. \tag{28}$$

We will assume as before that both protagonists behave *non-cooperatively*, the inspectee attempting to maximize the non-detection probability and the inspector trying to minimizing it. Thus we have a *zero-sum game*. The Nash equilibrium is defined by two inequalities referred to as the *saddle point criteria*:

$$\beta(\boldsymbol{n}^*, \boldsymbol{r}) \le \beta(\boldsymbol{n}^*, \boldsymbol{r}^*) \le \beta(\boldsymbol{n}, \boldsymbol{r}^*) \tag{29}$$

where $\boldsymbol{n}$ and $\boldsymbol{r}$ can take on any of their allowed values.

Using the results obtained for the single class situation, the probability of detecting at least one falsification in the K classes for drawing without replacement is just one minus the probability of not drawing a falsified item in any of the K sets of samples, i.e.,

$$1 - \beta(\boldsymbol{n}, \boldsymbol{r}) \approx 1 - \prod_{i=1}^{K} (1 - r_i/N_i)^{n_i}, \tag{30}$$

again assuming that the inspector's sample sizes are small compared to the population sizes N_i.

With (30) it is straightforward to show that the unique equilibrium $(\boldsymbol{n}^*, \boldsymbol{r}^*)$ and the corresponding value $1 - \beta^*$ of the overall probability of detection are given by

$$n_i^* = \frac{\epsilon}{\sum_j \mu_j \epsilon_j N_j \exp(-\kappa \epsilon_j)} \mu_i N_i \exp(-\kappa \epsilon_i) \tag{31}$$

$$r_i^* = N_i(1 - \exp(-\kappa \epsilon_i)), i = 1 \dots n \tag{32}$$

$$\beta^* = \exp(-\kappa \epsilon) \tag{33}$$

where the parameter κ is determined uniquely by the relation

$$\sum_{i=1}^{K} \mu_i N_i \exp(-\kappa \epsilon_i) = \sum_{i=1}^{K} \mu_i N_i - \mu. \tag{34}$$

Let us have a look at some of the interesting properties of this solution.

1. Since κ depends on the value μ of the total falsification but not on the available inspection effort ϵ, the optimal falsification strategy r_i^*, $i = 1 \dots K$ of the inspectee depends only on μ.
2. It can be seen by implicit differentiation of κ with respect to μ_i that β^* is a monotonically increasing function of μ_i. Therefore the inspectee will prefer to choose his class-specific falsifications μ_i as large as possible, i.e. $\mu_i = \mu_i^{max}$. This solves the inspector's dilemma of not knowing which μ_i values she should assume.
3. Suppose the total falsification μ is very large. The parameter κ and hence $1 - \beta^*$ are monotonically increasing functions of μ. Since the total falsification is limited according to

$$\mu \le \sum_{i=1}^{K} \mu_i^{max} \cdot N_i = \mu_{max}$$

the quantity κ can become infinite, see (34). Noting that

$$\lim_{\kappa\to\infty} \sum_j \mu_j \epsilon_j \exp(-\kappa(\epsilon_j - \epsilon_i)) = \begin{cases} \mu_i \epsilon_i N_i & \text{for } i \text{ such that } \epsilon_i = \min_j \epsilon_j \\ \infty & \text{otherwise} \end{cases}$$

it follows from (31-33) for maximum falsification $\mu = \mu_{max}$ that

$$n_i^* = \begin{cases} \epsilon/\epsilon_i & \text{for } i \text{ such that } \epsilon_i = \min_j \epsilon_j \\ 0 & \text{otherwise,} \end{cases} \tag{35}$$

$$r_i^* = N_i, \quad i = 1 \cdots K \quad \text{and} \tag{36}$$

$$1 - \beta^* = 1. \tag{37}$$

In this case of course only one single sample would be sufficient to detect illegal behavior. The fact that the available effort is concentrated on the class having the lowest verification effort per item is characteristic.

4. Taking the other extreme, if the total falsification is small, $\mu \ll \mu_{max}$, we have for $i = 1 \dots K$

$$n_i^* = \frac{\epsilon}{\sum_j \mu_j \epsilon_j N_j} \mu_i N_i, \tag{38}$$

$$r_i^* = \frac{\mu}{\sum_j \mu_j \epsilon_j N_j} \epsilon_i N_i, \tag{39}$$

$$1 - \beta^* = \frac{\mu \epsilon}{\sum_j \mu_j \epsilon_j N_j}. \tag{40}$$

This solution has a simple intuitive interpretation: $\epsilon_i N_i$ is the effort required to verify *all* reported data in the ith class, and $\mu_i N_i$ is the maximum falsification in the ith class. Thus the sample sizes of the inspector are to be proportional to the maximum possible data falsifications in each class, and the number of falsified items is to be proportional to the effort required to verify all data in each class.

5. Now suppose that all of the class-specific verification efforts are equal, $\epsilon_i = \epsilon_1$, $i = 1 \dots K$. Defining

$$n = \frac{\epsilon}{\epsilon_1}, \quad N = \sum_i N_i, \quad r^* = \sum_i r_i^* = \frac{\mu N}{\sum \mu_i N_i},$$

then (31), (32) and (33) reduce to

$$n_i^* = \frac{n r^*}{N \mu} \mu_i N_i,$$

$$r_i^* = \frac{r^*}{N} N_i,$$

$$\beta^* = (1 - r^*/N)^n.$$

We see that both players behave in this case as if there were only one class consisting of N items, r^* of which are falsified and n verified.

Finally it should be emphasized that, although the inspectee chooses his equilibrium falsification $(r_1^*, \dots r_2^*)$ such that the inspector is indifferent, nevertheless the inspector's equilibrium strategy is well-defined.

Let us come back to the question we discussed for the one-class case and seek immediately the "non-bureaucratic" solution. With (22) and (33) the overall inspection effort ϵ is determined by

$$\epsilon > \frac{1}{\kappa} \ln \left(1 + \frac{b}{d}\right)$$

where κ is given by (34). For small total falsifications we get explicitly

$$\epsilon > \left(1 + \frac{b}{d}\right) \frac{1}{\mu} \sum_i \epsilon_i \mu_i N_i,$$

which means the larger the ratio of gains to sanctions and the smaller the critical mass the lager must be the inspection effort expended.

5 Discussion

In the framework of verifying the peaceful use of nuclear energy, i.e. under the Nuclear Non-Proliferation Treaty, the sort of quantitative analysis presented here has been used, if at all, only at a rather technical level. It has been applied for instance to derive optimal inspection sampling plans at specific facilities, given hypothetical violation scenarios. One reason for this hesitance may be that game theory has a reputation for mathematical abstruseness and limited practical applicability. This reputation is ill-deserved, as we have demonstrated.

The Additional Protocol, the model for which was agreed upon by the Board of Governors of the International Atomic Energy Agency (IAEA) in May 1997 [8], seeks to introduce new subjective elements into the nuclear safeguards regime, a regime which had hitherto been founded on the quantitative principle of material accountancy. Some of these elements have been the subject of considerable controversy ever since. The objective was to strengthen safeguards following the failure to detect Iraq's illicit nuclear weapons programme. At several occasions the claim was made that any attempt to quantify the effect of the new measures within the overall IAEA safeguards verification regime would be pointless and should be avoided. But at the same time, there seemed to be very general consensus that the additional measures would serve to improve the effectiveness and efficiency of safeguards. For a systems analyst this was an absurd state of affairs: claiming improvement or optimization while at the same time denying the need for a measurable objective is surely self-contradictory. This confusion actually contributed to the long, difficult and at times cross-purposeful discussions that characterized the debate between Non-Proliferation Treaty member States and the Agency over the Additional Protocol.

The reluctance to define one's terms is not new, in fact it lurked within the old nuclear verification system. It can be illustrated by the paradigmatic example of a storage facility consisting of sealed items of nuclear material. Suppose a subset of the sealed items on inventory is checked by the Inspectorate. The probability of detecting at least one falsified seal is quantifiable approximately by the ratio of the number of items in the subset divided by the total number of items present. But just how large should the subset be for effective and efficient safeguards? Technically, one solves the problem by allowing the inspector to work for a given amount of time. If the time needed to check one seal is known, then the number of items she can check is also known. Her effectiveness, expressed as the probability of detecting illegal activity, is then a function of purely technical quantities, namely the size of the inventory, the inspection time per item and total time available. But is this efficient? Is the inspector wasting some of her time, or should she be investing more of it? "How much is enough?" as American verification theorist Allan Krass asked many years ago [9].

The answer is that the Inspectorate should invest that amount of verification effort which will deter the State, through the risk of timely detection, from illegally breaking a seal, no more and no less. But herein lies a difficulty: in order to treat the question of deterrence, we are forced to introduce the subjective aspects associated with perceived risk, namely the preferences of the inspected party for legal versus illegal behavior. If we do so, formal methods will help us come to a common understanding. It is argued by many, however, that an international verification organization like the IAEA has no business doing this sort of political analysis. Instead, the point of view is taken that the detection capability is an external variable that must be determined bureaucratically. Typically, some ad hoc measure, such as X percent detection probability for violation strategy Y, is specified which determines the overall inspection effort required for its achievement. This of course begs all questions regarding efficiency, and any further treatment of the matter is sterile.

An alternative is to try to arrive at a genuine quantification of the problem. Let the State's utilities, which as we have seen reflect the preferences of the State, be ordered as follows: some negative value for detected illegal behavior (the perceived likely sanctions), zero for legal behavior, and a positive value for undetected illegal behavior (the incentive, whatever that might be, to violate the agreement). The latter value may be arbitrarily small, but should never be exactly zero. This would be tantamount to saying that the inspection regime is superfluous, in contradiction of the international consensus that there is a genuine risk of clandestine violations. The normalization to zero for legal behavior is convenient and thoroughly consistent with the meaning of utility. The State's overall utility, if it decides to behave illegally, can then be expressed as a simple function of these basic utilities and of the detection probability. The potential violator will clearly be inclined to behave legally if it perceives this function to be less than zero. This leads immediately to a condition for the probability of detection required for deterrence and, in turn, to a condition for the time which an inspector has to spend in the facility. As we saw in the example at the end of Section 4.2, the larger the ratio of perceived sanctions to perceived benefits of illegal behavior, the smaller is the amount of effort that should be invested by the Inspectorate to achieve its goal, perfectly understandable from the common sense point of view.

As already mentioned, this way of looking at things has been criticized on the grounds that it is impossible, or worse, impolitic, to estimate utilities of parties to a treaty. But all we have really done is to relate, via the condition for legal behavior, a technical result (which connects the probability of detection with the time the inspector has to spend in the facility) to the reality of the situation to which it is being applied. If, for example, a State's incentive to break a seal is known to be much smaller than its perceived consequences of detection, a good inspection plan would be to make the inspection time very small. Then, just a single token seal check would be both efficient and effective. If, on the other hand, the utilities are indeed inaccessible, or even taboo, then at least we know why we cannot define effective and efficient verification and that the subject should best be dropped. In either case quantification has helped us.

Returning to the new Protocol: In the additional verification measures, it is even explicitly stated that qualitative elements like the motivation of States are to be taken into account. What can this be if not a recognition of the fact that different States may have different motivations? The sort of analysis just undertaken should therefore be all the more relevant. Thus if we extend the previous paradigm to two States each possessing one storage facility, these motivations are expressed by different utilities for each State. Then a formal analysis provides, under reasonable assumptions, a condition for legal behavior of both States which generalizes the previous considerations. But now the required detection probabilities (and hence inspection efforts) for each State are inextricably bound up with both States' utilities! The bureaucratic solution is all the more arbitrary. The inclusion of subjective preferences thus seems unavoidable.

There are, as we saw, roughly speaking three types of applications of formal methods which are relevant to the context of verification of international arms control and disarmament and environmental treaties: conceptual, operational and structural.

Conceptual applications are usually rather conjectural and technically fairly simple. They serve to place the specific verification regime in an overall political framework, trying to justify the need for it, if such a need exists.

The operational type of application deals with the analysis of constraints. The questions to be addressed are: How much time can an inspector spend for a major verification task? How should the overall manpower and budget of a verification authority be distributed between States with different motivations? And finally, to repeat the all important question, how much verification is enough? Here, necessarily, one must resort to utility functions which express the preferences of the parties involved. Even if they cannot be estimated numerically, the analysis of their interrelationships and their influence on the efficiency and effectiveness of verification measures is indispensable for understanding what verification really means.

The structural model involves solving the technical problem of implementing inspections given constraints of time and/or manpower. If, for example, an inspector has a given time at his disposal for some facility in a calendar year, then optimal inspection procedures during one visit, or optimal distributions of inspection visits over time, can be determined. Moreover, the best statistical evaluation techniques can be derived whenever actual measurements are performed and statistical errors (for example false alarms) cannot be avoided. Here, subjective preferences of inspected parties need not be taken into account explicitly.

Of course it is difficult to get diplomats, politicians and administrators interested in the type of thinking just outlined. Howard Raiffa [10] has described the general problem many times and very convincingly. We can only repeat his plea for our case, namely that practitioners and analysts approach each other in the interest of really solving the vital problems of verification.

References

1. J. Nash (1951): Non-cooperative games, *Ann. of Math.* 54, 286–295.
2. R. Myerson (1997): *Game Theory - Analysis of Conflict*, Harvard University Press, Cambridge MA.
3. F. F. Zagare and D. M. Kilgour (2000): *Perfect Deterrence*, Cambridge University Press.
4. J. Sanborn (2001): Considerations regarding the scheduling of unannounced random inspections, Proceedings of the IAEA Symposium on International Safeguards, Vienna, IAEA-SM-367/12/07, CD-ROM.
5. M. J. Canty, D. Rothenstein, R. Avenhaus (2001): Timely inspection and deterrence, *European Journal of Operational Research* 131, 108–223.
6. R. Avenhaus and M. J. Canty, (2005): Playing for time: A sequential inspection game, *European Journal of Operational Research* 167, 475–492.
7. R. Avenhaus and M. J. Canty (1996): *Compliance Quantified: An Introduction to Data Verification*, Cambridge University Press.
8. IAEA (1997): Model Protocol Additional to the Agreement(s) between the State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected).
9. A. Krass (1985): *Verification: How much is enough?*, Taylor and Francis, London and Philadelphia.
10. H. Raiffa (1991): Contributions of system analysis to international negotiation, in *International Negotiations - Analysis, Approaches, Issues*, V. Kremenyuk (Ed.), Jossey Bass Publishers, San Francisco.

V

Systems and Linkages - Crosscutting

Satellite imagery and change detection are verification techniques which can be used in a broad range of applications. Environmental monitoring and forensics provide also methods which will become more attractive in the future for verification. It is therefore reasonable to link and network the elements of those different disciplines. GMOSS is an example for such an attempt.

Civil Reconnaissance Satellites: Opportunities and Challenges

Bhupendra Jasani

1 Introduction

With the launch of the US QuickBird satellite on 18 October 2001, civil remote sensing made a very significant advancement. The spatial resolutions of the panchromatic and the multi-spectral sensors on board the spacecraft are 0.61m and 2.44m, respectively. This brought the capabilities of the commercial observation satellites close to those of US and Russian military spacecraft that were in orbit until the mid-1980s (see Table 1). Images from the KH 1-4 series were declassified and now they are commercially available. As for spectral resolution, until recently multi-spectral data typically consisted of five to 20 moderately wide spectral bands, but now hyper-spectral data consists of over 200 narrow bands with a bandwidth of some 10nm. In 1972, the US began to launch its civil remote sensing satellites that became known as the Landsat satellites. The sensor on board the first of these, the Landsat-1, was a multi-spectral camera with a resolution of 79m. The Landsat-4 launched on 16 July 1982 had a multi-spectral sensor with a resolution of 30m and that of the Landsat-7 launched on 15 April 1999 is 15m (panchromatic). The spatial resolution improved further when the US Company, Space Imaging, successfully launched its IKONOS-2 spacecraft on 24 September 1999 followed by the Digital Globe's QuickBird-2. The panchromatic and the multi-spectral sensors on board the Ikonos-2 spacecraft have resolutions 0.81m and 3-5m.

Thus, over a period of just under three decades, the sensor capability increased nearly 130 fold. In addition to the improved spatial and spectral resolutions, there is an increase in the number of states (see Table 1) launching and operating their own remote sensing satellites and selling the data generated from them on commercial basis. This has improved the temporal resolution considerably.

Table 1. Improvement in resolution of commercial remote sensing satellites during the last two and half decades as well as the spread of the capabilities to other countries

Satellite/ sensor	Spectral bands	Spatial Resolution (m)	Comments
France			
SPOT-5	3 VIS 1 SWIR 1 panchromatic	10 20 2.5 or 5	SPOT-1 was launched on 220286 and SPOT-5 on 040502
India			
IRS-1 C/D	3 VIS 1 panchromatic	23 5.8	IRS-1A was launched on 170388 and 1D on 290997
TES	1 panchromatic	1	TES launched on 221001
CARTOSAT-1	1 panchromatic	2.5	Visible and Near IR (VNIR) sensor; launched 050505
Resourcesat-1	3 bands 4 bands 4 bands	5.8 23.5 56	VNIR and Short Wave IR (SWIR) sensor; Advanced Wide Field Sensor (AwiFS) in 3 VNIR bands and 1 SWIR band; launched on 171003
Israel			
EROS-A1	1 panchromatic	1.9	Launched on 051200
Japan			
IGS-1a	1 panchromatic	1	Launched on 230303
Russia			
Resurs-F series			Resurs-1-03 was launched on 041194
KATE-200	3 multi-spectral	15 and 30	
KFA-1000	1 panchromatic	5 to 10	
MK-4	6 multi-spectral	5 to 8	
KVR-1000	1 panchromatic	2	
USA			
Landsat-7			Landsat-1 launched on 230772 and 7 on 150499
Enhanced Thematic Mapper (ETM)	6 VIS and SWIR 1 panchromatic 1 thermal	30 VIS and SWIR 15 150	Cant produce full quality images because of the failure of the scan line corrector (SLC)
ASTER	3 bands VIS 6 bands in SWIR 5 bands in thermal infrared	15 30 90	Duty cycle does not permit continuous data acquisition and has to prioritise data acquisition requests; launched on 181299
QuickBird-2	4 VIS 1 panchromatic	16103 0.61	QB-1 launched on 201100 failed but QB-2 was successfully launched on 181001
Ikonos-2	4 VIS 1 panchromatic	4 1	Launched on 240999
Early Bird-1	3 VIS 1 panchromatic	15 3	
EO-1			Launched 211100
Advanced Land Imager (ALI)	7 multi-spectral 0.43 to 2.35 m	30	
Hyperion	220 hyperspectral 0.4 to 2.5 m	30	
Orbview-3	1 panchromatic 4 multi-spectral	1 4	Launched on 260603
US military KH series			
KH 1-4	1 panchromatic	8 - 13	1959-1963
KH-4A	1 panchromatic	$\sim$ 3	1963-1969
KH-4B	1 panchromatic	$\sim$ 2	1967-1972
KH-6	1 panchromatic	$\sim$ 2	1963
KH-7	1 panchromatic	$\sim$ 0.5	1963-1984 1963-1984
KH-8	1 panchromatic	$\sim$ 0.15	1971-1984
KH-9	1 panchromatic	0.3-0.6	1976-present
KH 11-12		$\sim$ 0.15	

2 Opportunities

Such developments provide opportunities as well as challenges for the international community. For example, often inability to verify an arms control agreement is used as a reason for not signing a treaty. The USA and Russia use their national technical means (NTM) for verifying their bilateral and even multilateral treaties [1]. Observations from satellites form a very important element of their NTMs particularly because of its non-intrusive character. It has been argued that commercial observation satellites should now be used to verify multilateral treaties and it has been shown that the 1990 treaty on the reduction of Conventional Armed Forces in Europe (CFE) and 1987 Intermediate-range Nuclear Forces (INF) treaty could be verified using commercial satellite data. Not only this but such satellites could also be used in peacekeeping operations and to monitor, for example, disengagement zones [2]. The European Union Satellite Centre, a regional agency that was first proposed in 1983 [3], is using these techniques. Such an agency could be established in other regions, for example, in the Middle East (the Gulf Co-operation Council is considering purchasing a spy satellite) and in the Indian Sub-continent where space capability exists [4].

The Non-Proliferation Treaty

Commercial observation satellites can contribute to the verification of a number of arms control treaties. Consider first the 1990 Treaty on the Non-Proliferation of Nuclear Weapons (the NPT).

Under the safeguards agreement with the International Atomic Energy Agency (IAEA), a State is now required to give such information as the site diagrams and the sizes of the associated nuclear facilities. The State may not give details like network of roads and railway lines; nor, for that matter, the power lines, if any, associated with the nuclear facility. A dedicated plutonium production reactor generally does not have power lines, as it is not design to generate electricity. Moreover, from the heat signature of a facility, it would be possible to determine its function. Figure 1 shows an image acquired on 17 March 1996 by the Landast-5 satellite over the Canadian Bruce Nuclear Power Station complex.

The locations of various nuclear facilities can be determined and several major roads can be clearly identified in this image but at this resolution (30m) it is not very easy to resolve different elements of the power plant complex. However, with the help of maps of the area and aerial photographs, it is possible to identify many of the features as indicated in the image. Moreover, with the use of the thermal sensor on board the Landsat-5 satellite, it is possible to determine the operational status of a reactor. For example, Figure 2 shows the Bruce Nuclear Power Station complex as seen by the Landsat-5 satellite on 17 March 1996. The degradation of the image owing to the atmospheric conditions were, to some extent compensated using bands 7 and 5. Combining these with the thermal band 6 three warm water plumes discharged from the two Bruce Reactor A and B complexes and that from the heavy water production plant can now be seen clearly at **A**, **C** and **B** respectively. With the use of higher resolution (2m) images, for example from the Russian satellite borne KVR-1000 sensor, even power lines could be detected [2].

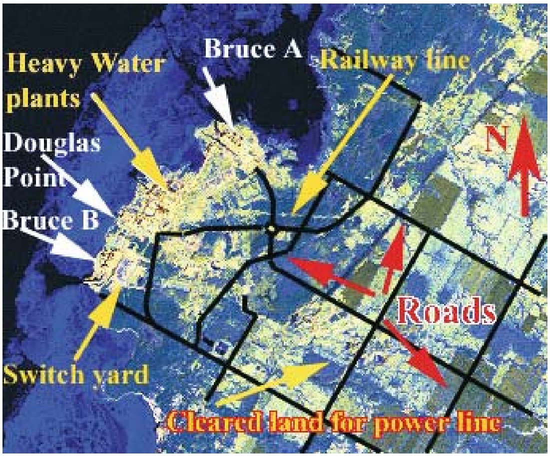


Fig. 1. This is a combination of bands 7 (red), 5 (green) and 4 (blue) of the Landsat-5 image acquired on 17 March 1996 over the Canadian Bruce Nuclear Power Plant with a number of features identified. Source: Landsat/EOSAT. Scale: 1:83,880

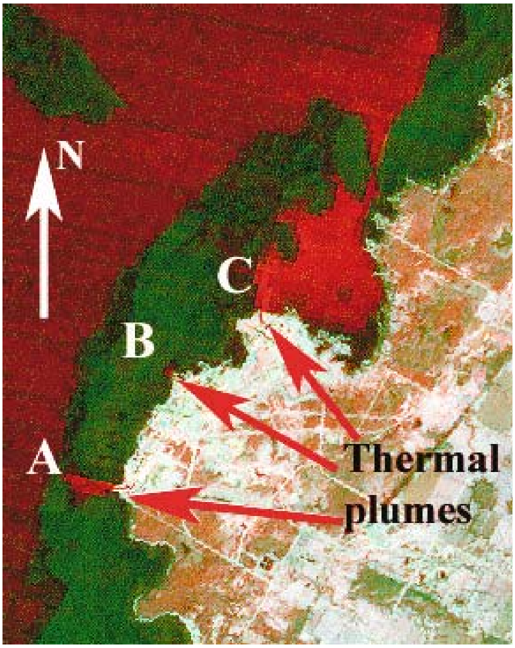


Fig. 2. Here bands 6 (red), 7 (green) and 5 (blue) of the Landsat-5 image acquired on 17 March 1996 over the Canadian Bruce Nuclear Power Plant were combined to enhance the thermal plumes recorded in band 6 at A from the Bruce B complex, at B from the heavy water plant and at C from the Bruce A complex. Source: Landsat/EOSAT. Scale: 1:109,230

Initially the IAEA may verify the validity of information provided by a member state. A relatively high-resolution (0.6m) optical image was acquired over the Bushehr power reactors in Iran. Figure 3 shows an image acquired by the US QuickBird-2 satellite on 26 June 2003. The reactor complex can be seen in considerable detail. The reactor Unit I in an advanced state of construction can be clearly seen at **A**. The reactor building is a cylindrical one with a dome shaped roof (the diameter of the dome is measured 55m) as expected for a PWR [6]. Close to the reactor at **B** is the rectangular turbine and electricity generator building the dimensions of which are 53.5m x 92.5m (these are in general agreement with the ones given in Jasani, INMM, 2004). The reactor control systems are housed in building **C**. Although the facility is being completed by Russia, the construction work was initiated by Germany. Thus, many of the features are similar to those of the German power reactors. For example, it is usual for German reactors to have a building closely situated that contains workshops, stores, a water treatment plant, a laboratory and welfare rooms. Such a building is located at **D**. It also contains an emergency diesel energy generator for the reactor Unit I. It is possible that the latter is housed in the thinner long structure at the end of the building **D**. There are four hybrid cooling towers ($\sim$ 8m x 24m) located at **E**. It can be seen that work on the Unit II, circled to the right of the building D, is not complete.

A security wall surrounds the nuclear facility. Along the wall a number of watchtowers, F, can be identified. Moreover, the facility is also protected by several anti-aircraft defence systems. An example of this is shown in the inset in Figure 3 and at least three more are identified in the image. However, these are a part of a series of such defences that are placed in a semicircle round the nuclear reactor complex. Presumably coastal guard ships in the Persian Gulf may provide the remaining defences along the water front.

Thus, it can be seen from above that some of the characteristics for a PWR plant developed earlier (Jasani, 2004) hold for the Iran's Bushehr power plant also. Moreover, the usefulness of the Landsat thermal band to monitor the operational status of nuclear facilities was again demonstrated.

A country embarking upon a nuclear weapons programme, usually initiates a missile programme also since this is an efficient way to deliver the warhead to its target. A missile could be faster as well as it can deliver the payload to greater distances. In the following section the case of South Africa is examined briefly as it had seven nuclear warheads [7] and its missile programme was well advanced. Some images over South Africa's missile test range were acquired and examined.

A missile test complex

As land area and airspace in many parts of the world get more crowded, defence establishments find it more difficult to conduct tests of advanced weapons and weapon systems. This is further limited by environmental and commercial concerns.

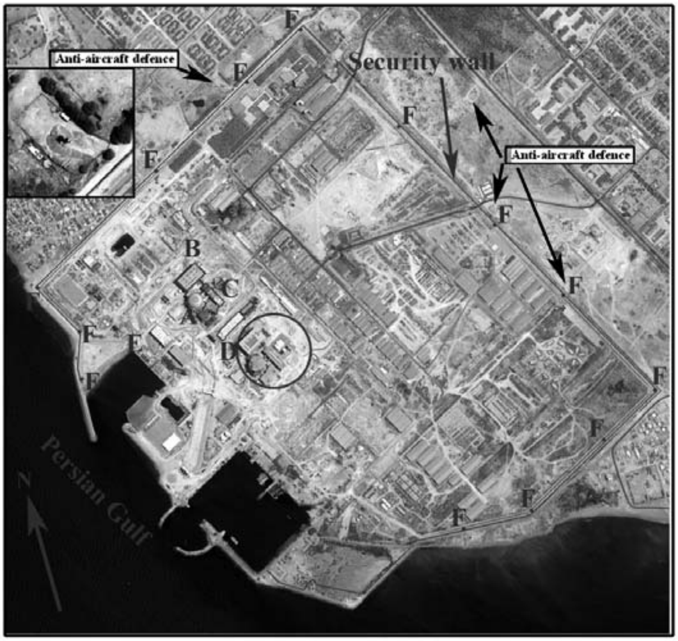


Fig. 3. Iran's Bushehr Pressurised Water Nuclear Power station Unit I is at A; turbine generator is at B; reactor control building is at C; D houses workshop, store, a water treatment plant laboratory, welfare rooms and also a diesel energy generator for reactor Unit I; there are four hybrid cooling towers at E; a number of watch towers (F) are constructed along the perimeter security wall; anti-aircraft defences are deployed round the reactor site, an example of which is show in the figure as an enlarged image in the inset. Site in circle is the reactor Unit II that remains incomplete. Source: DigitalGlobe

In 1980s as part of South Africa's ballistic missile and space programme, the Overberg Test Range (OTR) was developed. It was also made available for testing equipment and missiles of foreign governments. As a preliminary study, four low-resolution satellite images from SPOT (one) and ASTER (three) spacecraft were acquired over the OTR to investigate what can be learnt from such images about missile test activities. The OTR is located at Latitude 34 deg 35 min S and Longitude 20 deg 19 min E near Bredasdorp, 200km east of Cape Town, on the south-eastern coast of the Western Cape. The facility occupies an area of some 430km^2. Thus, with the 70km of coastline on the remote southernmost point of the African continent and a large overland area, OTR provides an ideal environment for advanced tests over land and sea.

The launch sites were located along the coast just northeast of Waenhuiskrans (see Figure 4 and at **C**, **D**, **E** in Figure 5), while the launch vehicle and payload assembly facilities were located at a near by air base at B (see Figure 5). The OTR site included tracking stations, insulated hangars for firing tests, computer facilities, the necessary equipment for integration of low-orbit satellite launch and a 3km runway and an instrumented test-bed aircraft. Within the airbase complex, there are two large buildings measuring 160m x 50m that could be either the payload assembly facilities or the insulated hangars for firing tests. It is possible that the space launch pad is within the area **A** in Figure 5.

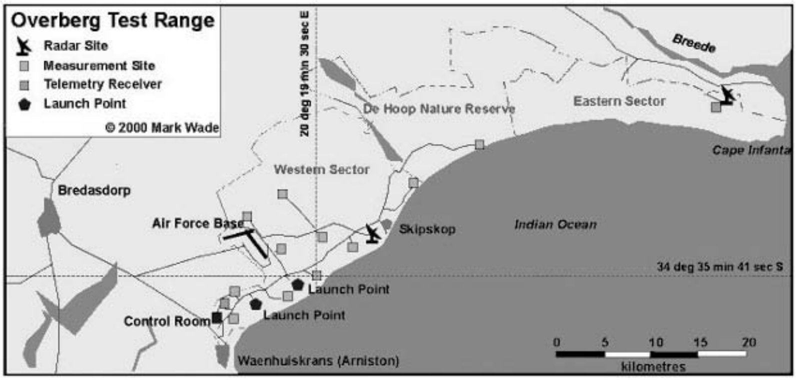


Fig. 4. This map shows the location of the South African Overberg Test Range and its surrounding area. Source: http://www.astronautix.com/sites/overberg.htm

Along with its nuclear weapons programme, South Africa had a relatively sophisticated intercontinental ballistic missile programme and was known to be working on more advanced nuclear weapons capable of delivery from such a platform. However, facing continuing US pressure, in June 1993 South Africa agreed to refrain from manufacturing long-range missiles and to dismantle its capability to produce large space rockets. Its RSA-3 and RSA-4 SLV programme were cancelled. By this time the nuclear programme had already been terminated. The possible launch pad appeared to be active in 1990 as seen in the SPOT image in Figure 5. The site has a well-defined structure. However, by 2002, these features are hardly recognisable in the inset **A'** in Figure 5. The inset **A'** is an extract from the ASTER image acquired on 3 January 2002. This would suggest that South Africa might well have complied with the US pressures to dismantle its launch activities.

To confirm some of these changes, the SPOT (4 January 1990) and the ASTER (3 January 2002) images were co-registered and matched accurately. The ASTER data were then subtracted from those from the SPOT image. The resulting image was then combined as red with the SPOT in green and the band 2 of the ASTER image in blue giving a multi-spectral image in Figure 6. The red in Figure 6 then represent differences in the two scenes. Some of the difference are indicated at **A** and **B**. It is concluded that while some changes such as new marking on the runway of the airfield and in some of the missile

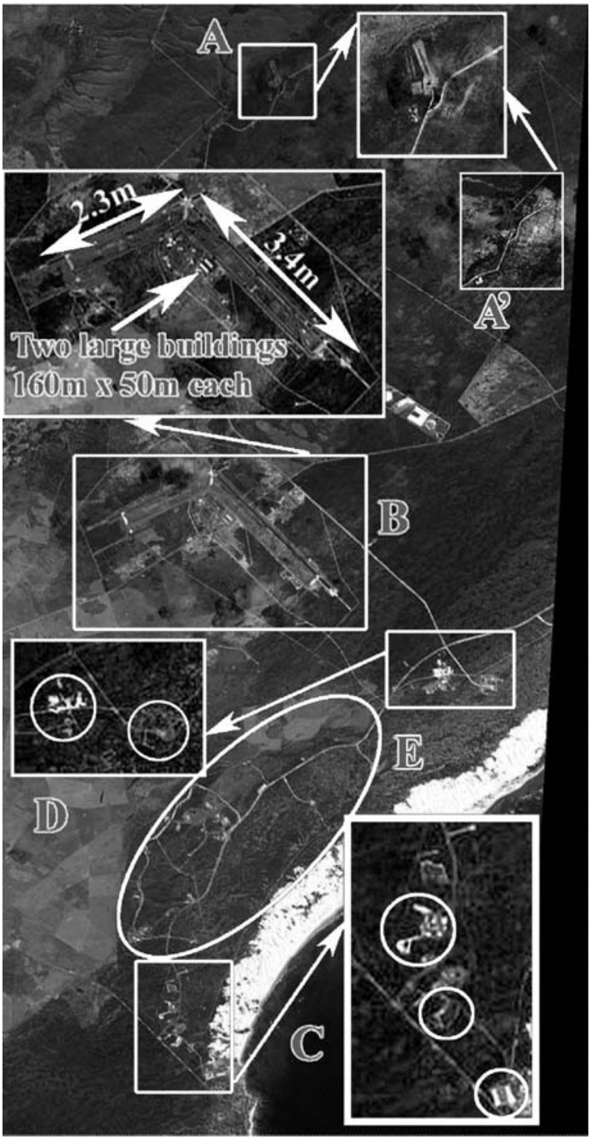


Fig. 5. This shows an extract from an image acquired by the French SPOT satellite on 4 January 1990 over the Overberg Test Range. The inset at A is an enlargement of a facility that may be a satellite launch pad and inset A' is the same area but observed by the ASTER satellite on 3 January 2002. The air base at B is enlarged from an ASTER image that shows some changes on the runway markings and also near the two large buildings (160m x 50m). Similarly, areas C and D on the SPOT image were compared with those on the ASTER image (insets) to indicate that some changes have taken place between 1990 and 2002. The changes are shown in circles in the insets. Source: SPOT/CNES and NASA/ASTER

launch sites have occurred by 2002, by and large neither new missile launch pads have been created nor any new infrastructure has been constructed.

Thus, with the availability of relatively high- and moderate-resolution imageries from commercial observation satellites, it is now becoming possible to verify a number of multilateral arms control treaties. Such treaties help to improve international security.

3 Challenges

From the above, it can be seen that with the aid of commercial observation satellites such as the QuickBird satellite (0.61 m), it is possible to obtained considerable details. This raises a question. During conflicts, should images over such areas be made available commercially or the image providers should exercise shutter control? During the Afghanistan crisis, the USA decided that images should not be disseminated and its National Imagery and Mapping Agency (NIMA) bought the exclusive rights to all images acquired over Afghanistan by IKONOS-2 satellite since the conflict began with the contract to be renewed each month until the end of the Afghanistan conflict [8]. Such restrictions may become even more frequent with the availability of data from the QuickBird satellite. Similar restrictions were placed during the 1991 Gulf War, when there was an embargo on the Landsat and SPOT imageries.

This is understandable since an adversary can learn about one's military deployment from such satellite imagery. However, the Principles Relating to Remote Sensing of the Earth from Outer Space (the Remote Sensing Principles) adopted by the United Nations General Assembly in 1986 [9] requires that a country being sensed has the right to obtain images acquired over its territory in a reasonable time and at a reasonable cost. Thus, by denying the sensed country imagery over its territory may well create conflict between the Remote Sensing Principles and the monopoly of data, although this would depend on how the sensing State is going to interpret "in a reasonable time". However, such problems would arise only if the sensed country knows that it is being photographed from space. This is not possible for most countries.

Even more important issue is that of treaty monitoring. Will the data providers exercise control over the dissemination of data to the UN or its specialised agencies involved in treaty verification? Such attitudes would be counter to the non-proliferation of WMDs and hence national and international security. Moreover, conflicts often bring with them problems of mass movement of people. It is often difficult to know where the concentrations of refugees are making the work of the aid agencies very difficult. A powerful tool for locating and tracking refugees would be observations from space; but if the information is not made available to such agencies their work becomes difficult and the refugees continue to suffer.

As the capabilities of commercial observation and military satellites converge, it is possible that civil spacecraft could become targets for anti-satellite

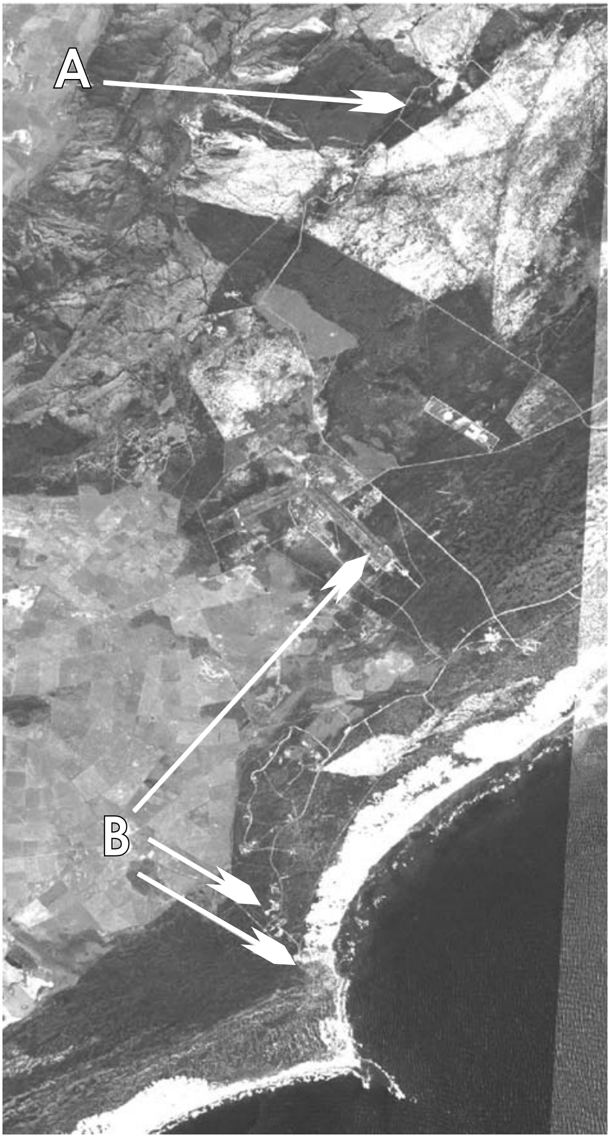


Fig. 6. The SPOT and the ASTER images were matched and the latter was subtracted from the former. The image in this figure is a combination of the resulting image (in red), the SPOT image (in green) and the ASTER band 2 image (in blue). Considerable changes have occurred in the scene but mainly in the vegetation as indicated by red. However, some new roads (for example at A) have been constructed between 1990 and 2002. The presumed launch pad at A does not seem to be maintained as the site is not well defined in the ASTER image. Some new changes in the runway (such as the marking) and at the missile launch site (B) can be seen in red. Compare these with image with that in Figure 5. Source: SPOT/CNES and NASA/ASTER

(ASAT) weapons. Even an accidental damage in times of crisis could aggravate an already tense situation. Civil remote sensing satellites are not protected by General International Law or by any specific multilateral treaty. Unlike military reconnaissance spacecraft, damage to such satellites may not be regarded as an attack on a country's national security assets and yet during crisis, such satellites could become very important. It is becoming essential to work on an ASAT treaty now.

4 Way forward

It can be seen from above that commercial remote sensing satellites have a potential use in multilateral arms control process and crisis management. They can become an important part of the multinational technical means (MTM) of verification. A number of bilateral treaties between Russia and the United States are verified by their NTM. Satellites are a vital element of this. As such, the treaties in which there is always a clause indicating that the parties are not to interfere with each other's NTM protect these satellites. This would include the use of ASAT weapons. It might be suggested that MTM becomes a part of multilateral arms control treaties as these could be enhanced by the use of satellites for verification regimes. Commercial remote sensing satellites should become a part of the MTM. In fact, they are becoming a part of the IAEA's safeguards procedures. Not only this but for some treaties, observation by satellites is vital. For example, the Comprehensive Nuclear-Test-Ban Treaty (CTBT) was opened for signature on 24 September 1996. While the CTBT has not come into force, it is important that its verification regime is strengthened. The verification tools discussed in the treaty can only indicate that a test has been carried out. This is too late. A technique that can detect a potential test would be more useful as a nuclear test can then be averted.

The other measure is the Missile Technology Regime (MTCR). This is an agreement between a number of states without being a formal international treaty. It has no verification mechanism either so that there is no way member states could check whether parties are complying with their commitment to the agreement. It could be suggested that the MTCR or a similar regime should be set up under the United Nations with a strict verification regime that would include observations from space. This way the ideals of non-proliferation of weapons of mass destruction could be realised more effectively. Observations from space could contribute to this goal.

References

1. Jasani, B. (1990): "Commercial observation satellites, and verification", *in Krepon, M., et. al. (editors), Commercial observation satellites and international security*, Basingstoke: MacMillan, pp. 142-150.

2. Jasani, B. (1990): "Arms control verification by satellites", *International Defense Review*, 23(6), pp.643-46; Jasani, B., (1992): "Satellites and arms verification", *Jane's Intelligence Review*, 4(8), pp.380-83; and Jasani B., (1993): "The value of civilian satellite imagery", *Jane's Intelligence Review*, 5(5), pp.235-39.
3. Jasani, B. (1983): "A regional satellite monitoring agency" , *Environmental Conservation, 10(3)*, pp.255-256.
4. Jasani, B., (1991): "The JDW Interview", *Jane's Defence Weekly, 21 September*, 16(12), p.540.
5. Jasani, B., and Ward, M.D. (2002): "Application of commercial satellite imagery: some case studies", Chapter 7 in *Commercial satellite imagery - A tactic in nuclear weapon deterrence*, Bhupendra Jasani and Gotthard Stein (edt), (Springer and Praxis Publishing, Chichester, UK).
6. Bhupendra Jasani (2004): "Identification of key features of nuclear reactors for interpretation of imageries from remote sensing satellites", *Journal of Nuclear Materials Management*, Vol. XXXII, No. 3, pp.28-36.
7. Baeckmann, A., Dillon, G., and Perricos, D.(1995): "Nuclear verification in South Africa", *IAEA Bulletin*, vol.37, No. 1.
8. The Economist (2001): 10 November;361(8247); p. 108.
9. UN (1986): UN Resolution 41 65.

Change Detection: The Potential for Nuclear Safeguards

Irmgard Niemeyer and Sven Nussbaum

1 Introduction

With the advent of commercial high-resolution satellite sensors, remote sensing images provide an essential open source of information for recognizing and monitoring even small-scale and short-term structural features of interest within nuclear facilities, for instance construction of buildings, plant expansion, changes of the operational status, preparation of underground activities etc. Event though satellite imagery does not yet entirely offer the spatial resolution of aerial imagery, image data gathered by earth observation satellites has the advantage to be comparable, verifiable, taken remotely and continuously, which in turn is generally required for routine treaty monitoring applications [1].

Commercial satellite imagery has therefore become apparently indispensable in the verification process of the Non-Proliferation Treaty (NPT) at this stage. The usefulness of commercial satellite imagery for strengthening IAEA safeguards has been effectually demonstrated in a number of case studies in the panchromatic, multispectral, hyperspectral and radar domain in the last years, please see [2] for a comprehensive overview. As a matter of fact, the application of satellite imagery for treaty verification has been cited by the vast majority of authors in this volume.

However, applications are dependent on several variables. Technical limitations in the use of satellite data for nuclear safeguards purposes are due to the spatial, spectral and temporal resolution of the imagery. Besides financial limits also political reasons might restrict the availability of data (e.g. by the shutter control) as well as the availability of ground information for data validation and modeling.

Nevertheless, both the number of nuclear sites monitored by remote sensing data and the time intervals for observations increase permanently. Moreover, the next generation of high-resolution satellite sensors (i.e. QUICKBIRD-3, IKONOS-3) will come along with an enhanced spatial resolution of 50 cm, that may be resolved to 25 cm with oversampling techniques. With this it can be expected, that the amount of data in the image archives of the IAEA will consequently accumulate more and more.

More data also involves a higher effort regarding image (pre-)processing, analysis and interpretation. Computer-based techniques could be of great value in this regard. Though a software system will not be able to replace an image analyst completely in the foreseeable future, she or he could benefit from (semi-)automation and transferability of digital image processing steps in order to detect and analyze significant features of interest much faster and probably more precisely too.

Against this background, the present paper focuses on the multitemporal analysis of satellite imagery, the so-called change detection, by digital techniques. In the following we will give a short review on the state-of-the-art of change detection techniques and then demonstrate and discuss some suitable procedures for nuclear safeguards purposes including possibilities for automation and transferability.

2 Digital Change Detection

Change detection is the process of identifying and quantifying temporal differences in the state of an object or phenomenon [3]. When using satellite imagery from two acquisition times, each image pixel or object from the first time will be compared with the corresponding pixel or object from the second time in order to derive the degree of change between the two times. Most commonly, differences in radiance values are taken as a measure of change.

2.1 Data Pre-Processing

Differences in radiance values indicating significant ("real") changes have to be larger compared to radiance changes due to other factors [3]. The aim of pre-processing is therefore to correct the radiance differences caused by variations in solar illumination, atmospheric conditions and sensor performance and geometric distortion respectively.

Geometric Correction:

A precise image registration is essential for an exact pixel-by-pixel or object-by-object comparison during the change detection process. By means of geometric correction algorithms, the image data can be registered to each other (image-to-image registration) or to a given map projection (georeferencing). In order to avoid false alarm signals due to misregistration effects, the procedure should be carried out at a sub-pixel accuracy level, i.e. with a RMS error well below +/- 1 pixel.

The registration of two data sets usually involves the selection of so-called Ground Control Points (GCPs) and Tie Points (TPs) in both images. Even though some standard remote sensing software systems offer an automation of the process to a certain extent today, the very time-consuming setting of GCPs still has to be done manually there. However, some techniques have been proposed for the (semi-)automatic determination of GCPs using for example Hough transform [4], Laplacian-of-Gaussian filtering [5] or image correlation [6].

For high-resolution imagery, the sensor's off-nadir viewing rather necessitates an orthorectifying procedure to remove sensor and terrain-related distortions. The orthorectification implies the existence of GCPs, the appropriate sensor model and a high-resolution digital elevation model (DEM). Elevation information can always be derived from satellite-based high resolution stereo image pairs [7, 8], but unfortunately stereo data is available either selectively in the archives of the data providers or on demand at a high price.

Atmospheric Correction:

Radiometric correction procedures aim to calculate the absolute surface radiance or reflectance by removing the atmospheric effects. A comprehensive correction scheme by modeling the atmospheric conditions during image acquisition based on a radiative transfer code implies the knowledge of the atmospheric parameters at that time. Information on the precise atmospheric properties is not easily available, and using standard atmospheric models instead may result in a non-satisfactory correction.

For change detection applications of satellite imagery, absolute atmospheric modeling is rarely necessarily needed, and this applies to nuclear safeguards applications, too. Assuming that the relationship between the at-sensor radiances measured at two different times can be approximated by linear functions, a relative radiometric normalization seems to be sufficient here .

The different methods introduced in the literature [9] differ regarding the time-invariant features used as the basis for normalization, e.g. pseudo-invariant features [10] or no-change pixels [11].

2.2 Change Detection Techniques

A variety of digital change detection techniques has been developed in the past three decades. Basically, the different algorithms can be grouped into the following categories: algebra (differencing, rationing, regression), change vector analysis, transformation (e.g. principal component analysis, multivarite alteration detection, Chi-square transformation), classification (post-classification comparison, unsupervised change detection, expectation-maximization algorithm) and hybrid methods. Reviews on the most commonly used techniques are given by i.e. [3, 12, 13, 14]. Many of the algorithms used for analyzing temporal changes are indeed not restricted to change detection. In summary, there is a wide variety of alternatives having varying degrees of flexibility availability and significance, and only a few studies have been carried out for quantitatively assessing the different methods for one case study [15, 16, 17]. However, the application of change detection corresponds to the schemes

- automated versus interactive/visual
- pixel-based versus object-based
- pre-classification versus post-classification
- simultaneous analysis versus comparative analysis
- change extraction versus change labeling
- bi-temporal versus multitemporal

Here, the possibilities of pixel-based and object-based algorithms for potential safeguards purposes should be introduced in detail.

2.3 Pixel-based change detection

For the detection of changes on a pixel basis, several statistical techniques exist, calculating e.g. the spectral or texture pixel values, estimating the change of transformed pixel values or identifying the change of class memberships of the pixels.

In regard to the specific application of nuclear monitoring the most satisfactory results were carried out by the so-called Multivariate Alteration Detection (MAD) transformation [18]. The MAD procedure is based on a classical statistical transformation referred to as canonical correlation analysis to enhance the change information in the difference images and briefly described as follows: If multispectral images of a scene acquired at times t_1 and t_2 are represented by random vectors X and Y, which are assumed to be multivariate normally distributed, the difference D between the images is calculated by

$$D = a^T X - b^T Y \tag{1}$$

Analogously to the principal component transformation, the vectors a and b are sought subject to the condition that the variance of D is maximized and subject to the constraints that $var(a^T X) = var(b^T Y) = 1$. As a consequence, the difference image D contains the maximum spread in its pixel intensities and - provided that this spread is due to real changes between t_1 and t_2 - therefore maximum change information. Determining the vectors a and b that way is a standard statistical procedure which amounts the so-called generalised eigenvalue problem. For a given number of bands N, the procedure returns N eigenvalues, N pairs of eigenvectors and N orthogonal (uncorrelated) difference images, referred to as to the MAD variates.

Since relevant changes of man-made structures will generally be uncorrelated with seasonal vegetation changes or statistic image noise, they expectedly concentrate in the higher order components (if sorted according to the increasing variance). Furthermore, the calculations involved are invariant under affine transformation of the original image data. Assuming that changes in the overall atmospheric conditions or in sensor calibrations are approximately equivalent to affine transformations of the pixel intensities, the method is insensitive to both of these effects.

The decision thresholds for the change pixels could be set in terms of standard deviations about the mean for each MAD component. Regarding automation a probability mixture model was applied to the MAD variates based on an EM algorithm to determine automatically the density functions for the change and no-change pixels and thence the optimal decision thresholds for discriminating change and no-change pixels. The mixture-model procedure was proposed by [19, 20] and applied recently in [21].

The application and expressiveness of the proposed procedure depends (among other things) on the spatial resolution of the imagery. When a change signal within nuclear sites is very significant in terms of radiance changes, it can mostly be detected by the pixel-based analysis of mid-resolution multispectral image data. But when adopted to high-resolution imagery, the results of the MAD transformation pixel-based algorithms are in general limited. Especially if small structural changes are to be detected, object-oriented procedures seem to be more precise and meaningful.

2.4 Object-based change detection and analysis

Processing satellite image data in an object-based way generally extends the possibilities to detect changes between two or more dates by taking into account the changes of the mean object features (spectral color, form, etc.), the modified relations among neighboring, sub- and super-objects or changes regarding the object class memberships. Moreover, specific knowledge can be easily involved into the procedure. Previous studies implying a combination of pixel- and object-based techniques have already demonstrated the advantages of firstly pinpointing the significant change pixels by statistical change detection and subsequently post-classifying the changes by means of a semantic model of change-related object features. According to the results the analysis and interpretation of changes within nuclear plants can be more precisely and reliably if the change detection procedure makes use of the characteristic features of facility objects and changes (e.g. compared to other industrial sites) [22]. The software solution for an object-oriented change analysis is currently given by eCognition [23].

In the following, both wide-area monitoring and detailed change analysis will be exemplified for case studies from the Iran. Regarding the automation of the processing aspects of standardization and transferability took the center stage of the investigations.

3 Application to bitemporal multispectral imagery

Seeing the recent proliferation implications of Iran's advanced nuclear program due to the potential of dual-use activities within uranium enrichment and reprocessing, a so-called nuclear monitoring system for the Iran was set up as an application (Figure 1). In the first instance, multitemporal area-wide ASTER imagery (AST_07, surface reflectance with 15m (VNIR) and 30m (SWIR) spatial resolution, [24]) for 17 nuclear-related locations built the database for this system, accompanied by different kinds of open source information and completed by high-resolution imagery from QUICKBIRD for some areas of interests. More satellite image data could be added later on demand.

Fig. 1. Nuclear monitoring system for 17 nuclear-related locations in the Iran

Different image analysis approaches suitable for nuclear safeguards applications were implemented and evaluated. In general, a two-steps attempt was realised based on the wide-area monitoring using medium-resolution ASTER data for pre-scanning of areas of interest, i.e. significant changes within the nuclear-related locations. They then could be explicitly analysed by change detection and analysis methods using the high-resolution QUICKBIRD image data.

In the following, examples both for pre-scanning and detailed analysis will be given.

3.1 Pre-scanning: Wide-area monitoring using medium-resolution satellite imagery

The so-called pre-scanning is intended for the detection of potential nuclear-related undeclared activities and the detection of major changes within declared nuclear sites and their surrounding areas. ASTER imagery of the sites located at Arak, Bandar Abbas, Bushehr, Esfahan and Natanz were used as training data in order to determine a fixed set of segmentation parameters for a sufficient multiresolution object extraction, to define satisfactory and transferable object features for object classes being relevant in terms of nuclear safeguards and to implement a measure for possibly changes within nuclear facilities.

For the standardization of the object extraction both solely multiresolution segmentation and a combination of chessboard and multiresolution segmentation was carried out. With respect to an acceptable computing time the latter segmentation was conducted as follows: After segmenting the image into a coarse chessboard grid, homogeneous chessboard cells with mean standard deviations in the VNIR channels below a specific threshold were excluded from the further segmentation, assuming that homogenous cells defined that way are unlikely to contain small-scale anthropogenic structures. The remaining adjacent cells were then divided in a finer chessboard, homogenous chessboard cells removed again on the basis of the standard deviation, the residual adjacent cells tiled into a yet finer grid and so on until the defined minimum cell size was reached. Only the pixels left thereafter were finally involved in the more time-consuming multiresolution segmentation process (Figure 2).

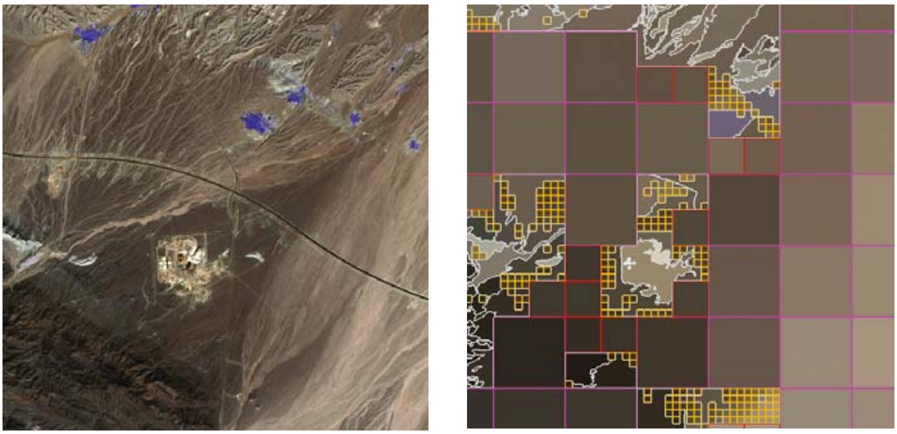


Fig. 2. Extract of AST07, green (R), red (G), NIR (B) over Natanz (left) and its chessboard/multiresolution segmentation, level 6 (right)

For the subsequent object classification a standardised and transferable semantic model being able to perform satisfactory results for all given ASTER (AST_07) scenes was developed. In order to avoid the likewise time-consuming "trial-and-error" practice while seeking for significant class separating object features approaches towards an automatic feature extraction were investigated. In the given project the optimal object features and the range of its membership functions were automatically determined by the feature analyzing tool SEaTH (SEparability and THresholds) [25]. This statistical procedure calculates the separability and corresponding thresholds for each possible object class combination and for any number of given features.

By this means, a classification model was defined for the object classes "industrial areas", "mountainous areas", "settlements", "soils", "vegetation" and "water", and applied to a number of scenes. Figure 3 shows the classification result for the scene of Bushehr.

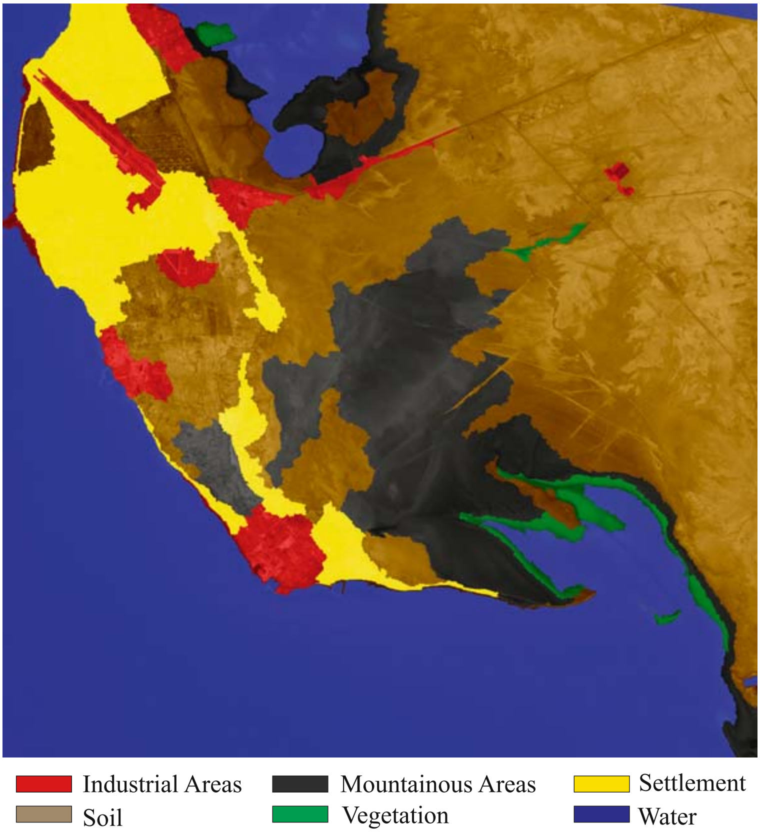


Fig. 3. Application of the automated classification model to the ASTER scene of Bushehr

The relevant site was correctly classified as industrial area, and some others in the left range, too. Water, soils, vegetation and settlements were indicated sufficiently aside from some misclassifications. Anyhow, without adapting the classification model for each scene, the results could be qualified as good to quickly get a general idea of the different land cover classes. The developed rule bases for the object classes can also be applied individually to the image data (Figure 4).

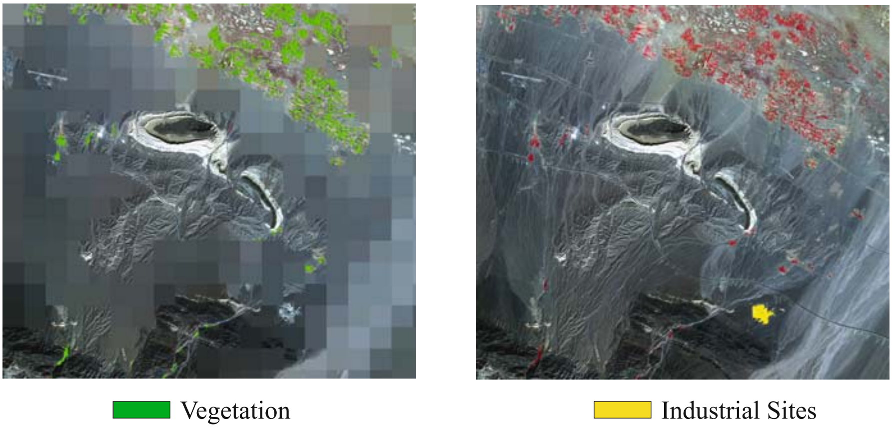


Fig. 4. Classification tasks for vegetation (left, indicating chessboard segmentation) and industrial sites (right) at the location of Natanz

In the next step a measure for potential changes within industrial facilities was implemented. On the basis of the co-registered bitemporal data sets change pixels were detected by using the multivariate alteration detection (MAD) transformation, producing a set of mutually orthogonal difference images. Figure 5 presents the first three so-called MAD variates of the ASTER scenes acquired over the site at Natanz in July 2000 and July 2001 (bottom left). They symbolize no change at all grey-colored pixels, while the pixels different from grey indicate changes. Imported as additional information layers they provide a measure of change within the semantic model and allow the classification of changes within a given class, i.e. changes within industrial areas (Figure 5, right).

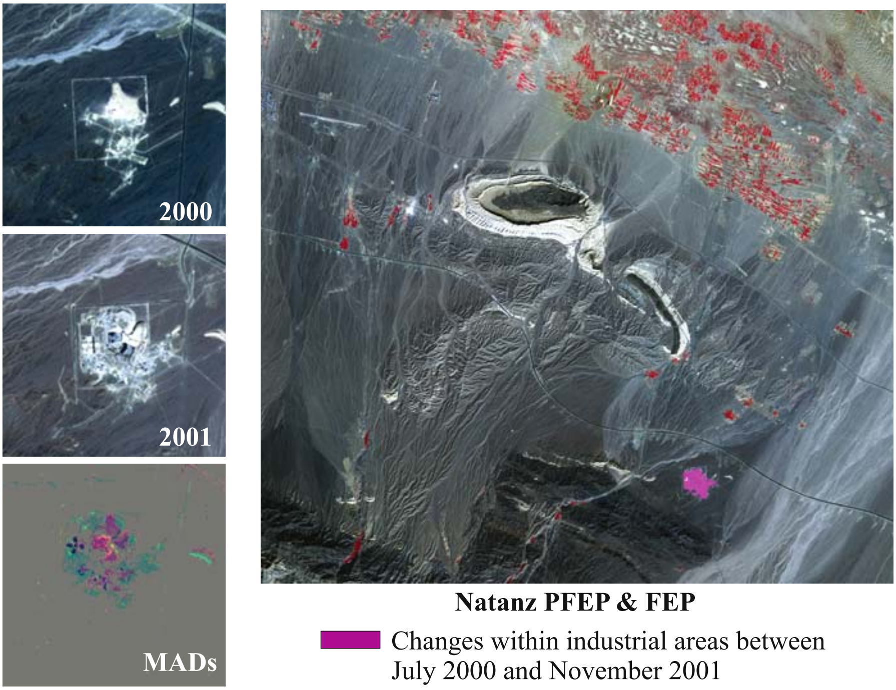


Fig. 5. Classification of industrial areas with enclosed significant changes, Natanz, ASTER Scenes from July 2000 and July 2001

3.2 Detailed change detection and analysis using high-resolution imagery

When areas with significant, safeguards-related changes have been detected, e.g. on the basis of medium-resolution image data, they then will be analyzed in detail using high-resolution imagery. Again, investigations were conducted as to the standardization and transferability of classification models. A QUICKBIRD scene acquired over the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) in July 2002 provided the basis for automatic feature extraction for the classification model. As before, the optimal object features and the range of their membership functions were automatically determined by the statistical procedure SEaTH analyzing the separability between the classes, in this case between the classes "building development", "walls", "shadows", "streets" and "vegetation". When applied to the image data, an overall accuracy of approximate 90% was achieved, depending on the respective segmentation level (Figure 6, left). In order to check the temporal transferability the 2002 classification model was applied to another image acquired over the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) in July 2003. After minor changes of the 2002 model in reference to one single feature, an overall accuracy of approximate 88% was obtained

(Figure 6, right). Moreover, the 2002 classification model was tested regarding the spatial transferability by applying it to another extract of the full QUICKBIRD scene (without figure).

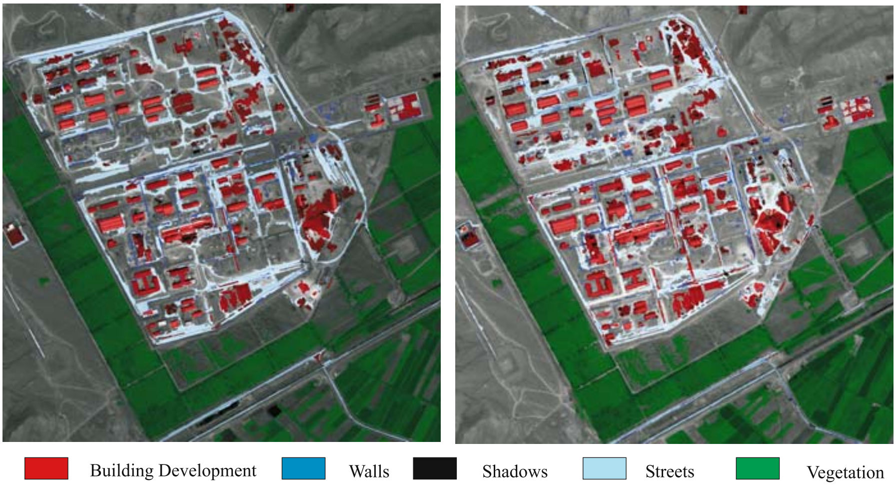


Fig. 6. Object-oriented classification of the 2002 (left) and 2003 (right) QUICKBIRD images over Esfahan Nuclear Fuel Research and Production Centre (NFRPC)

Finally, the possibilities to automate change detection and analysis procedures using high-resolution image data were examined. For this purpose a combination of pixel-based techniques for the detection of change pixels and object-oriented procedures for the subsequent analysis respectively classification of the change pixels was proposed. Given an subset of the 2002 and 2003 QUICKBIRD images over the Esfahan NFRPC, an MAD transformation was carried out in order to find the change degree for each pixel. The four MAD components (according to the number of input channels) were used for the object extraction within eCognition. A classification model distinguishing between two types of man-made structure changes was defined by combining the objects mean MAD values, the objects mean spectral values and indices, the correlation between MAD components and original image data, and relations between the objects. Figure 7 shows thus the most significant changes between July 2002 and 2003: The completion of buildings and the partly asphalting of the unmetalled roads.

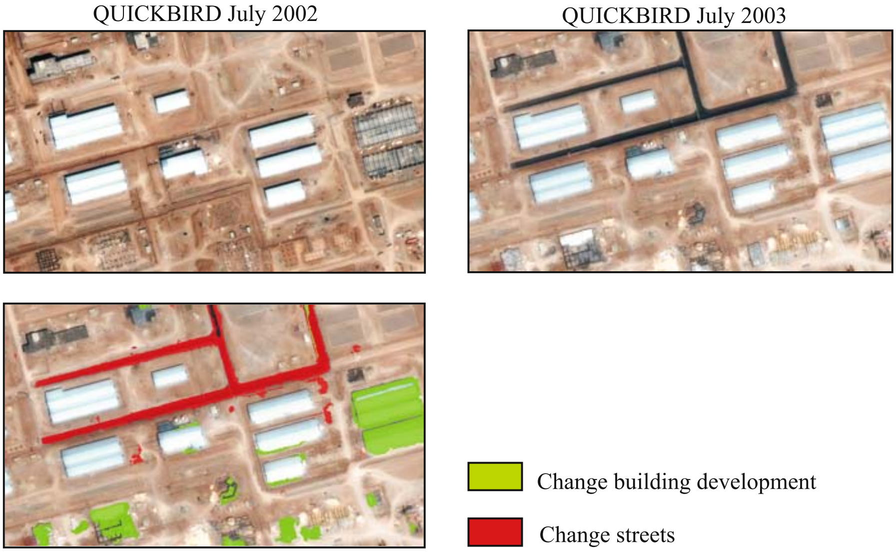


Fig. 7. Change analysis 2002-2003 for parts of the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) with respect to two types of man-made structure changes

4 Conclusions and Outlook

An object-oriented monitoring system for nuclear safeguards purposes was proposed in order to detect changes within nuclear facilities. By means of pixel-based change detection and object-oriented post-classification by eCognition some investigations were carried out in terms of automation, thus standardization and transferability. As a result, medium-resolution imagery could be considered as suitably for change-/no change-analysis in terms of wide area monitoring, for the detailed object-oriented analysis of significant changes high-resolution satellite imagery should be used. The automation and the transferability of the change detection and analysis procedures appears to be feasible to a certain extent, therewith giving rough and fast indications of areas of interest and explicitly analyzing the relevant areas.

For the advanced analysis of nuclear sites (using high-resolution imagery), a detailed classification model furthermore has to be able to differentiate between nuclear and non-nuclear industrial sites and preferably between the different types of facilities within the nuclear sites class, too. Though the preliminary results within this project and previous approaches on the automated object-oriented classification of German nuclear power plans have been somewhat promising up to now, a lot of case studies have to be performed for a comprehensive understanding of the nuclear sites signatures identifiable in satellite imagery. Furthermore, the attempts to extract the objects features automatically have to be continued and the accuracy of the classification in terms of spatial and temporal transferability needs to be assessed in detail.

Satellite imagery will never provide all the relevant information needed for nuclear safeguards and security, but represents a very important source of information. The developments in sensor technologies (spatial, spectral improvements) and thus the increasing application possibilities of satellite imagery for nuclear safeguards have to be permanently investigated and evaluated.

References

1. J. Aschbacher, Monitoring environmental treaties using earth observation, in *Verification Yearbook 2002*, T. Findlay and O. Meier (Ed.), VERTIC, London 2002
2. B. Jasani and G. Stein (ed.), *Commercial satellite imagery. A tactic in nuclear weapon deterrence*, Springer, Berlin, 2002
3. A. Singh, Digital change detection techniques using remotely-sensed data, *International Journal of Remote Sensing* 10(6): 989–1002, 1989
4. A. F. Habib and R. I. Alruzouq, Line-based modified iterated hough transform for automatic registration and multi-source imagery, *The Photogrammetric Record* 19(105): 5-21, 2004
5. H. Li, B. S. Manjunath, and S. K. Mitra, A contour-based approach to multisensor image registration, *IEEE Transactions on Image Processing* 4(3): 320-334, 1995
6. M. Lehner, Triple stereoscopic imagery simulation and digital image correlation for meoss project, Proc. ISPRS Commision I Symposium, Stuttgart: 477-484, 1986
7. K. Jacobsen: Orthoimages and DEMs by QuickBird and IKONOS, Proc. EARSeL Ghent 2003, Remote Sensing in Transition, Millpress: 513 525, 2003
8. C. V. Tao, Y. Hu, and W. Jiang, Photogrammetric exploitation of IKONOS imagery for mapping applications, *International Journal of Remote Sensing* 25(14): 2833–2853, 2004
9. D. Yuan and C.D. Elvidge: Comparison of relative radiometric normalization techniques, *ISPRS Journal of Photogrammetry and Remote Sensing* 66: 166-178, 1996
10. J. R. Schott, C. Salvaggio, and W. J. Volchok, Radiometric scene normalization using pseudo-invariant features, *Remote Sensing of Environment* 26: 1-16, 1988
11. M. J. Canty, A. A. Nielsen, and M. Schmidt, Automatic radiometric normalization of multispectral imagery, Remote Sensing of Environment 91: 441-451, 2004
12. R. S. Lunetta and C. D. Elvidge (ed.), *Remote sensing change detection. Environmental monitoring methods and applications*, Taylor & Francis, London, 1999
13. P. Coppin, I. Jonckheere, K. Nackaerts, B. Muys, and E. Lambin, Digital change detection in ecosystem monitoring: a review, *International Journal of Remote Sensing* 25(9): 1565–1596, 2004
14. D. Lu, P. Mausel, E. Brondizio, and E. Moran, Change detection techniques, *International Journal of Remote Sensing* 25(12): 2365–2407, 2004

15. J.-F. Mas, Monitoring land-cover changes: a comparison of change detection techniques, *International Journal of Remote Sensing* 20(1): 139–152, 1999
16. H. Liu and Q. Zhou, Accuracy analysis of remote sensing change detection by rule-based rationality evaluation with post-classification comparison, *International Journal of Remote Sensing* 25(5): 1037–1050, 2004
17. Y. Liu, S. Nishiyama, and T. Yano, Analysis of four change detection algorithms in bi-temporal space with a case study, *International Journal of Remote Sensing* 25(11): 2121–2139, 2004
18. A. A. Nielsen, K. Conradsen, and J. J. Simpson, Multivariate alteration detection (MAD) and MAF processing in multispectral, bitemporal image data: New approaches to change detection studies, *Remote Sensing of Environment* 64: 1-19, 1998
19. L. Bruzzone and D. F. Prieto, Automatic analysis of the difference image for unsupervised change detection, *IEEE Transactions on Pattern Analysis and Machine Intelligence* 11(4): 1171-1182, 2000
20. L. Bruzzone and D. F. Prieto, An adaptive semi-parametric and context-based approach to unsupervised change detection in multitemporal remote sensing images, Technical Report No. DIT-020030, Department of Information and Communication Technology, University of Trento, 2002
21. M. J. Canty, Visualization and unsupervised classification of changes in multispectral satellite imagery, *International Journal of Remote Sensing*, in press
22. Niemeyer, S. Nussbaum, and M.J. Canty, Automation of Change Detection Procedures for Nuclear Safeguards-Related Monitoring Purposes, Proc. of the 25th IEEE International Geoscience and Remote Sensing Symposium, IGARSS'05, Seoul, (CD-Rom), 2005
23. M. Baatz et al., *eCognition Professional User Guide 4*, Definiens, Munich, 2004
24. M. Abrams, S. Hook and B. Ramachandran, *ASTER User handbook, Version 2*, 2002 (Download:http://asterweb.jpl.nasa.gov/documents/aster_guide-v2.pdf)
25. S. Nussbaum, I. Niemeyer, and M. J. Canty, Feature recognition in the context of automated object-oriented analysis of remote sensing data monitoring the Iranian nuclear sites, Proc. SPIEs Europe Symposium Optics/Photonics in Security & Defence, Bruges, SPIE Vol. ED103 (CD-Rom), 2005

Aspects of Networking: Experience from Global Monitoring for Security and Stability

Iain Shepherd

1 Introduction

Only by combining forces can European research organizations begin to construct a European capacity for processing the enormous quantities of data coming from earth observation satellites into information useful for those responsible for Europes security. The GMOSS Network of Excellence has already made some progress. Partners are sharing software, agreeing on common standards, negotiating shared rights to data, defining the state of the art, setting priorities and developing a common research programme in socio-political analysis, generic earth observation technology and specific security-related applications.

2 Background

The annual total spending on research and development in the 25 Member States of the EU approaches 200 billion. Responsibility for managing the government-financed component of this budget is mostly the responsibility of the nation in which the research is carried out. The part that is managed at an EU level is much less - currently about 5 billion a year.

However a number of analysts have suggested that this fragmentation of research into programmes that are largely decided at a national level should be compensated by mechanisms that discourage duplication between national programmes and promote excellence at a European level. This is particularly the case where the objective of the research is to build a capability at a European level or where the scientific and technical challenge is so large that no one country can afford the critical mass of researchers necessary to move forward.

One of the mechanisms for doing so is the Network of Excellence which is designed to strengthen scientific and technological excellence on a particular research topic through the durable integration of the research capacities of the participants. This mechanism was introduced at the beginning of the EUs four-year Sixth Framework Programme for research in 2003.

Global Monitoring for Security and Stability (GMOSS) was one of the first networks to be set up. Its broad and ambitious aim is to integrate Europes civil security research so as to acquire and nourish the autonomous knowledge and expertise base Europe needs if it is to develop and maintain an effective capacity for global monitoring using satellite earth observation. That a common European effort is necessary in this domain is obvious.

First because the research underpins a long-term European effort to develop an improved commonly owned European global monitoring capacity. Although not fully defined yet, the joint European Union- European Space Agency initiative Global Monitoring for Environment and Security (GMES) will surely involve the construction of components and infrastructure shared between the European nations.

Second because a number of applications of this GMES capacity are European in nature. The capacity would, at least in part, be used to support security applications that are increasingly decided, implemented or coordinated at a European level.

And third because the scientific challenges implicit in developing these applications are so immense that no Member State on its own can hope to confront them.

2.1 Organization of GMOSS

The network of excellence mechanism allows partners to join or leave the consortium during its course. At the outset, in March 2004, there were 24 partners in GMOSS (Table 1). These were from 11 different countries and predominantly from the public sector (Figure 1). Integration involves sharing intellectual property and private organizations naturally tend to be more reticent than public ones about revealing the intimate details of their technology to potential rivals.

The partners undertake research in 12 work packages divided into three broad areas, namely applications, socio-political studies and generic technology. The relationship between these work packages is shown in Figure 2. Applications are the core business of the network - the main aim of the research being to develop and maintain applications of earth observation technology that support EU security policies. The applications chosen include treaty monitoring, early warnings, population monitoring, infrastructure monitoring, border monitoring and damage assessment.

Table 1. The GMOSS partnership

Partner	Abbreviation
Deutsches Zentrum für Luft- und Raumfahrt	DLR
Definiens Imaging GmbH	Definiens
Forschungszentrum Jülich GmbH	FZJ
AFES-PRESS	AFES-PRESS
Technische Universität Bergakademie Freiberg	Freiberg
Bundesanstalt für Geowissenschaften und Rohstoffe	BGR
Universitet Linköpings	Linköpings
OD Science Application	OD
Swedish Defence Research Agency	FOI
Commissariat à l'Energie Atomique	CEA
Centre national d́ études spatiales	CNES
Kings College London, Department of War Studies	Kings
QinetiQ	QinetiQ
Centro di Ricerca Progetto San Marco	San Marco
Università della Basilicata	Basilicata
Joanneum Research	Joanneum
University of Salzburg	Salzburg
Royal Military Academy Signal and Image Centre	RMA
Technical University of Denmark	TUD
The Netherlands Organisation for Applied Scientific Research	TNO
European Union Satellite Centre, Torrejon	EUSC
The Joint Research Centre	JRC
UNOSAT	UNOSAT
swisspeace	swisspeace

However many of these applications have common technological requirements: identifying changes in a time series of images, automatically identifying relevant features - buildings, land-cover - in images, and presenting image-derived information to users in a way that is intuitive. The aim of this generic technology research is to assess the state of the art in these areas, develop common standards and share the development work amongst the partners so as to avoid duplication.

Finally socio-political research is undertaken so as to clarify what security threats need to be monitored in the post-cold-war landscape, identify how the EU is responding to these threats and see which stakeholders civilian, and military, national and supranational need the information.

The work programme is updated every year. GMOSS funds the activity necessary to achieve integration between research programmes that are already funded from other sources. The distribution of funding amongst the different activities is decided entirely by the partnership.

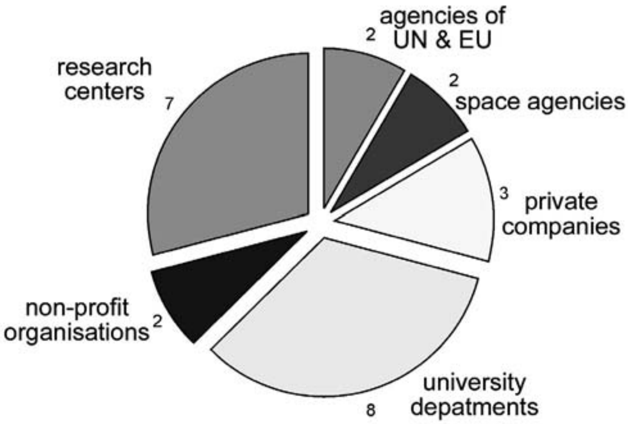


Fig. 1. Types of organization involved in GMOSS

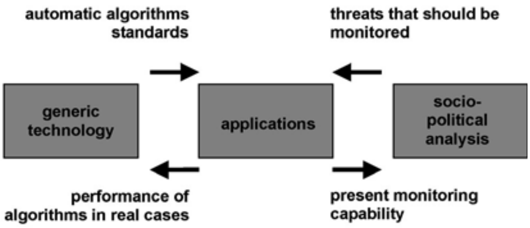


Fig. 2. The three areas of research in GMOSS

2.2 Progress after one year

The Network has been in operation for one year and initial findings have confirmed that it does indeed add value to the research of the individual partner laboratories.

Technical workshops were the principal motor for integration. Originally only 12 had been planned for the first year but the initial ones proved so successful that a total of 22 were held. The other main measures to achieve integration were data sharing, staff exchanges and a game involving the whole network. Agreements were reached with suppliers to provide images for use by the entire consortium.

In the following chapters we summarise the main findings of the research.

3 Socio-political research - defining threats, dealing with threats and responding to crises

There is no disagreement amongst researchers, policy makers and the general public that the events typified by the fall of the Berlin Wall in November, 1989 marked a change in Europe's security. However debate is still ongoing as to what the new security, threats, vulnerabilities and risks are or how we should face them.

3.1 Perceptions of security

AFES, one of GMOSS's partners, showed that the perception of security threats, challenges, vulnerabilities and risks depends on the world-views or traditions of the analyst and on the mind-set of policy-makers. They distinguish three - a Hobbesian pessimist (realism) where power is the key category; a Kantian optimist (idealism) where international law and human rights are crucial; and a Grotian pragmatist where cooperation is favoured. Simplifying somewhat they believe that social science institutions and research programmes focusing on war, military, strategic or security studies have a Hobbesian perspective whilst those focusing on peace or conflict prevention have a Grotian or Kantian view.

"Economic and social threats" are included as one of six categories of threat in the recent panel of experts report to the United Nations Secretary General. This includes poverty, infectious disease and environmental degradation. AFES suggested that those with a Hobbesian world-view tend to underestimate or neglect environmental challenges which disproportionately affect those with a high degree of societal vulnerability. Those with a Kantian or Grotian worldview believe that combating these threats marks a good opportunity to demonstrate international collaboration and that GMOSS should therefore devote more resources to them. However it was pointed out that research into these threats is already being conducted in other EU projects. Much less is currently being done at a European level to investigate threats to security resulting from man's inhumanity to man. It was therefore decided to focus on these.

3.2 EU Security Strategy

FOI examined the threats identified by the EU in its security strategy presented in December 2003: terrorism, proliferation of weapons of mass destruction, organised crime, regional conflict and state failure. On the first three of these issues - terrorism, proliferation and organised crime - they observed an increasing awareness that the EU needs to act collectively and an increasing consensus as to what needs to be done. Nearly all the measures proposed - increased police cooperation, legal instruments and treaties - are civilian in nature and, where military force is mentioned as a last resort, the central role of the United Nations is emphasised. Other than closer economic integration with near neighbours - eastwards towards Russia and on the southern shores of the Mediterranean - the response to state failure and regional conflict is less clear. Humanitarian aid and peacekeeping operations in the Balkans and the Democratic Republic of Congo show the EU's willingness to deploy troops although in other areas denoted as of being of special interest to the EU, such as the Southern Caucusus, the strategy is still being defined.

3.3 Comparison of the EU and US strategy on proliferation

A careful comparison by FOI of the EU and US strategies to counter the proliferation of nuclear weapons capability indicated that the differences are more apparent than substantive. Both stress the need for international cooperation. The US strategy does not mention the EU explicitly but the EU is forthright in its desire to promote closer coordination with the United States. The EU aims for a country-by-country approach that includes active diplomacy as well as policies that address the root causes of proliferation. Both the EU and US support the extension of international treaties. The EU indicates that it will work towards increasing the detectability of violations through the establishment of additional international verification instruments and, if necessary, the use of non-routine inspections under international control outside facilities declared under existing regimes. The EU strategy also supports the US idea of interdiction of suspected shipments carrying WMD-related equipment.

It is less easy to compare the strategies for countries where careful monitoring and gentle persuasion fail to prevent moves towards a nuclear weapons capability. The US is more explicit in how its counter-proliferation strategy would deal with such a threat. It does not, as we all know by now, rule out unilateral action. The EU strategy states that among the coercive measures the use of force is envisioned as a last line of defence. The role of the UN Security Council as the final arbiter on the consequences of noncompliance as foreseen in multilateral regimes needs to be effectively strengthened.

3.4 Responding to crises

Effective handling of crises is central to the EU's security responsibilities. The partners of GMOSS have focused on developing a common understanding of what is meant by a crisis, on seeing how quickly images could be produced in response to real crises and on some exploration of how advanced information technology can support crisis management.

A four dimensional description of crises has been developed: (1) causative - humanitarian disasters, terrorism, natural disasters and conflicts; (2) - actors: decision makers at European, national and provincial level, security and relief officials, policy makers and the public (3) key elements to facilitate a possible crisis response and mitigation: technical systems, response strategies, organisational and hierarchical structures, information and response resources as well as analysis and interpretation systems and schemes. (4) key policy drivers: Common European Security and Defence Policy (Petersberg, Schengen, Relex etc.), Internal security (Member States, Monitoring and Information Centre, etc.) humanitarian aspects (DG - ECHO, Member States ministries etc.).

QinetiQ noted that a number of mechanisms have already been developed to pool the resources of individual European information suppliers during crises. These include PROCIV-NET which interconnects designated national contact points and other available resources that deal with environmental and civil protection emergencies, the Charter for Space and Major Disasters which facilitates the provision of images by Space Agencies to civil protection bodies, as well as a number of European Space Agency-sponsored efforts which form part of their contribution to GMES. QinetiQ suggest that these initiatives need a stronger and more permanent coordination and better standards for information exchange. This could be achieved by a distributed webservices model using service chaining to disseminate information to end-users derived from raw data. They believe that such a model could be tested in a GMOSS scenario.

Several near real time satellite data acquisitions for analysis of crisis situations were made during the course of the first year. These included situation analysis in the context of a continuous accidental explosion of an arms dump in the Ukrainian (threatening ten thousand local residents and a nearby nuclear power plant for days), analysis of earthquake damages in Iran and Morocco as well as forest fire assessment in Portugal. In case of the arms dump explosions the response time between onset of the crisis event until newly acquired satellite 1m imagery was acquired and evaluated for reporting was only 44 hours. Often the response time in cases such as forest fires or earthquakes can be of the order of a few days, depending on satellite availability and cloud cover. Only through very good networking and the establishing of effective communication and cooperation channels can such fast and efficient image request, acquisition, transfer, analysis and information dissemination be achieved.

Many of the GMOSS partners provided maps and images to support relief efforts following the 26 December 2004, tsunami.

3.5 Gaming

Gaming, a common technique in military circles, was adopted by GMOSS as a useful tool for (1) scenario analysis identifying what information is available in crisis situations, who needs it and what the bottlenecks are (2) integration of the network arriving at a common understanding of the problems to be solved and (3) training - seeing problems from another perspective, putting the researcher in the shoes of the user. The first GMOSS attempt to understand scenarios through gaming took place on the afternoon of 8 November 2004 in Brussels. About 70 participants representing all the GMOSS partners took part.

The participants were split into two teams. Team A had to react to an influx of refugees crossing the Mediterranean from North Africa and team B was given a scenario involving an Iran with a reported nuclear weapon capability being threatened by attack from Israel.

Some partners thought that more preparation of the scenarios would have allowed a deeper analysis but the participants did get to know each other better, they did gain a measure of understanding of the complexities involved in ensuring that the Member States of the Union work together in harmony and they did realize that the European Union has some way to go if it is to have the capacity to deal with unexpected crises effectively.

Fig. 3. Partners assessing options during the GMOSS game of November 2004

3.6 Focus for the second year of GMOSS

In the second year of GMOSS research will continue on translating the threats identified by the EU strategy into requirements for monitoring for space, on clarifying the endusers for this monitoring and on exploring the boundary between the needs of confidentiality and openness. A further game will take place.

4 Generic technology - change detection, feature recognition and visualization

Earth observation satellites in orbit above our planet are increasing in number and in resolution - spectral, spatial and temporal. Those on a typical sunsynchronous polar orbit circle the globe more than 14 times a day. The now widespread use of spaceborne cameras that can point, tilt and swivel means that every point on the earth can be revisited once every two or three days. Launches already planned are increasing the number of satellites and reducing the time between passes. This trend is expected to continue as technology matures and the price of satellites falls.

This mountain of information totally swamps the capacity of human analysts to cope. Highly skilled analysts can examine areas that have been identified by other means, for example open-source intelligence, as being suspicious or interesting but they cannot:

- analyze but a fraction of the number of sites of interest. For instance globalsecurity.org identifies 32 suspect sites in Pakistan alone;
- search for new unreported features a convoy of refugees escaping from a conflict, a nuclear fuel enrichment facility, a landslide in a remote zone.

GMOSS is tackling these needle in haystack problems by focusing on two specific areas of research, namely

- change detection - identifying what has changed in a time series of images,
- feature recognition - locating specific features refugees tents, reactor cooling towers in large volumes of data.

Further research is ongoing on presenting information extracted from images to those who need to act it.

4.1 Feature recognition

The long-term objective of the work on feature extraction is to take the drudgery out of image interpretation through the development of automated algorithms and software. The approach is to clarify the state of the art, identify issues related to open standards, develop, evaluate and compare new software for image understanding, determine how to integrate algorithms into an operational image interpretation center and improve exchange of information on cognitive vision methodologies within GMOSS.

Joanneum and Definiens have begun work to establish the state of the art by defining the stages of recognition pre-processing, image optimization, segmentation, classification and object detection, quality inspection and system optimization.

The first three stages - pre-processing, image optimization and partly segmentation - can be undertaken using software operating on a pixel level. QinetiQ have demonstrated the importance of the image optimisation phase. Their speckle-reduction algorithm improves the detectability of features in high resolution polarimetric synthetic aperture radar (SAR). This allowed software developed for optical imagery to detect linear features of the same width as the image resolution. Roads of width 3 metres and above can be detected in 4 metre resolution images.

However the other phases require operations on groups of pixels. Definiens Imaging - a GMOSS partner have developed the eCognition software suite to incorporate the functionalities necessary for a knowledge based image analysis, operating on segments. It is now one of the most advanced commercial softwares available and is being adopted by other partners in the Network. It allows the context of an object to facilitate identification when the local intrinsic object structure provides insufficient information.

The team are also examining computer vision technologies for techniques that might be applied to remote sensing. An example is a "cascaded classifier". These are different from single-stage classifiers (such as, neural network based or decision tree based classifiers), because they do not attempt to classify the pattern under investigation at once in a single step of pattern class discrimination. Instead, a first decision step rejects a large part of the search space, making the job of any other classifier - operating on the remaining, accepted part of the complete search space - more simple. In this sense, each classification step determines appropriate features of the pattern, and appropriate rules to evaluate these in order to branch into rejected and accepted patterns as part of the associated feature space. Cascaded classifiers can be learned from training samples by means of the mathematical framework of boosting, i.e., starting with simple hypotheses, and refining until most detailed class samples can be discriminated.

Cascaded classifiers can be used in conjunction with hierarchically organised data bases. This allows objects to be recognised at various levels of detail. For instance we can classify an object as being a tree or a person before we identify the species of the tree or the name of the person. Applying these in remote sensing might allow the same database to be used with different resolution sensors.

Although neither cascaded classifiers nor hierarchical databases have yet been used for remote sensing they are a promising way forward that should be investigated.

Partners working on application work packages treaty monitoring, border monitoring etc have been asked to suggest potential test cases for these new or improved algorithms. An example has been the classification of an Iranian reactor by Definiens Imaging and Kings. Expert knowledge about the classification of pressurised water and boiling water reactors was captured by a set of rules using eCognition's class hierarchy editor. This allows the inheritance of classes and uses fuzzy logic for their classification. Rules developed on German reactors confirmed, using Quickbird imagery, that the Iranian Bushehr reactor under construction is indeed a pressurised water reactor (PWR).

The next step is to prepare a road-map for future development. Sharing of the results of this development will be facilitated by open standards that allow developments and products of one partner to be integrated with those of others QinetiQ is currently implementing a number of solutions adopting Open GIS Consortium standards (OGC) and recommend that GMOSS adopt these standards for feature recognition Access, to distributed sources of geospatial information and processing tools is enabled through implementation and exploitation of the OpenGIS Web Service Specifications.

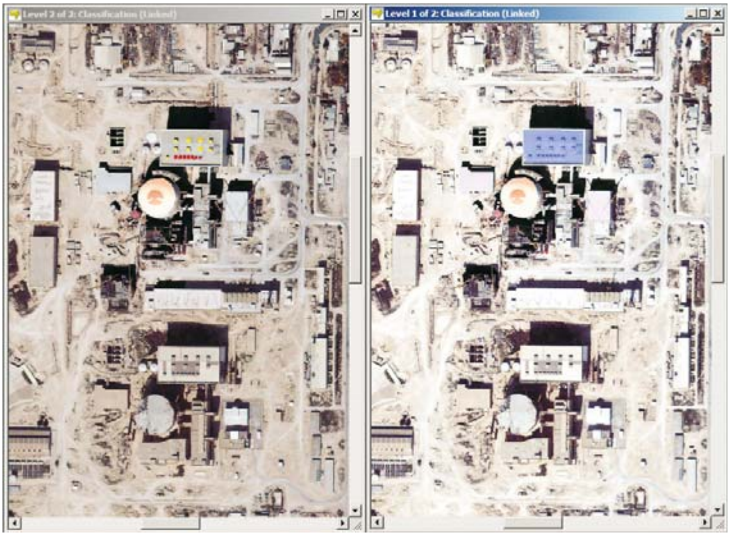


Fig. 4. Analysis of 28 February 2004 Quickbird image of pressurised water reactor in Bushehr (Iran). Since one reactor dome and most of its surrounding buildings have already been finished, the ontology for this typical pattern could be developed and applied to classify the semiautomatically generated image objects. The classification of the buildings which are typical of PWRs is made firstly based on (1) shape (size and roundness for the reactor, rectangular (for the turbine and control building); (2) distance - only buildings within a distance of 120 (fuzzy membership degree of 1.0) and 200 (fuzzy membership degree of 0.0) pixels around the reactor building were taken into account (see Figure 2); (3) spatial contextual information.
Turbine buildings generally have characteristic windows and ventilation exhausts. In the image the objects classified as windows are coloured yellow and ventilation exhausts red. The turbine building is the only bigger building close to the reactor with ventilation exhausts and windows on top

4.2 Change detection

Automatically detecting changes in a time series of images or between an image and a map are fundamental challenges in nearly all security applications of remote sensing. Many of the partners have long-established research backgrounds in this technology although not necessarily for security applications. In constructing an integrated research programme from the different ongoing efforts, the partners aim to identify and strengthen areas of expertise within the Network, to improve European capabilities in change detection and to support other partners in the Network in tackling security related applications treaty monitoring, infrastructure monitoring etc.

Two broad classes of change detection algorithm have been identified. First to identify areas that have been disturbed in order to focus the attention of image interpreters and second to quantify and classify the changes.

Identifying changes

Both optical and radar imagery have been used for the first class of problem locating areas that have been disturbed.

Algorithms have developed by TUD for medium resolution multispectral and hyperspectral optical imagery and implemented in the ENVI software. These take advantage of the statistics (covariance matrices) of different spectral bands to isolate and enhance the change information. Change signals exceeding predetermined thresholds are taken to be statistically significant and subject to further interpretation. These algorithms have been installed and applied by a number of GMOSS partners.

The potential of synthetic aperture radar imagery (SAR) to provide imagery under all weather conditions has been recognized and a number of satellite systems will be launched in the near future with higher resolution and more polarisation options than systems currently in orbit.

QinetiQ, TUD and TNO have been using airborne SAR to test the ability of these future systems to provide useful information in security-critical situations. QinetiQ and TNO have demonstrated that measuring the interferometric coherence between carefully chosen repeat pass datasets allows the detection of the rearrangement of objects, vegetation damage due to tracked vehicles, demolition, construction and modification of man-made objects.

Degrading imagery to 3 metres in order to simulate a potential spaceborne instrument halved the average detection probability from 74 to 37%. TUD have shown the usefulness of very high resolution polarimetric SAR for detecting changes within an area particularly the building, removal or destruction of man-made objects. Some of the presently available lower resolution radar imagery available from Radarsat and Envisat-ASAR has also been tested in security applications. Using noncoherent change detection techniques with Radarsat fine-mode (10 metre resolution) TNO could identify changes in images of Baghdad during its bombardment in early 2003 and in the Iranian nuclear research centre in Isfahan.

TNO, Definiens Imaging, QinetiQ and JRC analysed the difference between Radarsat Standard mode (25 metre resolution) images of Aceh, Indonesia, before and after the catastrophic tsunami of 26 December 2004. At this resolution it was not possible to assess damage to buildings but changes to the coastline and vegetation cover could be measured.

Lastly JRC have developed software for constructing three-dimensional representations of an object with satellite imagery (stereo pairs with the use of photogrammetry or from satellite images combined with a digital terrain model), airborne stereoscopic imagery or from ground data. using laser range instruments. i.e. laser range data and optical images acquired with instrumentation mounted on a mobile vehicle: in this case, the 3D model is given by the laser range measures combined with optical images for a better visualization.

Classifying changes

It is much harder to develop automatic algorithms to classify the changes. Each of the methods studied needs considerable effort to set-up for each particular application. Indeed the partners of GMOSS concluded that operator-guided methods are presently the only option if quick results are needed. Nevertheless, some progress has been made both with medium and very higher resolution imagery.

Fig. 5. Area in Iran where uranium mining has been reported. Left picture shows very high resolution Quickbird image overlaid on digital elevation model. Right image shows changes detected by FZJ between July 2000 and July 2002 in lower resolution ASTER imagery. The areas in green indicate change and focus attention on areas that merit further inspection

The medium resolution analysis is focusing on changes in land-cover classification. First indications are that Corine Land Cover classes, which have become a standard in Europe for measurement of environmental change, are not wholly suitable for security applications. Although certain "level 4" classes such as "industrial or commercial units", "road and rail networks", "port areas", "airports", "construction sites", "sport and leisure facilities" could be useful, it was concluded that the 100-metre-pixel spatial resolution is too coarse and that these level 4 classes are too general. They need to be subdivided.

Supervised classification, as used in setting up Corine, gives the best results for classification but is subject to analyst influence and is difficult to extend outside the ground-truthed area. DLR have therefore been developing a knowledge tree-based approach for determining the change in certain land-cover types - coal, dense vegetation and pyrametamorphic bedrock. 93% accuracy has been been obtained in applying spectral test sequences without user intervention over long periods - 15 years - and across continents for these cases where the searched-for classes make up a small fraction of the total image area.

The challenges in working with very high resolution imagery are immense - differences due to camera angle or solar illumination can produce greater changes in the image patterns than those due to landscape changes. Work is ongoing on two applications (1) determining the ability of automatic algorithms to compare an image with a map in Belgium and (2) comparing pixel-based to object-oriented techniques for detecting changes between a pair of very high resolution images of Isfahan, Iran.

The research by RMA assessed the ability of automatic algorithms to identify changes in road networks and built-up areas between a 5 metre resolution Spot5 image and a database of vector objects based on an earlier map. The algorithm missed between 10 and 20% of the changes - a score which was quite similar to the score of some professional image interpreters but produced many more false alarms. Enhancing the resolution of the image to 2.5 metres improved the performance of the human interpretation and the automatic algorithm by a few percent but doubled the false alarm rate for the algorithm. Using a vegetation index (NDVI) derived from multispectral imagery increased the false alarm rate and had little impact on the number of real changes detected.

Freiberg are working together with FZJ, to analyze changes in a pair of Quickbird images of the Isfahan reactor site in Iran. The first pixel-based approach used the MAD algorithm which is more normally used with medium resolution imagery. The second, objectoriented procedure is being improved in order to create an automated workflow for the multiscale extraction of the (change) objects and the subsequent post-classification of changes. The object classes are modelled on the basis of the correlation between input bands and MAD variates, features derived from the a-priori knowledge on nuclear sites and some site- and region-specific features.

5 Security applications

The outcome of GMOSS research should be better earth observation-based algorithms, methods and technology for monitoring security. Effort is concentrating on six broad areas of application - treaty monitoring, early warnings, population monitoring, border monitoring, infrastructure monitoring and damage assessment. Seven workshops helped to focus the partners' efforts.

The treaty monitoring work is concentrating on finding clandestine nuclear activities in Iran. Techniques developed within other GMOSS work packages - feature recognition and change detection - are being brought to bear on finding recent unusual or anomalous activities on sites identified from open source material as being worthy of attention. The burial of recently-constructed building and their protection by perimeter fences and missile defence systems certainly suggest that something is going on.

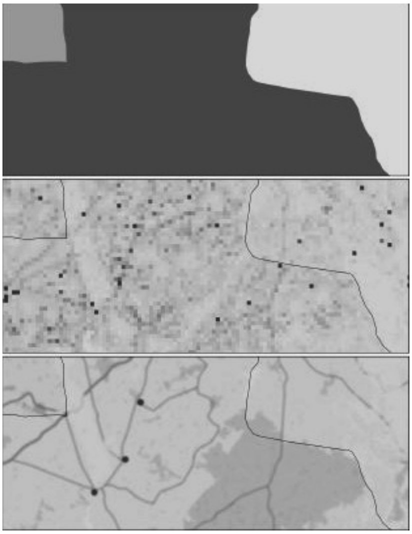


Fig. 6. Landscan, a dataset produced by the Oak Ridge National Laboratory in the United States, is a reference dataset for global distribution of population. But its accuracy is unknown. The methodology for producing it. Is not divulged in detail but it is known to take census data at a district level (the top picture shows the district boundaries in an area of Zimbabwe) and distribute the population according to parameters derived from satellite images such as land-use, road density, night light (centre picture). JRC checked this distribution using very high resolution satellite images and came up with a very different image (bottom picture). Work is ongoing to investigate reasons for this discrepancy

Efforts to provide better early warnings have indicated how satellites can pick up troop build-ups at borders, shown how geostationary satellites can identify significant events and identified the similiarities and differences among different approaches for identifying potential flare-ups from news reports. A significant success was a demonstration of the ability of the Meteosat second generation SEVIRI imager to pick up very early indications of an event. Fires in pipelines and the October 2004 explosion at the Red Sea resort of Taba could both be identified in these images. Its 15-minute repeat cycle offers the potential of extremely fast response times.

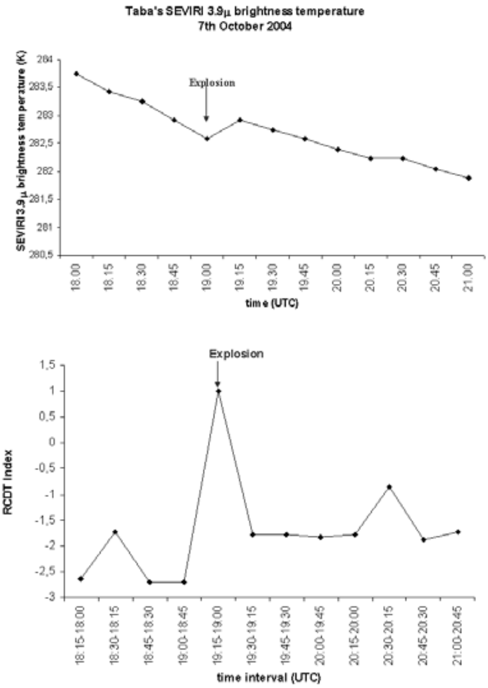


Fig. 7. Geo-stationary satellites offer low resolution but high repeat frequency. The infrared channel on Meteosat 2 SEVIRI imager has a 3 km resolution but a 15 minute repeat cycle. Using this sensor Basilicata could identify a signal from the October 7 2004 explosion in a hotel in Taba on the Red Sea. The upper figure shows the magnitude of the 15-minute-apart signals and the lower one shows the signal after processing to remove the longer-term decreasing trend

Identifying how many people are present in a particular area is a challenge in nearly all security applications. A satellite-image-based estimate of the population in a region of Zimbabwe found reasonable agreement (within 15%) at a district level with the US - produced reference world global dataset, Landscan but not at the finer 1 km resolution (Figure 6) GMOSS is also developing and testing methods to find and count mobile populations. The ability of nighttime light sensors to pick up campfires at refugee camps and very high resolution optical imagery to estimate populations in these camps has been demonstrated.

Work has begun on determining whether remote sensing can help to localise and identify threats to Europe's pipeline-supplied energy supply. Interferometry has been identified as the most appropriate technique and ERS image pairs have been ordered for the Caspian region.

Monitoring traffic across land borders from space would require very high resolution imagery. But narrow swaths and infrequent repeats for satellites with this capability mean that this will not be an operational possibility in the near future. The more modest objective is therefore to identify medium-term changes in crossing points and to develop indicators for the facility with which the border can be crossed - the permeability. Algorithms will be developed and tested on a region on the Poland-Ukraine border for which very high resolution images have already been acquired. Work is also ongoing to analyse the possibility of using radar imagery to monitor maritime borders. Here the challenge is to integrate other information - from coastal radar or on-board vessel identification systems - to obtain a complete picture.

Assessments have been made of damage caused by the Ryongchon train-wreck event in North Korea, the Bam earthquake, Coalition bombing of Iraq and the Indian Ocean tsunami. These confirm that high resolution imagery - 2 metres or less - is required to determine the extent of damage in urban areas. This holds for both optical and radar imagery and even at this resolution it is essential to have pre-event information. The lack of any fine-resolution pre-crisis radar imagery limited the extent to which the partnership were able to determine the damage caused by the tsunami. There is general agreement that combining different imagery - for instance optical and radar - is the way forward but nobody has yet demonstrated examples of how this can be done. Another challenge for the future?

6 Outlook

The task of automatically processing and classifying the huge amount of information flowing from earth observation satellites to provide usable information for those responsible for formulating and implementing Europe's security policies is certainly daunting. But Europe's research community has made a good start. One year after the start of GMOSS, there is a better understanding of our present capability. Duplication is being eliminated. The most promising algorithms or software for attacking certain problems image rectification, change detection, feature recognition - have been identified and distributed amongst the partners of GMOSS. Many of the partners have identified standards as an issue - for defining baseline properties in a time series of images, for classifying image segments, for cataloguing critical infrastructure. It is expected that over the next year progress in agreed standards will allow a distributed scientific community to share the tasks of algorithm development and image analysis more effectively.

The declared aim of networks of excellence is to create durable integration between partners even beyond the formal four-year duration of the present funding. Now that the advantages of working together are becoming apparent to all partners, it is difficult to believe that this will not be the case. There will be no turning back.

Environmental Sample Analysis

Martin B. Kalinowski, Johann Feichter, Mika Nikkinen and Clemens Schlosser*

1 Introduction

Environmental sample analysis becomes increasingly important for treaty verification. The first applications date back to the beginning of nuclear weapons programs. The first treaty verified with environmental sampling activities as national technical means (NTM) is the Partial Test Ban Treaty (PTBT, 1963). For the Comprehensive Nuclear-Test-Ban Treaty (CTBT, 1996) measurement of atmospheric radioactivity represents one out of four sensor technologies applied for the International Monitoring System (IMS) that is currently being established. After the first Gulf war, the monitoring and verification mandate gave IAEA strong tools to apply various nuclear material and radioactivity measurements in Iraq since 1991. The successful implementation of environmental sampling in Iraq was the baseline for further development. Following the 93+2 programme for enhancing the effectiveness and efficiency of nuclear safeguards for NPT (Non-Proliferation Treaty, 1968) verification, the IAEA started to apply routinely swipe sampling in nuclear facilities. Environmental sampling got an enhanced legal basis with the Additional Protocol of 1997 wich includes provisions for both location specific and wide-area environmental sampling.

Detection of relevant radioactive indicators in the environment poses a strong opportunity for treaty verification. The full potential of this method develops with the recent advances in powerful methods for determining possible source areas with atmospheric transport simulations. Especially if two or more detections are related to the same source, correlations in the source-receptor relationships facilitate a useful localisation precision. This can be further enhanced, if additional information is available like the time of the release. The Provisional Technical Secretariat of the CTBTO Preparatory Commission in

* The views expressed herein are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission nor the Max Planck Institute nor the IAEA nor the BfS.

cooperation with the World Meteorological Organisation is currently putting this ground-breaking approach for source location in an operational mode.

This paper puts a focus on measuring radioactivity in the atmosphere because this kind of environmental sample analysis has found the broadest range of application for the verification of international agreements. However, there are other opportunities related to environmental sampling of non-radioactive tracers, for example greenhouse gas emissions with relevance to the Kyoto Protocol. It can be expected that the increasing number of applications, the growing experience and the related scientific progress with regard to analysis of air samples for radioactivity will also promote similar applications on non-radioactive tracers for the verification of international agreements

2 Definitions, goals and general procedures

The *environmental sampling* for various treaty verification purposes is rather broad issue. In this chapter it means that a sample is taken from the ambient environment in order to analyze it for traces of chemical compounds, elements or isotopes that can serve as an indicator that is relevant for the verification purpose. This indicator can be identical to or part of the characteristic signature that is created by the activity or facility being investigated. Since this paper deals mainly with applications in the context of nuclear arms control and non-proliferation, the tracers of interest are radioactive isotopes.

Unlike the sampling that occurs inside the inspected and verified processes, environmental analysis needs some kind of carrier that is dispersing the signals and keeps them in a form where they can be collected. Typical *sampling media* are air, water, biota and soil. If environmental samples are taken continuously over extended periods of time without interruption, time series can be analyzed in order to detect anomalies and changes of background tracer levels. This is a special case of environmental sampling called *monitoring*.

Dispersion may occur for basically any release but the distribution of signatures in the environment is especially effective for gases and small particles. Typically the release is travelling in 3-dimensional space and when sampled in sufficient volume it may reveal a signature of interest. Environmental traces are naturally the strongest the closer the sample is taken to the release point. The environmental monitoring can even occur inside the building that is to be verified. On equipment surfaces, the signal can be so strong that simply by cleaning the surface with a cotton swipe is collecting enough material for verification purposes.

It is also important to notice that environmental sampling is a *dynamic process* with respect to time. The sample taken represents the traces of that particular location in space and moment in time. It may also contain traces of the past either by accumulation over time or due to mixing and re-suspension. This is especially true when collecting samples close to sites where the emissions are frequent. The verified substances may also decay, for example by radioactive decay or by chemical reactions. Decay may occur before or after the sampling and also during the sampling process in case of extended sample periods.

The *detection goal* depends on the treaty obligations to be verified. The major purposes for environmental sample analysis are the following.

- Detect the existence of a clandestine facility and its location
- Determine the source strength
- Verification of declarations
- Verification of non-existence by complementary access

Typically the *verification procedure* based on environmental signals is following this pattern:

- First, the scope of verification defines where to take the samples, the used technique, the amount of samples needed to cover necessary signals (either presence of signals or absence of them).
- Samples are collected as described in procedural instructions. To ensure the integrity of samples some precautions may be necessary to make sure that the sampling is not mixing signals from other places or that a relevant signal is not missed.
- The environmental sample is measured and the measurement result is analyzed. This can be a challenging scientific problem, if the verification requires that even very small signals close to the detection limit need to be measured.
- After completing the analysis, the analyst may have quite detailed results at hand. It still needs to be evaluated whether the detected signal is reliable and if the result is in line with declared facts.
- Based on the overall understanding of uncertainties, detection limits and representativity of the sample, one can draw (or refuse to draw) the final conclusions based on verification criteria.

3 Applications

3.1 Early applications

Before environmental sampling became a verification procedure for arms control treaties, it has been extensively applied secretly by governmental agencies and laboratories as well as openly by independent scientists. Already in the fall of 1944, the method of xenon-133 detection in atmospheric air samples was used for the search of evidence for reactor operation in Germany. In 1949, the Soviet Union was not able to keep its first nuclear explosion secret, because the analysis of aerosol particles in air filter samples taken by the US Air Force revealed the evidence.

Since 1951, the USA determined the amount of Russian weapons plutonium production from the total atmospheric content of krypton-85 by subtracting the known sources (Operation "Bluenose"). All krypton-85 in the atmosphere was released during the reprocessing of nuclear fuel elements or plutonium breeding targets. Towards the height of the arms race in the Cold War, this method was applied and the results published by independent scientists [1][2]. Atmospheric nuclear testing released significant amounts of radioactivity into the atmosphere and was distributed within one or two weeks across a zonal band. It rested for months and years in the stratosphere. The fall-out was detected world-wide in all kinds of media. Typically, hot particles were identified in air filters or on vegetation; radioactive noble gases were found in atmospheric air samples; fission and activation products were found in precipitation, sediments, surface waters and agricultural products.

Already in 1958, a Geneva Conference of Experts on the Means of Detection of Nuclear Explosions considered radioactive debris as the only indicator that is available for analysis at large distances and that can be used to determine that an explosion has been a nuclear event. Accordingly, ground-based as well as airplane mounted air filtering devices and analysis of the collected fission products were suggested as a means to detect nuclear explosions at distances of several thousand miles and at times of ten to twenty days after the event.

The Partial Test Ban Treaty (PTBT) of 1963 was the first arms control agreement that has been verified by environmental sampling. The main purpose of this treaty was to end nuclear testing in any environment other than underground. Another provision is that underground nuclear testing is prohibited, if the explosion causes radioactive debris to be present outside the territorial limits of the State Party conducting the test. Verification was carried out by National Technical Means (NTMs) and it did happen that a rapid venting or another incident caused radioactive plumes to be transported through the atmosphere and across the borders. In fact, it happened that the radioactivity was transported over thousands of kilometers, detected and traced back to the source.

3.2 UNSCOM/UNMOVIC

Before the 1990's, the verification of the NPT made no use of environmental sampling in the sense covered in this paper. The nuclear safeguards were focusing on declared facilities and materials to detect the diversion of nuclear material handling facilities for nuclear weapons purposes. Only non-routine swipe samples were applied under certain circumstances. A significant step forward for environmental monitoring occurred while searching for the weapons-of-mass-destruction programs in Iraq just after the first Gulf war by UNSCOM (United Nations Special Commission) and UNMOVIC (United Nations Monitoring, Verification and Inspection Commission)[3]. The discovered environmental traces of biological, chemical and nuclear weapon developments were crucial prove for understanding what kind of clandestine programs Iraq was running. During the inspections the inspectors got access to the facilities where the development was going on, the picture was forming piece by piece and the evidence given by environmental samples was so obvious that it did not leave space for denial of programs [4].

This was an important step also for the nuclear material safeguards. A new method was introduced that could even after a long period of time reveal the use of undeclared materials. When the IAEA started a process to strengthen the safeguards system, environmental sampling played a very important role.

3.3 From Program 93+2 to the Additional Protocol to the NPT

One of the main goals of the so-called Program 93+2 to enhance the efficiency and effectiveness of nuclear safeguards was to develop methods for detecting clandestine nuclear activities. This effort led to the negotiation of the Model Additional Protocol (INFCIRC/540)[5]. Since this protocol has began to be implemented [6], environmental sampling is not only complementing the assurance of presence of declared materials and activities; it is used also to assure the absence of undeclared materials. This approach is currently extensively being used for safeguards by taking cotton swipe samples inside inspected facilities during inspections and during complementary access to locations and sites.

The Additional Protocol has the potential of increasing the importance of environmental sampling even further as more sampling methods may be introduced. It distinguishes two different approaches under the provision of complementary access. The location-specific environmental sampling in Article 6 can already be applied to certain special locations of interest with regard to nuclear materials. Its purpose is to resolve discrepancies in the range of adjacent facilities.

In Article 9, the Additional Protocol foresees so-called wide-area environmental sampling that could be conducted anywhere in a country under inspection. This would in the future enable the collection of nuclear material traces further away from nuclear facilities, tens or even hundreds of kilometres away from a facility handling nuclear materials [7]. However, according to Article 9, "the Agency shall not seek such access until the use of wide-area environmental sampling and the procedural arrangements therefore have been approved by the Board" of Governors. Further research is under way to provide a scientifically sound basis for an assessment of the effectiveness of this method under certain assumptions regarding procedural arrangements. Especially, the related methods are under field-testing, and the results are promising from the verification point of view [8].

If the environmental sampling is used for verification purposes, one has to take care of the sample chain of custody, so that in the end the conclusions can be drawn with high assurances that the sample has not been tampered, changed or contaminated. Therefore, the sealing of the samples and proper containment are necessary requirements. The purity of the samples has to be assured. In some cases, the traces used for verification are less than nanograms of material. This is why the laboratories are required to always analyze a set of blank samples to assure the absence of cross contamination of real samples.

3.4 CTBT

The Comprehensive-Test-Ban Treaty (CTBT) has been opened for signature in September 1996. Though the CTBT has been signed by 175 states and ratified by 121 (as of May 2005), it is not yet in force due to its specific conditions for entry-into-force. However, the Preparatory Commission for the CTBT Organisation has a mandate to establish the International Monitoring System. This will consist of 321 stations using four different sensor technologies to detect seismic, infrasound, hydroacoustic or radioactivity signals [9]. 80 of these stations have radioactivity detectors. Two parallel systems are being installed, one for the measurement of radioactive particles on filter samples, the other for radioactive noble gases.

The most likely future scenario for a clandestine nuclear test is an underground explosion. Radioactive material produced during underground testing could be released into the atmosphere by leaking through geological faults. Since gases have a larger probability of being released in this way than particle-bound radioactivity, noble gas monitoring is very important. Additional advantages of noble gases are that they are chemical inert and that they are not removed from the atmosphere by wet or dry deposition processes. The only relevant sink of these radioactive nuclides in the atmosphere is their radioactive decay. Therefore traces of radioactive noble gases could be detected at large distances from the source. This behaviour makes the radioactive noble gas isotopes attractive as indicator for the detection and verification of nuclear activities [10].

The radioactive xenon isotopes that are produced by the fission of uranium and plutonium have very large fission yields of up to approximately 7%. The challenge of using these isotopes as indicator for nuclear explosions is the fact that these are the released to the atmosphere by nuclear power plants during routine operations. The relative abundance of different radionuclides in the samples can be used to determine whether a nuclear reactor or an explosion produces the material. Source characterization is possible by investigating the isotopic activity ratios. The establishment of what constitutes a typical atmospheric background concentration is also useful to distinguish between normal and anomalous observations.

The radionuclide stations submit regularly their measurement data to the International Data Centre (IDC) in Vienna. The IDC does the analysis and sends reports to the member states. The waveform monitoring technologies (seismic, infrasound and hydroacoustic) allow for a highly precise location of explosions in time and space. However, only the association with a relevant detection of radionuclides could provide an indication for an explosion to possibly be a nuclear event. In order to facilitate data fusion, i.e. the combination of events from these different sensor technologies, atmospheric transport modelling is applied to determine the possible source region in order to allow for an event correlation in time and space.

It is up to the member states to interpret the signals and make a judgement about suspected treaty violations. Besides of the routine atmospheric monitoring, the CTBT has also provisions for on-site inspections for the case that a consultation and clarification process cannot remove doubts about a suspicious event. On-site inspection will rely mainly on the analysis of sub-soil gases. Underground nuclear explosions do not only generate fission products but also activation products that are useful as indicators during on-site inspections. Especially argon-37 can be generated by neutron bombardment of the calcium contained in the subsurface soil. It forms by an (n,α) reaction on calcium-40 that has a natural abundance of 96.9%.

3.5 Future opportunities

Since many years, there is broad consensus that a Fissile Material Cut-off Treaty (FMCT) should be negotiated at the Geneva based Conference on Disarmament (CD). In 1995 the Shannon Mandate was agreed according to which the CD should negotiate a ban on the production of fissile material, "... a non-discriminatory, multilateral and internationally and effectively verifiable treaty banning the production of fissile material for nuclear weapons or other nuclear explosive devices."

Since this would involve former military facilities a conflict of interest arises between the goals of transparency versus military confidentiality. For this reason, non-intrusive ways of monitoring the non-production of plutonium are required. A combination of remote sensing methods like satellite imagery as well as measurement and modelling of krypton-85 in the atmosphere can serve the purpose to ensure a high confidence in compliance with a cut-off agreement without compromising too greatly perceived national security requirements by releasing sensitive information.

The same applies to possible bilateral or regional agreements for freezing the production of nuclear weapons-usable materials. This has been proposed for South Asia as well as for the Middle East. In the latter case, a broader approach has been taken by proposing a weapons-of-mass-destruction free zone.

3.6 Examples for non-radioactive tracers

The Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (CWC) entered into force on 29 April 1997. The chemical industry has obligations for declaration and will be subject to verification inspections on a basis of managed access. The CWC has an extensive Verification Annex and the Organisation for the Prohibition of Chemical Weapons (OPCW) is in the process of establishing its work. Remote verification is of minor importance for the CWC. Environmental measurements have some significance in investigating an allegation of the use of chemical weapons in a war.

Another case for environmental sampling is the verification of greenhouse gas emissions that are reported by member states according to the UN Framework Convention on Climate Change and the Kyoto Protocol. This kind of verification is currently limited to national technical means and depends strongly on atmospheric transport modelling to determine regional source strengths based on observations.

There are further UNEP Conventions for which environmental sample analysis might be applied in order to verify compliance:

- Vienna Convention for the Protection of the Ozone Layer
- Montreal Protocol on Substances that Deplete the Ozone Layer
- Stockholm Convention on Persistent Organic Pollutants (POPs)
- Basel Convention on Transboundary Movements of Hazardous Wastes

4 Indicators and technologies for their measurement

4.1 Radioactive particles

For nuclear material safeguards, the major indicators of use of materials are the actinides and derived fission and activation products. A broad variety of analytical techniques for traces of indicator nuclides has been developed [11][12][13]. Technologies and methods applied in the context of identifying sources of illicit nuclear material trafficking have been summarised under the new working area of nuclear forensics [14][15].

Usually, the actinides have reasonably long half-lives making them easy to be detected with various mass spectrometric assays. Verification of uranium is typically based on $^{235}U/^{238}U$ ratio and ratios of minor isotopes to each other (234/235/236). If the material has been introduced to a reactor, one can detect also various isotopes of plutonium. In addition to the effective ratio of ^{240}Pu to ^{239}Pu, ratios of different plutonium isotopes to ^{235}U are also important attributes of nuclear material. The isotopic ratios can reveal information on how the material has been irradiated, if separation processes are used at the facility and about the time since separation or irradiation occurred.

In the nuclear material analysis the samples can be analyzed using either bulk or particle analysis.

Bulk analysis means that the whole sample or part of it is completely analyzed and the average isotopic abundances of the material are reported. This is useful method if one can assume that the material is more or less homogenised throughout the sample. Usually, the whole sample can be analyzed when using non-destructive methods like High-Resolution Gamma Spectrometry to detect the fission and activation products. When destructive methods are applied, the analyzed part of the sample is lost nearly completely in the analysis process. Therefore, the sample is usually split and part of the sample is archived to make sure that something is still left if further analyses need to be performed later.

There are a number of destructive analysis methods for nuclear material samples:

- Thermal Ionisation Mass Spectrometry (TIMS) and Inductively Coupled Plasma Mass Spectrometry (ICPMS) to detect uranium and plutonium isotopes.
- Accelerator Mass Spectrometry (AMS) to detect specially the presence of ^{236}U and ^{129}I.
- Alpha spectrometry after radiochemical separation to detect the amount and isotopic composition of uranium and plutonium.

In particle analyses methods, individual particles are analyzed separately. By doing so, more detailed information can be retrieved even if the inspected facility has been performing operations with various kinds of isotopic compositions. The detected particles may tell different kinds of stories about the used materials, the time when the operations are done with these materials, what did happen to the material before it was left over as a separate particle etc.

Typically there are 2 methods that are routinely used to detect and characterize the particles of interest:

- Secondary Ion Mass Spectrometry (SIMS) is a rather automated method that is able to pick the selected particles and perform mass spectrometric analysis with prepared samples.
- Thermal Ionization Mass Spectrometry with fission track etching (FT-TIMS) is more laborious but also more accurate method to define the true isotopic composition of even the smallest particles. In this method the sampled material is irradiated with a neutron flux and after the etching the fissioned particles are shown visually in the prepared sample surface. Then these particles are picked with micromanipulator and analyzed individually using TIMS.

In order to identify and characterise nuclear explosions, various radio-chemical and nuclear analytical methods have been successfully applied. Early methods focused on total beta counting of rain samples and auto-radiographs of single hot fall-out particles. The most reliable method for timely and continuous monitoring is to collect aerosol particles on air filters. This was done by various laboratories on the ground level as well as on high altitude with the help of air planes and balloons [16]. For example, the ^{140}Ba concentrations in the atmosphere that were reported in the literature and that were thought to indicate a nuclear test explosion at large distances range from 30 to $5 \cdot 10^5 \mu Bq/m^3$.

For the CTBT, the list of relevant particle-bound fission and activation products is long and includes barium-140, lanthanum-140, zirconium-95, as well as anthropogenic radioisotopes with other legitimate sources like cesium-137, iodine-131 and technetium-99m. The selection of these isotopes as indicators is based on their production rate in an explosion as well as on their half-life.

The sequence of the monitoring activities starts with a 24-hour sampling period. A high volume pump draws at least $500 m^3$ per hour through a filter. The sample will be allowed to decay for 24 hours in order to reduce the background that is dominated by short-lived natural radionuclides. Measuring the radioactivity with a High-Resolution Gamma Spectrometer typically takes another 24 hours. A very high sensitivity for traces of anthropogenic radioactivity is achieved. For Ba-140 it is below $30 \mu Bq/m^3$.

4.2 Radioactive noble gases

Since the first nuclear weapons were built many laboratories world-wide developed manual and automated techniques to collect and measure radioactive noble gases in the air, in soil gas and in the ocean with high sensitivity. The measurement of the atmospheric concentrations of noble gases requires a five step procedure: (1) noble gas collection and concentration (2) further enrichment and purification, (3) activity measurement, (4) determination of the volume of stable noble gas volume in the counting device and (5) calculation of the atmospheric activity concentration in Bq per m^3 of air.

The collection of the relevant gas and the avoidance of other components in the sample require the complete elimination of nitrogen, oxygen, carbon dioxide, water, radon and other trace elements. Dryers and chemical sieve traps are used for purification. Another basic principle for the separation of noble gases from the air is the adsorption and desorption of the noble gases at activated charcoal at different temperatures (-193°C to 300°C). After further fine purification steps using standard gas purification techniques the relevant noble gas fraction is transferred into counters. The activities are measured and the gas volume of the noble gas component is determined. Based on the world wide constant stable argon (0.93%), stable krypton (1.14 ppm) and stable xenon (0.087 ppm) in the atmosphere an equivalent air volume could be calculated. In the northern hemisphere the today ^{85}Kr atmospheric background level is approximately 1.5 Bq/m^3 and the ^{133}Xe level is around a few mBq/m^3. In the southern hemisphere the mean atmospheric activity concentration of ^{85}Kr is lower by 0.1 to 0.2 Bq/m^3 [17] and the atmospheric activity concentration of ^{133}Xe is well below the detection limit of the existing systems of $< 1\ mBq/m^3$ [18] at most locations. The world wide ^{37}Ar background level is in the order of mBq/m^3. Special counting techniques have to be applied to detect these low activities. For the detection of ^{85}Kr and ^{133}Xe liquid scintillation counting and proportional counting techniques are used. The measurement of the 2.8 keV decay energy of ^{37}Ar requires special low-level gas proportional counters.

During the last decade, special efforts were undertaken for the simultaneous detection in atmospheric samples for the four CTBT relevant isotopes and isomers of xenon (^{131m}Xe, ^{133}Xe, ^{133m}Xe and ^{135}Xe) [19]. Two different techniques were further developed for their use in fully automated systems for xenon monitoring: (1) High-Purity Germanium (HPGe) Gamma Spectrometry and (2) the Beta-Gamma Coincidence technique. A HPGe gamma detector was integrated into a xenon monitoring system with special emphasis on low detection limits in the order of mBq/m^3 or below for the CTBT relevant isotopes of xenon. Further improvements in sensibility are also reached by evaluating the X-rays emitted in the decay of the radio-xenons in the energy range between 28 and 37 keV. The other approach to reach the required high sensitivities is the simultaneous measurement of the electrons and photons by the beta-gamma coincidence technique. The xenon sample is contained in a scintillation cell that serves also as electron detector. The scintillation cell is surrounded by a Na(I) for the detection of the photons in coincidence to the electrons. The advantage of this method is the very low background together with a very high detection efficiency, which allows the detection of very low activities. In comparison to the HPGe detection system, the coincidence method needs a smaller sample volume to get the same sensitivity, if all other conditions, like counting times, are the same.

5 Atmospheric modelling

5.1 Introduction

If relevant radionuclides are detected in the atmosphere, this information is of use for verification purposes only if it can be attributed to a certain geographical area as possible source region. Atmospheric modelling is applied for this and other purposes [20].

Many attempts have been made in recent years to develop and improve global numerical models to simulate atmospheric transport and chemical reactions of gaseous and particulate constituents as well as the manifold interactions between meteorology and chemistry [21]. Atmospheric dynamics and cloud processes control the concentration and distribution of atmospheric constituents. Winds transport gaseous and particulate matter and loft dust and sea-salt aerosols into the atmosphere. The intensity of the solar radiation and the temperature determine the chemical reaction rates. Cloud droplets are chemical reactors and contribute to the formation of aerosol particles and the precipitation cleans the atmosphere from gases and particles.

GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data), a project recently started and funded by the 6th framework program of the European Commission attempts to develop assimilation capability for greenhouse gases, reactive gases and aerosols from global to regional scales (50 km) and covering the troposphere and stratosphere.

5.2 Atmospheric transport processes and characteristic time scales

At a given location and time, the atmospheric chemical composition is mostly determined by transport of the substance or its precursor into or out of the area. The atmosphere possesses a large spectrum of motions from planetary waves, synoptic scale disturbances, meso-scale processes to turbulent exchange. The scales of motion that are important for the transport of a specific constituent depend on the atmospheric residence time of the species in question. Generally, the distribution of highly reactive species is dominated by chemical and microscale interactions at surfaces, while that of less faster reacting species is dominated by fast mixing processes, and that of slowly reacting species by large-scale transport. On larger spatial scales the winds transport species with long lifetimes far away from the source region. Pollutants predominantly released in the northern hemisphere continents are moved across entire continents and also contribute by interhemispheric transport to the load of the southern hemisphere. Subgrid-scale processes, such as turbulent exchange and vertical transport in clouds, dilute quite efficiently polluted boundary layer air by mixing with free tropospheric air masses. The degree of vertical mixing controls the dry deposition at the ground, the transit time until a parcel enters a cloud or the rate of photochemical decomposition.

Three main circulation regimes can be distinguished in the troposphere. The Hadley Cell is a meridional circulation that is driven by the heating of air in the equatorial region. Equatorial air moves upward and air from higher latitudes moves laterally toward the equator. These lower branch winds, the trade winds (the most persistent wind system of the atmosphere), move over the sea and carry water vapour towards the equator. The trade winds from both hemispheres converge near the equator (Inter-Tropical Convergence Zone ITCZ) and water vapour condenses within the ITCZ forming large cumulonimbus clouds. This flow is balanced by a return flow at higher altitudes. The Hadley Cell is closed by subsidence at about 30° in both hemispheres (horse latitudes). The Coriolis force, associated with the Earth's rotation, deflects moving air parcels to the right direction of the motion north of the equator and to the left south of the equator. Due to this Coriolis force air parcels in the upper branch of the Hadley Cell are deflected to the east and air in the lower branch to the west. Convection in the ITCZ is very effective in transporting atmospheric constituents into higher altitudes. Convection provides also for downward transport within the "downdrafts" and by slow sinking processes in between clouds.

The differential heating between the equator and the poles creates a pole-to-equator temperature gradient which results in westerly wind flow in the mid-latitudes. These zonal winds (jet streams) become baroclinically unstable and in the free troposphere troughs and ridges of low and high pressures are formed. This cyclogenesis results in poleward moving warm air which is lifted above the cold air that is moving towards the equator. This exchange of mass across the latitudes is far less regularly ordered than the regimes in high and low latitudes.

The polar region is in particular in winter covered by a high pressure system, the Polar High. Within this Polar High, air subsidence occurs and at higher altitudes air moves poleward to take its place. This forms a meridional circulation cell.

Table 1 shows typical transit times between different atmospheric reservoirs and of different transport processes.

Table 1. Characteristic transport times in the atmosphere

Vertical transport within convective clouds	1 hr
Mixing between the boundary layer and the free troposphere	2 - 10 days
Large scale vertical mixing in the troposphere	1 - 4 weeks
Mixing within a latitude belt	2 - 4 weeks
Hemispheric mixing	2 - 6 months
Inter-hemispheric exchange	1 yr
Stratospheric-tropospheric exchange	1 - 3 yrs
Transport from the Earths surface up to the mesosphere ($\sim$ 50-100 km)	5 - 8 yrs

5.3 Methods for global atmospheric transport modelling

GCMs (Global general circulation models) and CTMs (Chemistry Transport Models) calculate the large-scale transport of atmospheric constituents by wind (three-dimensional advection) and subgrid-scale vertical transport by turbulent exchange and within clouds. Horizontal diffusion of trace constituents is mostly neglected. Generally, these transport processes are calculated in the same way as the transport of water vapour.

The advection equation for the trace constituents is $\delta q/\delta t + \mathbf{v}\nabla q = 0$, where q represents a "mixing ratio-like" quantity and $\mathbf{v}$ is the wind vector. The numerical method used for the solution of this equation should fulfil a number of constraints:

- Accuracy
- Monotonicity (i.e. not introducing new extremes)
- Positive definiteness (no generation of negative values)
- Mass conservation

Furthermore, it should be local, i.e. processes far away from that point should not influence the solutions at a given point, and transportive, i.e. the information should propagate primarily downwind. In light of the computational demands of three-dimensional chemistry transport simulations, the advection scheme must also be computationally efficient. This becomes important when using an approximately equiangular mesh in spherical geometry. In this geometry, the spacing between longitudes becomes increasingly small as one approaches the poles and thus very small time steps are required due to the Courant-Fredrichs-Lewy (CFL) condition, in order to maintain stability ('pole problem'). One method, which has a much less stringent time stepping restriction, is the 'semi-Lagrangian' transport (SLT) technique. However, this method is not mass conserving.

Other methods, based on the flux form of the advection equation, have been developed in recent years. These are inherently mass conserving and allow for an SLT-like time step. However, some of them are not strictly monotonic while others do not provide the required accuracy in certain situations. Though intuitively, advection appears to be a fairly easy process to model, no optimum method has yet been identified that meets all the requirements mentioned above and that is computational effective.

5.4 Methods for atmospheric chemistry modelling

Atmospheric chemical reaction rates are usually dependent on temperature, and in many cases also on pressure. There has been considerable work in laboratories to determine the rate constants for key atmospheric reactions, and the results have been compiled in comprehensive evaluations (JPL, Atkinson). Yet, because of experimental difficulties, several reaction rates remain unknown or very uncertain. Photodissociation reactions are governed by the available UV intensity (the actinic flux), the absorption cross section of the molecule, and the quantum yield determining the efficiency of the dissociation reaction. All of these parameters are wavelength dependent. The absorption cross-section and quantum yield may also depend on temperature and pressure.

In general radioactive nuclides behave chemically like stable isotopes of the same element. Their ionizing effect would impact on the atmospheric chemistry only at very high activity concentrations. The formation of ions by radioactive decay may also impact the nucleation of particles and subsequently impact cloud formation and climate.

In an atmospheric chemistry model, the concentration changes of trace gases are computed at each time step by solving a set of ordinary differential equations describing the production and loss rates of the molecule and the reaction stoichiometry. Due to the different time scales for atmospheric reactions (spanning several orders of magnitude), the system is very stiff, and special solvers had to be developed in order to treat the matrix numerically. Two techniques, which are widely used by global modellers, are the "Quasi-steady State Approximation" and the "Euler Backward Iterative Method".

Atmospheric chemical processes are not limited to the gas phase, but also occur on the surface of solid particles and within liquid particles, such as aerosols and cloud droplets. The important role of these so-called heterogeneous reactions on aerosol surfaces has been shown in studies of the stratospheric ozone hole. Reactions on sea salt may also play an important role in the marine boundary layer. Mineral dust particles react with sulfur and nitrogen particles to form sulfates and nitrates, respectively. Clouds control the formation of aerosols and their removal by scavenging. For example, the oxidation of SO_2 to sulfate in cloud droplets is much more efficient than in the gas phase. Generally, reaction pathways and rates differ considerably from those in cloud-free air. Moreover, clouds also affect the photochemistry by enhancing the actinic fluxes above the cloud and by reducing it below the cloud compared to clear-sky conditions. Aqueous-phase reaction rates depend on the gas-phase concentrations, solubility and rate of mass transfer of oxidizing agents. The cloud receives trace gases from its inflow region, its vertical winds redistribute the gases, and the cloud transforms the gases through gas and aqueous-phase chemistry.

For many reactive gases, the primary atmospheric sink is reaction with the OH radical or photolytic dissociation. Removal from the atmosphere takes place through deposition on aerosol and land surfaces, uptake by oceans and lakes, and by uptake in cloud droplets and subsequent precipitation. Radioactive decay is treated as a sink in accordance to the half-life.

5.5 Downscaling

Atmospheric general circulation models have a typical resolution of 100 - 300 kilometres. Since GCMs are usually considered to yield unrealistic results on spatial scales smaller than several grid cells, there is in general little confidence in the simulated, regional-scale variability. Downscaling techniques are often used to derive variability from GCM simulations on or below the grid-cell scale. They are based on the assumption that atmospheric variability on small spatial scales is conditioned, though not determined, by larger scales. In recent years, a number of dynamical and statistical downscaling methods have been developed, which are reviewed in [22] and [23]. Dynamical downscaling is based on the application of a finer resolving global model to simulate short episodes or on the nesting of a finer resolving regional scale model. In both cases models are driven by the meteorology produced by the coarse resolving global model. Statistical downscaling is based on the view that regional meteorology is conditioned by the large-scale state of the atmosphere and by the regional topography.

5.6 Use of radionuclides as tracers to test atmospheric transport

Not only are atmospheric models applied to simulate the transport of radionuclides. These tracers are in turn playing an important role in understanding atmospheric processes and validating models (for review see: [24])

Comprehensive chemical evaluation of thousands of man-made chemicals is a challenging task, which has to comprise transport in and cycling between the atmosphere, the soil, the vegetation and the ocean. Cosmogenic and terrigenic natural radiotracers and radionuclides from nuclear bomb tests have been widely used to test a large variety of relevant processes [25].

Species used as test tracers should ideally meet the following conditions. They should be chemically inert, sources and sinks should be well known and sufficient observational data should be available for comparison to model results.

Radon-222 measurements at surface sites, by ships or by aircrafts were applied to test models boundary layer transport and exchange between the boundary layer and the free troposphere. The long-range transport of radon from the African continent to subantarctic islands situated at several thousand kilometres downwind from South Africa (radonic storms) provides a test for the treatment of advection and diffusion in global models [26].

Krypton-85 was used to evaluate the inter- and intra-hemispheric transport times. This long-lived radionuclide (half-life of 10.76 years) is produced in nuclear reactors and released during reprocessing of spent fuel. These sources are mostly located at Northern Hemisphere mid-latitudes. This makes it a good proxy for inter-hemispheric transport of pollutants. The very pronounced latitudinal profiles that have been measured for ^{85}Kr permit to evaluate the interhemispheric exchange time of approximately 1.1 years [27].

^{14}CO is a very good tracer of stratosphere-troposphere exchange and can also be used to assess the tropospheric OH abundances. The main source for ^{14}CO is generation by cosmic rays and the only sink is by OH oxidation. One challenge that models have to meet is to represent accurately the tropopause height since the vertical resolution decreases with height in models. Higher resolution models (typically 60 vertical layers) will certainly help resolve this issue independently of having the correct cross tropopause exchange.

To address the downward transport from the stratosphere to the troposphere, ^{14}CO and $^{14}CO_2$ are well-suited tracers. The upward transport from the troposphere to the stratosphere occurs in great part in the tropical regions where convective systems inject lower tropospheric air into the high troposphere/low stratosphere region. The importance of these events would require having vertical profiles in the altitude range 10-22 km regions. No such profiles have been acquired recently and measurements of one radionuclide ^{222}Rn or a suite of them including ^{222}Rn/^{210}Pb would greatly enhance the observational basis to understand these phenomena.

Radionuclides that condense on particle surfaces provide tests of aerosol physics, e.g. wet and dry deposition. Radiotracers like ^{210}Pb, ^{7}Be, ^{10}Be and ^{90}Sr have been used for this purpose.

5.7 Determining optimal station placement and procedures

During the negotiations of the CTBT at the Conference on Disarmament in Geneva, various possible designs for the global network of radionuclide stations were discussed. The network was optimised by atmospheric transport modelling studies undertaken by several countries with the goal to detect a 1 kt nuclear explosion within 14 days and with a certain detection probability (90% for atmospheric explosions). Basic design criteria for the network were derived from four different scenarios and related performance criteria for detection, identification, and location. These scenarios were non-evasive as well as evasive atmospheric, underwater and underground explosions. Existing national stations that many countries had established and operated over several decades were considered as candidate sites.

As a result, 80 radionuclide station locations were selected and listed in the Protocol to the CTBT. At that time, it was left open where the 40 noble gas stations should be located and whether the noble gas network should be expanded to all 80 sites. As a result of further network design studies undertaken by France, Canada, and the USA 40 out of the 80 sites were chosen by the Preparatory Commission in 1998 as a start to locate noble gas detection systems.

The optimum procedures for wide-area air sampling under the NPT Additional Protocol are not yet sufficiently determined. This has to be based on a reasonable detection goal that is related to the significant quantities of plutonium and highly enriched uranium as well as to the timeliness goals as defined by the IAEA. In particular, the detection and false alarm probabilities as well as the detection sensitivity (minimum amount/rate of plutonium separation and uranium processing) need to be determined. This will be dependent on the geographic dimensions considered for wide-area air sampling. These performance parameters will have to be determined under certain assumptions. These are different material production scenarios, sampling procedures like sampling period and number of sampling sites and the distance from a source. The current state of thinking is that the monitoring of key radionuclides like krypton-85, iodine-129 and iodine-131 might work at distances up to 100 km. It is likely that this range can be significantly improved by determining the background concentration from global atmospheric transport modelling and nested regional models by making use of the known sources of these isotopes.

5.8 Source localisation

The first attempts of atmospheric transport modelling to locate the origin of detected radionuclides used wind fields to determine the trajectories of single particles. These could be considered as indicating the centre of a plume. If time is reversed in the model, the locations passed by back-trajectories would be considered as potential origins of a radioactive release. More advanced methods modelled dispersion in a plume with time-inversion by inverse modelling resulting in so-called retro-plumes.

However, single sample modelling without event time information does not allow for a meaningful source location. With every time-step, the potential source region increases. Allowing for transport times of about 10 to 14 days, almost any location on a whole hemisphere could be the origin of a particular detection. If multiple samples at the same site or at different locations are related to the same release, the correlation of source-receptor relations can result in significant confinements of the possible source region. The more samples are combined in the network analysis, the more precise can the source location be determined.

Various possible products can be generated with atmospheric transport modelling. In order to account for the inherent uncertainties of modelling atmospheric processes, the standard presentation of results considered for CTBT purposes is the so-called field of regard (FOR). This means that the shown geographical area is only indicative for a possible source region and, therefore, is a field that can be taken into regard for further investigation. The FOR is defined as the geographic area indicating possible sources of air that may have contributed to the radionuclide measurement at a specific station within a specific sample collection period. In estimating this area certain assumptions have to be made (e.g. source at ground level). The FOR is a function of certain parameters, especially the transport time and dilution ratios. Especially, the geographic area depends on time and is the larger the longer the radio-active plume travel time is assumed to last.

The origin time of a radionuclide event can be determined only, if suitable isotopic ratios can be calculated. Plume age information would confine the FOR area to be meaningful for source location. If the origin time is not known, standard FORs are shown e.g. for 24-hour, 48-hour, and 72-hour periods prior to the collection stop time.

An enhanced version of the standard FOR quantifies for each region and points in time the maximum release concentration that is consistent with the collected sample. This value can be derived either from the measured concentration at the detector site or - if this is not available - from the Minimum Detectable Concentration by accounting for the dilution caused by turbulent mixing, scavenging, and other processes along the transport path.

A significant reduction of the possible source area as well as a determination of the origin time can be achieved by inverse multi-sample modelling, i.e. by combining FORs that are related to different detector sites (network analysis) and to more than one collection period (consecutive sample analysis). Under most favourable meteorological conditions, the best achievable accuracy is in the order of the model resolution. The state-of-the-art is a resolution of 3 hours and 1° times 1° for longitude and latitude. Rejecting and confirming areas that are covered by FORs related to other samples can confine the possible source region of a particular event. The confirmed region can be defined by the union of all geographic areas which are matching in travel time estimate for all sites that detect the same event (positive indication)., The region can be further confined by cutting off those areas that have matching travel times and are related to samples in which the relevant radionuclide is not detected (negative indication).

The method of choice for calculating FORs and combining them is to calculate the source-receptor sensitivity matrix which contains the transfer functions between all possible regions for a radioactive release, the sources, and all detector sites, the receptors [28]. The source-receptor matrix can be calculated by transport and dispersion models operating in backward mode to calculate the retro-plume from the detector sites. Depending on the conditions, the inverse modelling with multiple samples may be solvable only with so-called regularisation, i.e. the input of a-priori knowledge, which may especially be either the origin time or the location [29]. This could be applied in for hypothesis testing related to seismoacoustic events that might be source of the radioactivity.

A further significant reduction in possible source area can be achieved, if the origin time of the detected radionuclides can be estimated. Given the presence of certain isotope pairs with suitable half-lives in the sample, isotopic ratios could be utilised to determine the age of the sampled plume. Useful isotope pairs based on particulate samples are ^{140}Ba/^{140}La, ^{95}Nb/^{95}Zr, and based on noble gas sampling ^{133}Xe/^{131m}Xe, ^{133m}Xe/^{133}Xe, and ^{135}Xe/^{133}Xe. The advantage of the latter is that they are not distorted by fractionation effects. A plume age probability distribution can be derived from the error associated with the isotopic concentration ratios. Since the elements of the source-receptor-matrix are a function of the travel times they can be multiplied by the plume age distribution to get the source probability matrix as a function of space and time.

The source probability could be even further improved, if information about the release scenario, especially the source strength probability distribution, is available.

In order to support the CTBT member states, the International Data Centre (IDC) runs its own atmospheric transport models for routine operations and cooperates with the World Meteorological Organisation (WMO) to do more extensive modelling for relevant cases. A framework agreement between the Preparatory Commission for the CTBTO and the WMO was finalised in 2001 and is now being put in operation. Under this agreement the WMO Regional Specialised Meteorological Centres will run their models to determine potential source regions for radionuclide events of interest and the IDC will receive meteorological analysis data to drive its atmospheric transport models.

6 Conclusions

Environmental sample analysis is not a new verification method. It has been applied ever since the first nuclear weapons were produced and tested and related national technical means played a major role in verifying compliance with the Partial Test Bean Treaty of 1963. However, scientific progresses in measurement technologies and source location methods as well as major verification applications for nuclear arms control (UNSCOM/UNMOVIC since 1990 and CTBT since 1996) in recent years have brought significant progress.

New opportunities are being explored with regard to wide-area environmental sampling according to the NPT Additional Protocol (model agreement of 1997). Further proposals include the to-be-negotiated Fissile Materials Cut-off Treaty (Shannon Mandate of 1995) as well as bilateral or regional agreements on cooperative environmental monitoring as confidence building measures.

References

1. Sittkus A. und H. Stockburger (1976): Krypton-85 als Indikator des Kernbrennstoffverbrauchs. *Naturwissenschaften* 63, 266-272
2. Hippel, F. von, D.H. Albright and B.G. Levi (1986): Quantities of Fissile Materials in US and Soviet Nuclear Weapons Arsenals. Centre for Energy and Environmental Studies. The Engineering Quadrangle, Princeton University, PU/CEES Report No.168.
3. Donohue, D.L. and R. Zeisler (1992): Behind the Scenes: Scientific Analysis of Samples from Nuclear Inspections in Iraq. *IAEA Bulletin 34* (1).
4. Baute, J. (2006): The Iraq Case. This volume.
5. INFCIRC/540 (1997): Model Protocol Additional to the Agreement(s) Between States and the International Atomic Energy Agency for the Application of Safeguards. INFCIRC-540 corr., Vienna, September 1997.
6. Cooley, J. (2006): The Nuclear Non-Proliferation Treaty NPT. This volume.
7. Nicholson, K.W. (2004): Technical Solutions and Directions - Wide Area Monitoring. ESARDA 4th Workshop on Safeguards Perspectives for a Future Nuclear Environment. Cernabbio, Italy, 14-16 October 2003.
8. Kalinowski, M.B., H. Sartorius, S. Uhl and W. Weiss (2004): Conclusions on Plutonium Separation from Atmospheric Krypton-85 Measured at Various Distances from the Karlsruhe Reprocessing Plant. *J. Environ. Radioactivity* 73/2 203-222.
9. Kalinowski, M.B. (2006): Comprehensive Nuclear-Test-Ban Treaty CTBT verification. This volume.
10. Bowyer T.W. (1998): *Xenon Radionuclides, Atmospheric Monitoring*, in. Encyclopedia of Environmental Analysis and Remediation, Editor Robert A. Meyers, John Wiley & Sons, Inc. ISBN 0-471-11708-0
11. Foggi, C. and F. Genoni (eds.) (1997): *Status of Measurement Techniques for the Identification of Nuclear Signatures*, Proceeding of Workshop held in Geel, Belgium, 25-27 February 1997, EUR 17312 EN.
12. Donohue, D.L. (2002): Key tools for nuclear inspections. Advances in environmental sampling strengthen safeguards. *IAEA Bulletin* 44 (2), 17-23.
13. IAEA (2003): International Conference on Advances in Destructive and Non-destructive Analysis for Environmental Monitoring and Nuclear Forensics, 21.-23.10.2002, Karlsruhe, Germany, IAEA-CN-98/5/08P, IAEA.
14. Koch, L. (2003): Traces of Evidence: Nuclear Forensics and Illicit Trafficking. *IAEA Bulletin*, 45 (1) 21-23.
15. Mayer, K. (2006): Nuclear Forensics. This volume.
16. Miller K.M. and R.J. Larson (2002): The Development of Field-Based Measurement Methods for Radioactive Fallout Assessment, Health Physics 82/5.

17. Winger, K., J. Feichter, M.B. Kalinowski, H. Sartorius, C. Schlosser (2005): A new compilation of the atmospheric krypton-85 inventories from 1945 to 2000 and its evaluation in a global transport model. *Journal of Environmental Radioactivity*, 80, 183-215.
18. Stocki, T.J., X. Blanchard, R.D'Amours, R.K. Ungar, J.P. Fontaine, M- Sohier, M. Bean, T. Taffary, J. Racine, B.L. Tracy, G. Brachet, M. Jean, D. Meyerhof (2005): Automated radioxenon monitoring for the Comprehensive Nuclear-Test-Ban Treaty in two distinctive locations: Ottawa and Tahiti. *Journal of Environmental Radioactivity*, 80, 305-326.
19. Auer M., A. Axelsson, X. Blanchard, T.W. Bowyer, G. Brachet, I. Bulowski, Y. Dubasov, K. Elmgren, J.P. Fontaine, W. Harms, J.C. Hayes, T.R. Heimbigner, J.I. McIntyre, M.E. Panisko, Y. Popov, A. Ringbom, H. Sartorius, S. Schmid, J. Schulze, C. Schlosser, T. Taffary, W. Weiss and B. Wernsperger (2004): Intercomparison experiments of systems for the measurement of xenon radionuclides in the atmosphere, *Applied Radiation and Isotopes* 60, 863-877.
20. Kalinowski, M.B. (2001): Atmospheric transport modelling related to radionuclide monitoring in support of Comprehe*nsive Nuclear-Test-Ban Treaty verification.* Kerntechnik 66/3 129-133.
21. Feichter J, Schultz M, Diehl T (2002): Modelling chemical constituents of the atmosphere, *Computing in Science & Engineering* (5): 56-63.
22. Wilby, R.L. and T.M.L. Wigley (1997): Downscaling general circulation model output: a review of methods and limitations. *Progress in Physical Geography*, 21, 530-548.
23. Giorgi, F., B. Hewitson, J. Christensen, C. Fu, M. Hulme, L. Mearns, H. von Storch, P. Whetton, and contributing authors (2001): *Regional Climate Simulation. Evaluation and projections.* In IPCC WG1 Third Assessment Report, Cambridge University Press.
24. World Meteorological Organization, Global Atmosphere Watch (2004): 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies, Gif sur Yvette, France, 3 - 5 June 2003.
25. Reiter, ER (1978): Atmospheric Transport Processes, Part 4: Radioactive Tracers, DOE Critical Review Series, Virginia, U.S.A, pp 605.
26. Heimann, M., P. Monfray, G. Polian (1998): Long-range transport of Rn-222 - a test for 3d tracer models, *Chemical Geology* 70 (1-2): 98-98.
27. Weiss W., H. Sartorius, H. Stockburger (1992): Global Distribution of Atmospheric ^{85}Kr, In Isotopes of Noble Gases as Tracers in Environmental Studies, Proceedings of a Consultants Meeting, Vienna, 29 May - 2 June 1989, 29-62, IAEA, ISBN 92-0-1000592-X
28. Wotawa, G.; Denier, Ph.; DeGeer, L.-E.; Kalinowski, M.B.; Toivonen, H.; D'Amours, R.; Desiato, F.; Issartel, J.P.; Langer, M.; Seibert, P.; Frank, A.; Sloan, C.; Yamazawa, H. (2003): Atmospheric transport modelling in support of CTBT verification - Overview and basic concepts. *Atmospheric Environment* 37, 18, 2529-37.
29. Seibert, P. (2001): Inverse modelling with a Lagrangian particle dispersion model: applications to point releases over limited time intervals. In: Gryning, S.E., Schiermeier, F.A. (Eds.): *Air polution modeling and its application XIV.* Plenum Press, New York, pp. 381-389.

Tracing the Origin of Diverted or Stolen Nuclear Material through Nuclear Forensic Investigations

Klaus Mayer, Maria Wallenius and Ian Ray

1 Introduction

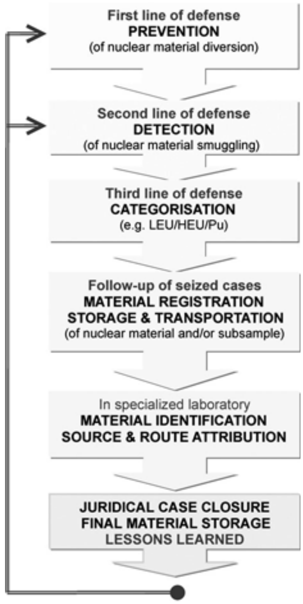
Since the beginning of the 1990's, more than 600 cases of illicit trafficking involving radioactive or nuclear material have been reported in the IAEA database. The reported seizures obviously represent only the tip of an iceberg and we have to assume that the real number of cases of illicit trafficking of nuclear and radioactive material is significantly higher. Most of the reported seizures refer to radioactive sources (such as ^{137}Cs, ^{192}Ir, ^{60}Co or ^{90}Sr) originating from medical or industrial applications. These materials pose a radiological hazard due to their high activity. The seized samples of nuclear material were generally of higher mass, yet of lower activity as compared to medical or industrial radioisotope sources. The threat associated with nuclear material is going beyond the shear consideration of the number of Becquerel of seized sample. The radiotoxicity of the alpha emitting nuclides typically encountered in nuclear material is significantly higher than that of beta or gamma emitters usually applied in medical sources. This represents a considerable hazard if the material is handled in inappropriate ways and particularly if considered in a terrorist context. The use of nuclear material in a radiological dispersal device (colloquially referred to as a "dirty bomb") is therefore a matter of serious concern. Furthermore, nuclear material -if available in sufficient quantity and quality- may be used in nuclear explosive devices. Nuclear material is generally under strict control of competent national or international authorities. This control may involve accountancy and safeguards measures and is generally combined with strict physical protection of the material. However, the reported seizures of nuclear material prove that nuclear material can be diverted or stolen in some instances. This leads to the conclusion that the implementation of treaties, agreements or conventions on safeguards and physical protection has not been fully achieved or suffers from gaps. Closing these gaps and improving the control of nuclear material at the sites where theft or diversion occurred are therefore of prime importance. This, however, requires the identification of the origin of the seized nuclear material.

As a result, nuclear material has become a part of the forensic investigations and a new discipline - nuclear forensic science - was developed. Obviously, the questions on the origin of the material, its intended use and last legal owner need to be answered. The methodology developed in nuclear forensics may also be applied for source attribution of nuclear material in environmental samples, e.g. illegal dumping of nuclear waste, contaminated scrap metal or accidental release. The source attribution can be achieved using the characteristics inherent to the nuclear material. For each seized sample a specific analytical strategy needs to be developed, taking into account the particular conditions of the seizure, the very nature of the material and of its packing and other evidence. The analytical strategy is based on a step-by-step approach, where experimental results are compared to information on nuclear material of known origin contained in a relational database. Based on the actual findings, the next step is defined and performed. Numerous analytical techniques are used in the investigations, including radiometric and mass spectrometric techniques as well as electron microscopy. The samples of seized nuclear material were investigated in the early 1990's at the Institute for Transuranium Elements (ITU), later also Lawrence Livermore National Laboratory (LLNL) and other laboratories analyzed such material and contributed to the development of nuclear forensic science. The instrumentation available in the laboratories is specifically adapted for work with nuclear material. The instruments are routinely applied for nuclear material analysis in several areas, e.g. safeguards, material science, contractual work, method development, environmental studies.

Beyond the actual analytical work in the laboratory one also needs to consider the actions to be taken at the incident site (place of seizure of the material), the legal and law enforcement aspects and the question of data interpretation. The complexity of these issues and the fact that illicit trafficking of nuclear material is a border crossing problem, call for international collaboration and for co-ordinated measures.

2 General Approach

Nuclear forensic investigations have to be considered as part of a comprehensive set of measures for detection, interception, categorization and characterization of illicitly trafficking nuclear material. As mentioned above, nuclear forensic analysis may result in important conclusions on the origin of the material and thus provide the most essential contribution to the prevention of future diversions from the same source. It is therefore crucial to ensure throughout the entire process the integrity and authenticity of the collected evidence. This requires a close collaboration between the various actors on the scene: law enforcement, radioprotection services, forensics experts and nuclear measurement experts. The international technical working group on nuclear smuggling (ITWG) has developed a Model Action Plan for handling cases of seized nuclear material. This action plan lays out the elements that are needed in the instance that illicit nuclear material is uncovered, e.g. incident response, crime scene analysis, collection of evidence, transportation to a nuclear facility, subsequent laboratory analysis, and then development of the case.



3 Analytical Methodology

Like other pieces of evidence, nuclear material intercepted from illicit trafficking carries information that might be useful to illuminate the case. Obviously, classical forensic investigations may be carried out as well as nuclear forensic investigations. The preservation of evidence is of key importance for obtaining a maximum of information on the material, its history and its intended use.

3.1 Classical Forensic Investigations

Classical forensics is a well established discipline with roots reaching far back in the past [1]. In the present context we want to focus on forensic investigations that are carried out on nuclear or radioactive material. The analytical techniques that are applicable refer to investigations of the packing material, of associated materials and of traces (hair, fibre, cells, fingerprints) associated with the radioactive material. Results of such classical forensic investigation provide information that is complementary to the clues obtained from the nuclear forensic analysis. Hence, it will help to establish a more complete picture of the case.

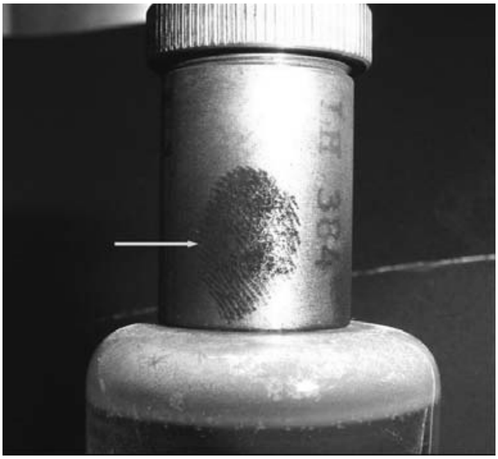


Fig. 1. Fingerprint after treatment with cyanoacrylate vapour on a contaminated brass vial containing PuO2 powder

The challenges encountered in classical forensics of preserving the evidence and of analyzing the meaningful traces are further complicated by handling problems due to the radiological hazard arising from the material. Such investigations call upon the vast forensics experience available in the laboratories of the police and simultaneously require special installations (e.g. glove-boxes) for handling radioactive samples. This particular area of forensic science is at its very beginning. To date only few cases have been reported where classical forensic evidence was taken from contaminated items or from an actual radioactive specimen. Figure 1 shows a fingerprint which was made visible using cyanoacrylate vapour, a standard technique applied in forensics laboratories. In the present case, the treatment had to be performed inside a glove-box in order to protect the analyst from the alpha radiation emitted by the plutonium contamination on the surface of the container. In the example given in figure 4, where a piece of contaminated scrap metal was seized, the exotic composition of the alloy (determined by SEM/EDX) and its particular geometry helped to identify Russia as the origin of the material. In another case, highly enriched uranium (HEU) was seized in Bulgaria. The nuclear forensic analysis of the material was supported by investigations on the non-nuclear materials, i.e. the lead container, the wax and the paper attached to container and the glass ampoule containing the HEU powder [2]. The colorant of the wax, the wood fibre in the paper, the lead isotopic composition and the antimony content in the lead provide useful forensic clues, i.e., consistently pointing at an Eastern European origin.

3.2 Nuclear Forensic Investigations

Nuclear forensic investigations will start after material has been seized and categorized as 'nuclear material'. They are carried out in order to answer specific questions on the nature of the material and its origin, such as the intended use, the mode of production, the plant and production batch, the last legal owner and the smuggling route. The investigations may comprise conventional forensic tests applied to radioactive material, the morphology of the material, the structure of the material components, the composition of traces in the material and its packing, the isotopic composition of the nuclear material itself and of minor constituents.

Nuclear forensic investigations basically draw upon the information inherent to the material. Nuclear material is generally of anthropogenic origin, i.e. the result of a production process. The nature of this production process is reflected in the elemental and isotopic composition of the material as well as in its microscopic and macroscopic appearance. All of these parameters can be measured using the appropriate analytical technique. Some parameters can be combined to a "nuclear fingerprint", i.e. they are characteristic for the mode of production of the material. Hence, they may provide a clue on the origin of the material. Nuclear material is either produced by uranium mining which is normally followed by isotope enrichment of uranium or by neutron capture (e.g. in a reactor) which transforms uranium into the transuranium elements neptunium, plutonium etc. The isotopic composition of the latter depends on the reactor conditions and thus allows drawing conclusions on the reactor type and the fuel initially used [3]. Consequently, a suite of analytical techniques, specifically adapted to the needs of radioactive material, is required. Most of the analytical techniques used are normally applied for accountancy and safeguards measurements or for the characterization of nuclear fuel. However, specific measurement protocols may apply.

The analytical techniques used in nuclear forensic investigations may be subdivided into two categories: commonly applied chemical and physical analytical methods and radioanalytical methods. The latter make use of the radiation emitted from the material. This radiation is characteristic for the emitting nuclide. The two categories of analytical techniques offer results of complementary nature, thus provide a maximum of information on the material under investigation. Table 1 summarizes the analytical techniques used most commonly in nuclear forensic investigations. Some techniques are applicable to radioactive materials only (e.g. alpha- or gamma spectrometry) but most of the methods are commonly applied in analytical chemistry or in materials science (e.g. Secondary Ion Mass Spectrometry-SIMS, Scanning Electron Microscopy-SEM). In the latter case the techniques need to be adapted to the specific requirements associated with handling radioactive materials (gloveboxes, shielding etc.).

Controlling the radiological hazard is of paramount importance at all stages of the investigation. Furthermore, attention should be paid to preserve classical forensic evidence. In the nuclear analytical laboratory, the material is first subjected to visual inspection. This may already reveal useful information on the material itself (e.g. physical form, geometry, primary packing) and provides the starting point for further analysis. This may be complemented by imaging techniques, namely optical microscopy for examination of the sample at high magnification.

In case the analyzed material contains fuel pellets, their dimensions (height, diameter and the size of a possible central hole) and mass are measured. These so-called macroscopic parameters together with the ^{235}U enrichment are characteristic and they often already reveal the reactor type for which the pellets are intended.

Table 1. Techniques used for analyzing seized nuclear material

Techniques/Methods	First Analysis	Information	Detailed Analysis	Information
Radiological	Estimated total activity Dose Rate (α, γ, n) Surface contamination	Radiological hazard Precautions		
Physical characterization	Visual inspection Photography Size measurement Optical microscopy Radiography Weighing	 Macroscopic dimensions Mass	SEM (EDX) XRD TEM	Microstructure and elemental composition Crystal structure Microstructure
Traditional forensic analysis	Fingerprints, fibers			
Isotope analysis	γ-spectroscopy	Isotopic composition	Mass spectrometry (SIMS, TIMS, MC-ICP-MS) Radiochemical separations α-spectrometry	Accurate isotopic composition
Elemental/Chemical analysis			ICP-MS XRF Assay (titration, IDMS) GC/MS	Chemical impurities Chemical compostition

Seizures occur under varying circumstances: at border crossings, during searches on specific targets or just by accident. They reveal nuclear material in different amounts and different shapes. Figures 2 a-d illustrate this variety.

Radiometric Methods

Radiometric techniques measure the radiation that radioactive nuclides emit when they decay to a daughter nuclide. Most of the heavy nuclides (e.g. U and Pu) decay by emitting an alpha particle. However, also gamma radiation is often emitted after the alpha decay to bring the daughter nuclide from an excited state to the ground state. Each nuclide emits gamma rays of energies characteristic to this particular nuclide.

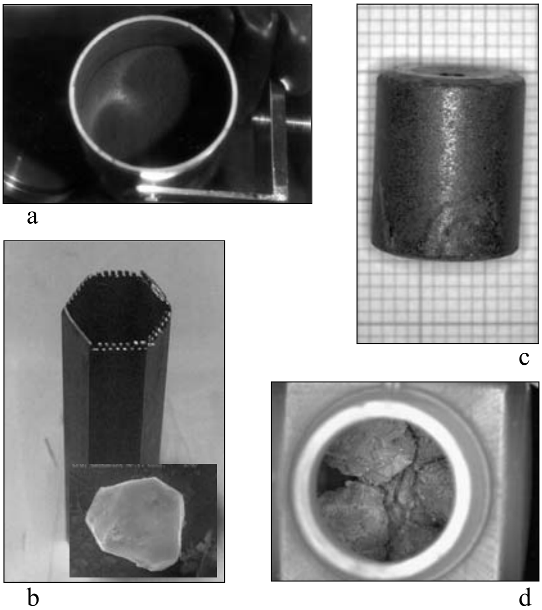


Fig. 2. (a) Sample of uranium-plutonium mixed oxide powder seized in Germany in 1996, (b) Piece of contaminated scrap metal and highly radioactive particle, seized in Germany, (c) Uranium oxide fuel pellet, intended for RBMK-1500 reactor, seized in Lithuania, (d) Sample of yellow cake, containing natural uranium, seized in Rotterdam (NL) in 2003

Gamma spectrometry

Gamma spectrometry is the first technique that is used when seized nuclear material is investigated. This is essentially due to the non-destructive character of the technique, gamma rays, i.e. photons of some ten up to several hundred keV are only slightly attenuated by the packing material (unless shielding like lead is used). Thus, already the initial measurements in the field (e.g. in border control points) are carried out with simple, portable gamma spectrometers. They aim at a categorization of the material. i.e. distinguish between naturally occurring radioactive material, radioactive source, radiotherapy nuclide or nuclear material.

In laboratories more sophisticated gamma spectrometers, so-called high resolution gamma spectrometers (HRGS), are used. Their energy resolution is much better than in the portable instruments, thus gamma rays with energies very close to each other can be resolved in the spectrum. Specific codes like the MGA[4], FRAM[5] or MGAU[6] codes are used to deconvolute the low-energy spectra as observed for plutonium and uranium respectively and allow calculating the isotopic composition of the material. It should, however, be noted that some nuclides like ^{242}Pu or ^{236}U cannot be detected by gamma spectrometry; in these cases mass spectrometry offers a useful analytical alternative. An example of a gamma spectrum of a natural uranium sample is shown in Figure 3.

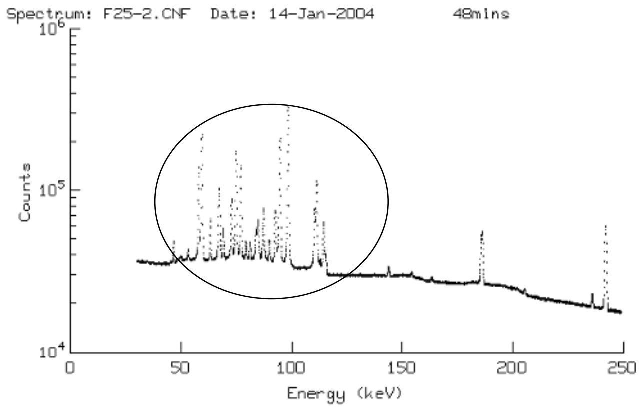


Fig. 3. Gamma spectrum of the yellow cake sample shown in Figure 2(d). The spectrum proves that the material consists of natural uranium, the isotopic composition was determined by analyzing the energy range indicated

Alpha spectrometry

Alpha particles, i.e. ${}^{4}_{2}He^{++}$ having energies of 3 to 8 MeV, are stopped e.g. by a paper sheet, because of their strong interaction with matter. Consequently, an alpha measurement through packing material or shielding is impossible. Alpha spectrometry is a destructive technique, which requires rather laborious sample preparation. This may include dissolution, chemical separation and the target preparation. Especially Pu/Am separation is important, because the alpha particles emitted by ${}^{238}Pu$ and ${}^{241}Am$ have similar energies and thus overlap in the spectrum. Similarly, the alpha energies of ${}^{239}Pu$ and ${}^{240}Pu$ are very close and cannot be resolved in the spectrum, consequently they can be measured only as a sum.

Alpha spectrometry offers low detection limits for Pu measurements, due to the relatively short half-lives of the plutonium isotopes (e.g. half-life of ${}^{238}Pu$ is 87,7 a).

Mass Spectrometric Methods

Mass spectrometric techniques make use of the mass differences between nuclides. If these are nuclides of the same chemical element, they are called isotopes. The isotopic composition of uranium and plutonium is an important parameter for determining the mode of production of the material. In mass spectrometry the atoms contained in a sample are converted to ions and then separated according to their mass (actually, according to their mass to charge ratio). Mass spectrometric techniques can be applied to both radioactive and stable isotopes.

Thermal Ionisation Mass Spectrometry

Thermal Ionisation Mass Spectrometry (TIMS) is a routinely used method for the determination of the isotopic composition of U and Pu. If a known amount of a spike (an isotope not occurring in the samples or only in small abundance) is added, the amount of the element under investigation can be determined quantitatively (element assay), by so-called isotope dilution mass spectrometry. A small amount of sample (some nanograms up to few micrograms) is deposited on a metallic filament. Ions are produced by resistive heating of the filament. Modern instruments offer so-called multi collector detection, thus enabling the simultaneous measurement of the ion currents of different isotopes. Thermal ionization mass spectrometry provides isotope ratio data of high precision and accuracy. A disadvantage of the TIMS technique is the laborious sample preparation. As in the case of alpha spectrometry, the sample needs to be dissolved and chemically separated and purified in order to avoid mass interferences.

Inductively Coupled Plasma Mass Spectrometry

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a versatile technique that came to the market in the 1980's and was used mainly for impurity measurements. Samples are usually introduced in the form of an aerosol, which is generated by nebulizing the sample solution. The ions are produced in the plasma at temperatures of 5000 to 8000 K. The salient features of ICP-MS are the multi-element capability, the high sample throughput, the good sensitivity and the large dynamic range. In modern instruments magnetic sectors are replacing the quadrupoles for mass separation. Consequently, also multi collector detection (enabling simultaneous detection of different isotopes) can be combined with the ICP-source, and isotope ratios can be measured at precisions similar to those of the TIMS technique. ICP-MS measurements have been applied for impurity measurements as well as for isotope ratio measurements in seized samples and in samples of known origin [7,8]

Glow Discharge Mass Spectrometry

Glow Discharge Mass Spec is the most comprehensive and sensitive technique available for the analysis of inorganic solids. It is capable of analyzing conducting, semi-conducting and insulating samples. Its elemental coverage encompasses lithium through uranium with the ability to determine impurity levels from the sub-ppb range to the percent level. In Glow Discharge Mass Spectrometry (GDMS) the solid sample serves as cathode for the sputtering and ionization process. Basically, it can be used for the same purpose as ICP-MS, i.e. impurity and isotope ratio measurements [9]. GDMS can be a very effective tool for panoramic impurity analysis in solid samples. However, it suffers from matrix-effects and does not reach the degree of precision and accuracy achieved in TIMS or ICP-MS. Due to the small spot size which is sputtered, sample heterogeneity may yield misleading results. The fact that the analysis is directly performed from solid samples and that very small samples can be investigated are most advantageous features of this technique.

Secondary Ion Mass Spectrometry

Secondary Ion Mass Spectrometry (SIMS) is a microanalytical technique, applicable even to micrometer sized particles. It offers both elemental and isotopic information. A finely focused primary ion beam (e.g. O^+ or Cs^+) hits the sample and sputters atoms from the surface. These secondary ions then pass a mass spectrometer for analysis. SIMS is applied in nuclear forensics when only small amounts of sample (e.g. particles) are available or when the sample is inhomogeneous (e.g. a powder mixture) and the individual constituents are to be investigated [10,11].

Table 2. Typical sample sizes and typically achieved measurement uncertainties

Technique	Parameter investigated	Typical Sample Mass or Particle Diameter	Typical relative Measurement Uncertainty
TIMS	Isotope Ratios	10 ng - 1 μg	0.05% - 1%
ICP-MS	Isotope Ratios	0.1 ng - 1 μg	0.1 % - 2 %
	Concentration	0.1 pg - 1 μg	1% - 30 %
GDMS	Isotope Ratios	1 - 100 μg	1% - 10 %
	Concentration	1 - 100 μg	15% - 25 %
SIMS	Isotope Ratios	> 0.5 μm	1 % - 10 %
	Concentration	> 0.5 μm	10 - 20 %

Microstructural techniques

Profilometry

Profilometry is used to measure e.g. surface roughness of the materials and crater depth after sputtering. In the nuclear field this technique can be used to determine the surface roughness of fuel pellets. Fuel pellets are finished by grinding to bring the cylindrical shape to the specified diameter with low tolerance. There are two different grinding procedures used, so-called wet and dry grinding. By wet grinding generally smoother surfaces are achieved than by dry grinding. Thus if pellets for a certain type of reactor are produced in several fabrication plants, they can be distinguished from each other by surface roughness, if the plants use different grinding methods [12].

Electron Microscopy

Electron microscopes use a focused beam of electrons of high energy to examine objects on a very fine scale. Interactions with the sample affect the electron beam. These effects are detected and transformed into an image, a spectrum or a diffraction pattern. This may yield information of topography, morphology, elemental composition and crystallographic structure and led to the development of the concept of a microstructural fingerprint [13].

Scanning Electron Microscopy

Scanning electron microscopy (SEM) provides pictures of the surface of objects at high magnification and with a large depth of field. SEM detects the electrons that are back-scattered or emitted (i.e., secondary electrons) from the specimen surface. The characteristic X-rays emitted from the specimen due to fluorescence provide information on the chemical elements contained in the material. Preparation of the samples is relatively easy since most SEMs only require the sample to be conductive. In nuclear forensics, the application of SEM is particularly interesting for powder samples or inhomogeneous samples. Different components may be investigated separately for their particle morphology and elemental composition, thus possibly providing hints on the production process. A sample seized at Munich Airport in 1994 consisted of a powder mixture of three components: uranium, plutonium rod shaped particles and plutonium platelets. The latter were investigated in detail by SEM and TEM as shown in Figures 4 to 5. While the SEM pictures do not allow to unambiguously distinguish between the two materials, TEM analysis provides complementary and useful information.

Transmission Electron Microscopy

Transmission electron microscopy (TEM) makes use of the electrons that have passed through the specimen. Therefore only thin layers can be examined. The sample preparation is rather laborious. However, the resolution reaches the sub-nanometer range.

The results obtained by SEM and TEM clearly show that the two materials originate form different processes. The significantly different grain size distribution indicates that the techniques for precipitation and the conditions for calcining the material were not identical.

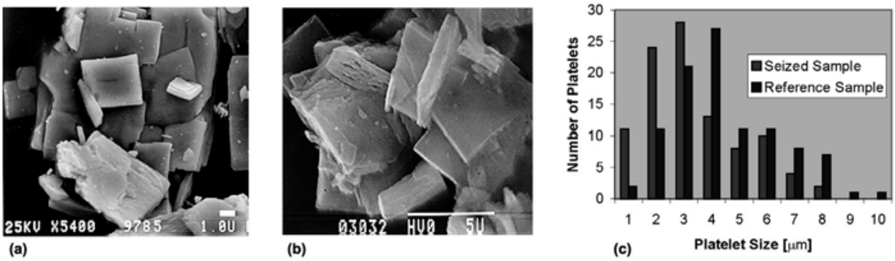


Fig. 4. (a) SEM picture of PuO2 platelets from a sample seized in 1994 at Munich Airport, Germany, (b) SEM picture of a PuO2 reference sample of a known fabrication plant, (c) The platelet size distribution was established by SEM for the two samples. It does, however, not show a significant difference between the two samples

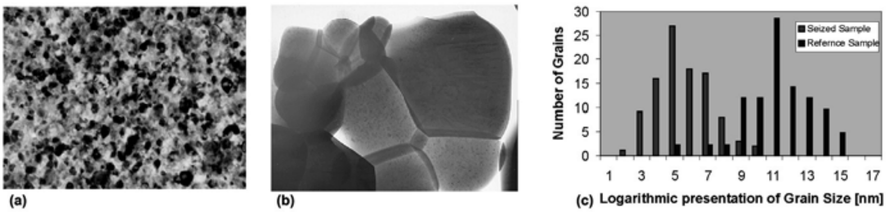


Fig. 5. (a) TEM picture of PuO2 platelets from a sample seized in 1994 at Munich Airport, Germany, (b) TEM picture of a PuO2 reference sample of a known fabrication plant. Please note Fig. 9 and 10 are at the same magnification, (c) The grain size distribution was established by TEM for the two samples. It reveals a remarkable difference, indicating a different production process used for manufacturing the PuO2

Recent Developments

When the phenomenon of nuclear smuggling appeared in the early 1990's and the first seized samples needed to be investigated, the methods available in other fields (e.g. safeguards analysis) were applied for nuclear forensic analysis; no specialized methods were available. Later, the methods were adapted and focused to the specific needs of nuclear forensics. Then it was, however, noticed that new methods dedicated only to investigations of nuclear forensic materials needed to be developed in order to obtain specific information. In this chapter the main developments from recent years are discussed.

Age determination

Determination of the age of materials is common in geology and archaeology. The age of organic materials (e.g. bones) is determined using the ^{14}C-"clock", whereas inorganic materials (e.g. minerals) have several more possibilities for the age determination (e.g. measurement of isotope abundance ratios in Sr/Rb, Sm/Nd, U/Pb). Basically, the disintegration of a radioactive (parent-) isotope and the build up of a corresponding amount of daughter nuclide serve as built-in chronometer. The same principle is applicable to nuclear materials, however under different boundary conditions, because the time periods to be determined (age of the material, i.e. time elapsed since the last purification of the material) are short compared to the half-life of the nuclides. This means that in this short time only a small amount of daughter nuclide will grow-in. Thus the resulting parent/daughter ratios are always very high, which often makes the direct measurement impossible. Additionally, a separation and very sensitive measurement techniques are required. Useful parent/daughter pairs are $^{234}U/^{230}Th$ and $^{235}U/^{231}Pa$, and in case of plutonium $^{238}Pu/^{234}U$, $^{239}Pu/^{235}U$, $^{240}Pu/^{236}U$ and $^{241}Pu/^{241}Am$. As the daughter products are also radioactive, the granddaughters (e.g. $^{234}U/^{226}Ra$) as well can be used for the age determination. Age determination was first developed for bulk plutonium samples. This is classically achieved by a γ-spectrometric measurement of the $^{241}Pu/^{241}Am$ ratio. In a more recent work, the samples were spiked with ^{244}Pu, ^{243}Am and ^{233}U, elements were separated and measured by TIMS [14]. If consistent ages are obtained for the four useful parent/daughter relations, systematic errors can be excluded. Incomplete separation of the initial material will not properly set the clock to zero. The impact on the age determination of residual uranium in a plutonium sample was studied for different types of plutonium [15].

Age determination of Pu particles poses a particular challenge [16]. In the case of single particles, no U/Pu/Am separation can be performed; the isotope ratios need to be measured directly by SIMS. Parent/daughter ratios suffering from isobaric interferences (e.g. $^{241}Pu/^{241}Am$), cannot be used for age determination. As outlined above, the consistency of results allows drawing conclusions on possibly present residual uranium. For an accurate age determination, measurement effects (due to e.g. different ionization potentials of U and Pu) need to be quantified and corrected for.

Due to the long half-lives of the uranium isotopes and consequently the small amounts of daughter products growing in, age determination of uranium is more challenging than for plutonium. The preferred parent/daughter relation is the $^{234}U/^{230}Th$ although ^{234}U is a minor abundant isotope in uranium. U age determination has been demonstrated for a wide range of ^{235}U enrichments, namely from natural uranium up to highly enriched material [17, 18, 19, 20]. Three different methods for quantifying the daughter nuclide have been tested, i.e. alpha spectrometry using ^{228}Th as a spike, TIMS using ^{232}Th as a spike and ICP-MS without spiking, i.e. direct ratio measurement. U age determination has also been demonstrated using the other parent/daughter relation, $^{235}U/^{231}Pa$ by alpha spectrometry; however this suffers from lack of suitable spike isotopes of Pa [21]. The longest living Pa isotope after the ^{231}Pa is ^{233}Pa, with a half-life of 27 days.

4 Data Interpretation

The data and information obtained trough nuclear forensic analysis may be grouped into two categories: endogenic and exogenic information. Endogenic information is normally self-explaining. The age of the material is a direct result of measurements and straightforward calculations. Also the intended use of the material (commercial power reactor, nuclear weapons) can normally be concluded from the data as such. Exogenic information requires empiric data, archive material or historical database.

4.1 Reference Data

The determination of the production mode requires comparison to reference data or to burn-up calculations. Also the determination of the place of production requires comparison to data contained in a nuclear materials database (compiled from the open literature and provided by fuel manufacturers). The IAEA maintains an illicit trafficking database in which information on the seizure and on the material are stored. This allows checking for links between different seizure, e.g. whether the same material type was uncovered at different spots. The Institute for Transuranium Elements and the Bochvar Institute in Moscow jointly established a database on nuclear materials with focus on nuclear fuels[22, 23, 24]. This database has recently been complemented by an electronic literature archive on non-conventional fuels [25]. Once the production batch or the reactor type have been identified, the last legal owner may be found out. Source attribution is an iterative process, where first investigation results are compared against archive material or database entries (of known material). Based on the findings, a number of potential origins can be ruled out (exclusion principle). The difference in certain parameters of the remaining candidate sources are used for guiding the next steps of the analysis.

4.2 Reactor type determination (Pu production)

Plutonium is generated in nuclear reactors after neutron capture of uranium and subsequent decay of the intermediate product. Heavier isotopes of plutonium are produced by further neutron captures. The probability for this reaction (the so-called cross section) depends on the energy of the neutrons and varies also from one Pu isotope to the other. Different reactor types show different neutron energy distributions, therefore the plutonium isotopic composition is a key parameter for the identification of the reactor type where the Pu was produced. The isotopic composition of Pu is influenced by several parameters. These include the neutron spectrum of the reactor (hard or soft, i.e. fast or thermal neutrons), initial U fuel composition (^{235}U enrichment) and burn-up (duration and intensity of irradiation in the reactor). The isotopic composition of Pu in most common reactor types (e.g. light-water reactor, heavy-water reactor, fast breeder reactor) can be calculated using computer codes, e.g. ORIGEN [26] and SCALE [27], thus measured data from seized samples can be compared to calculated values. A correlation was found that separates the main reactor types clearly from each other (Figure 6) [28, 29]. The ^{238}Pu abundance (x-axis) is affected by the initial enrichment of the ^{235}U in the fuel, i.e. the higher the enrichment, the higher the ^{238}Pu abundance. The y-axis (^{242}Pu/^{240}Pu ratio) is affected by the neutron spectrum, i.e. the softer the spectrum, the higher the ratio.

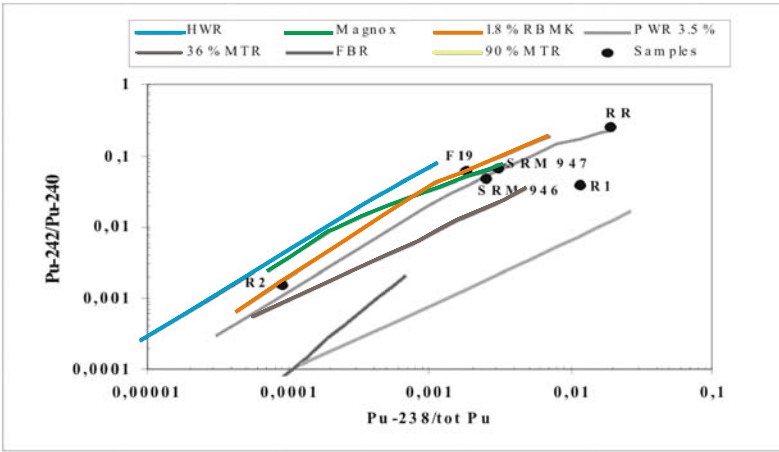


Fig. 6. The isotopic composition of plutonium indicates the reactor type in which the material was produced. Isotopic correlations were calculated for different reactor types and a number of samples were attributed to reactor types. NBS reference materials SRM 746 and 947 originate from Pressurized Water Reactors (PWR), two samples of Russian origin R1 and R2 were produced in a materials testing reactor (MTR) and in a RBMK reactor. The material used in the ITWG round robin exercise, RR, originates from a PWR. The plutonium seized at Munich airport in 1994 was generated in an RBMK reactor

4.3 Geolocation

The natural variations in the isotopic composition of certain elements may provide clues on the geographic origin of the material, and is in fact one of the methodologies used in geolocation [30]. Oxygen in nature consists of three stable isotopes, ^{16}O (99,762%), ^{17}O (0,038%) and ^{18}O (0,200%). However, the isotopic composition can vary slightly due to the different chemical and physical reactions (e.g. isotope exchange, evaporation, condensation) and lead to isotopic fractionation. Relative variations up to 5% in the ^{18}O/^{16}O ratio have been observed in rain water. These variations depend on the average annual temperature, the average distance from the ocean and on the latitude.

As water is a common solvent in uranium processing and isotopic exchange during the processing can be assumed, geographical differences in $^{18}O/^{16}O$ ratio will be reflected in the UO_2 product. An intensive study was performed using three mass spectrometric techniques, TIMS, SIMS and GDMS. In particular the TIMS and SIMS results reveal significant differences between UO_2 pellets produced in different locations [31, 32, 33].

Also other parameters are being studied for geolocation purposes. In natural uranium the chemical impurities may provide information on the ore body where the material was mined. Furthermore, it could be shown that the isotopic composition of stable elements (e.g. Pb[34,35]) also shows significant variations that may be attributed to the origin of the material. TIMS and ICP-MS are used for accurate determination of the isotopic composition of the relevant elements.

5 International Co-operation

Nuclear forensic science is closely related to the phenomenon of illicit trafficking, thus to nuclear security and nuclear safeguards. A border crossing threat is associated with it, hence calling for an internationally co-ordinated response [36]. The International Technical Working Group on combating nuclear smuggling (ITWG) was established some ten years ago under the auspices of the Non-Proliferation Expert Group of the G-8 countries, in order to advance the science of nuclear forensics for attributing nuclear material [37]. This is achieved by exchange of information, by developing procedures and recommendations and by exercises [38, 39].

A number of bi- or multilateral assistance programmes have been set up in order to improve the detection capabilities and to arrange for nuclear forensic assistance [40]. Also the International Atomic Energy Agency promotes the development of nuclear forensics and facilitates the provision of assistance to requesting states which do not have own nuclear forensic capabilities [41].

6 Conclusions

In the last fifteen years we have see the emergence of a new and potentially hazardous form of smuggling: that of nuclear and radioactive materials. This triggered the development of a new discipline in science, enabling to support law enforcement authorities in combating illicit trafficking and dealing with criminal environmental issues: nuclear forensics. Existing analytical techniques as used in material science, in nuclear material safeguards and in environmental analysis, were adapted to the specific needs of nuclear forensic investigations. Characteristic parameters (e.g. isotopic composition, chemical impurities, macro- and microstructure) can be combined to a "nuclear fingerprint", pointing at the origin of the material. Further research is being carried out, aiming at identifying other useful material characteristics in order to reduce the ambiguities often remaining in the interpretation of the data and in the source attribution. New methodologies need to be developed, validated and implemented in order to determine parameters with good precision and accuracy. The availability of up-to-date reference on nuclear material is essential in order to identify the origin and the intended use of the material, or to exclude certain origins.

Significant progress has been achieved in a relatively short time in this new and fascinating discipline. Due to the nature of the material involved and the related handling problems, the specific adaptation of measurement instrumentation, the complexity of the data interpretation and the particular expertise required, only few laboratories are working in this area. However, the hazards involved with nuclear smuggling and the potential relation with nuclear terrorism are the driving forces for deploying and further improving this methodology.

Acknowledgement

The authors express their appreciation for the valuable contributions of Mr. H. Ottmar, H. Eberle, S. Abousahl, A. Nicholl, G. Rasmussen, O. Cromboom, H. Thiele, G. Tamborini and M. Betti and many other colleagues to nuclear forensics investigations.

References

1. Schäfer (2004): T., Mord, Brandstiftung, Sprengstoffanschläge, Chem. Unserer Zeit, 37, 392-398
2. Niemeyer, S., Hutcheon, I. (2002): Forensic analysis of a smuggled HEU sample interdicted in Bulgaria, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, IAEA-CN-98/2/09, 21-23 October 2002, Karlsruhe, Germany.
3. Wallenius M.: Origin determination of reactor produced plutonium by mass spectrometric techniques: Application to nuclear forensic science and safeguards, Thesis, University of Helsinki, http://ethesis.helsinki.fi/julkaisut/mat/kemia/vk/wallenius/
4. Gunnink, R. (1990): MGA: A Gamma-Ray Spectrum Analysis Code for Determining Plutonium Isotopic Abundances, Volume 1, Methods and Algorithms, Lawrence Livermore National Laboratory, USA, UCRL-LR-103220.
5. T.E. Sampson, G.W. Nelson and T. A. Kelly (1989): "FRAM: A versatile Code for Analyzing the Isotopic Ratios of Plutonium from Gamma-Ray Pulse Height Spectra", Los Alamos National Laboratory Report LA-11720-MS.
6. R. Gunnink, W. Ruhter, P. Miller, J. Goerten, M. Swinhoe, H. Wagner, J. Verplancke, M. Bickel and S. Abousahl (1994): "MGAU: A New Analysis Code for Measuring U-235 Enrichments in Arbitrary Samples". Presented at the IAEA Symposium on International Safeguards, Vienna, Austria, Mar. 8-14; ISBN 92-0-101994-7.

7. Wallenius M., Mayer K., Nicholl A., Horta J. (2002): Investigation of correlations in some chemical impurities and isotope ratios for nuclear forensic purposes; International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October;
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
8. K. Mayer, G. Rasmussen, M. Hild, E. Zuleger, H. Ottmar, S. Abousahl, E. Hrnecek (2002): Application of Isotopic Fingerprinting in Nuclear Forensic Investigations - A Case Study; International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October;
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
9. Pajo, L., Schubert, A., Aldave, L., Koch, L., Bibilashvili, Y. K., Dolgov, J., Chorokhov, N. A. (2001): "Identification of unknown nuclear fuel by impurities and physical parameters." J. Radioanal. Nucl. Chem. 250(1) 79-84.
10. Betti, M., Tamborini, G., Koch, L., (1999): "Use of secondary ion mass spectrometry in nuclear forensic analysis for the characterization of plutonium and highly enriched uranium particles." Anal. Chem. 71(14) 2616-2622.
11. Tamborini, G., Wallenius, M., Bildstein, O., Pajo, L., Betti, M. (2002): Development of a SIMS method for isotopic measurements in nuclear forensic applications, Microchimica Acta 139, 185-188.
12. Pajo L., : UO2 fuel pellet impurities, pellet surface roughness and n(18O)/n(16O) ratios applied to nuclear forensic science, Thesis, University of Helsinki, http://ethesis.helsinki.fi/julkaisut/mat/kemia/vk/pajo/
13. Ray I., Schubert A., Wallenius M. (2002): The concept of a "microstructural fingerprint" for characterization of samples in nuclear forensic science, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October;
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
14. Wallenius M. (2000): Age determination of plutonium material in nuclear forensics by thermal ionisation mass spectrometry; Fresenius' Journal of Analytical Chemistry; 366, 234-238.
15. K. Mayer, A. Morgenstern, M. Wallenius, G. Tamborini, (2001): Development of Analytical Methodologies in Response to Recent Challenges; 42nd INMM Annual Meeting, 15 -19 July, Indian Wells, CA, USA
16. Wallenius, M., Tamborini, G., Koch, L. (2001): The "age" of plutonium particles; Radiochim. Acta 89, 55-58.
17. Moorthy, A. R., Kato, W. Y. (1995): HEU age determination, 36th Annual Meeting of the INMM.
18. Wallenius, M., Morgenstern, A., Apostolidis, C., Mayer, K., (2002): "Determination of the age of highly enriched uranium." Anal. Bioanal. Chem. 374, 379-384
19. Morgenstern A. (2002): Uranium age determination - Separation and analysis of Th-230 and Pa-231, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October;
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
20. Wallenius M. (2001): Age determination of highly enriched uranium, IAEA Symposium on International Safeguards: Verification and Nuclear Material Security,

Vienna, Austria;
http://www-pub.iaea.org/MTCD/publications/PDF/SS-2001/Start.pdf
21. Morgenstern, A., Apostolidis, C., Mayer, K. (2002): "Age determination of highly enriched uranium: Separation and analysis of Pa-231." Anal. Chem. 74, 5513-5516.
22. Dolgov, J., Bibilashvili, Y. K., Chorokhov, N. A., Koch, L., Schenkel, R., Schubert, A. (1997): Case studies with a relational database system for identification of nuclear material of unknown origin. Russian International Conference on Nuclear Material Protection, Control and Accounting, Obninsk, Russia
23. Dolgov, J., Bibilashvili, Y. K., Chorokhov, N. A., Schubert, A., Janssen, G., Mayer, K., Koch, L., (1999): Installation of a database for identification of nuclear material of unknown origin at VNIINM Moscow; 21st ESARDA Symposium, Sevilla, Spain; Report EUR 18963 EN.
24. Schubert, A., Janssen, G., Koch, L., Peerani, P., Bibilashvili, Y. K., Chorokhov, N. A., Dolgov, J. (1998): A software package for nuclear analysis guidance by a relational database. ANS International Conference on the Physics of Nuclear Science and Technology, New York, USA.
25. Dolgov Y., (2002): Development of an electronic archive on non-conventional fuels as integral part of a nuclear forensic laboratory, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October; http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
26. Bell M.J. (1973): ORIGEN- The Oak Ridge Isotope Generation and Depletion Code, ORNL-4628.
27. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200, Rev. 6 (ORNL/NUREG/CSD-2R6), Vols. I, II, and III (May 2000)
28. Wallenius M. (2000): Origin determination of plutonium material in nuclear forensics, J. Radioanal. Nucl. Chem. 246(2), 317-321.
29. M. Wallenius, L. Pajo, K. Mayer (2001): Development and Implementation of Methods for Determination of the Origin of Nuclear Materials; IAEA Conference on Security of Material, 7 - 11 May, Stockholm, Sweden;
http://www-pub.iaea.org/MTCD/publications/PDF/CSP-12-P_web.pdf
30. Niemeyer, S., Hutcheon, I. (1999): Geolocation and route attribution in illicit trafficking of nuclear materials, 21st ESARDA Symposium, Sevilla, Spain, Report EUR 18963 EN
31. Pajo L. (2001): Investigation of the oxygen isotopic composition in oxidic uranium compounds as a new property in nuclear forensic science, Fresenius J. Anal. Chem 371, 348-352.
32. Pajo, L., Tamborini, G., Rasmussen, G., Mayer, K., Koch, L. (2001): "A novel isotope analysis of oxygen in uranium oxides: Comparison of secondary ion mass spectrometry, glow discharge mass spectrometry and thermal ionization mass spectrometry." Spectrochim. Acta Part B 56, 541-549
33. Tamborini, G., Phinney, D. L., Bildstein, O., Betti, M. (2002): "Oxygen isotopic measurements by secondary ion mass spectrometry in uranium oxide microparticles: A nuclear forensic diagnostic." Anal. Chem. 74, 6098-6101.
34. Bollhofer, A., Rosman K.J.R. (2000): Isotopic source signatures for atmospheric lead: The southern hemisphere. Geochim. Cosmochim. Acta 64, 3251-3262.
35. Bollhofer, A., Rosman K.J.R. (2001): Isotopic source signatures for atmospheric lead: The northern hemisphere. Geochim. Cosmochim. Acta 65, 1727-1740.

36. Koch, L., Niemeyer, S. (1996): A report on recent international progress for enhancing nuclear forensic capabilities for cases of illicit nuclear materials: 1-26.
37. Niemeyer S. (2002): The nuclear Smuggling International Technical Working Group: Making a difference in combating illicit trafficking, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October; http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
38. Dudder G.B. (2001): Plutonium Round Robin Test, IAEA Conference on Security of Material, 7 - 11 May Stockholm, Sweden; http://www-pub.iaea.org/MTCD/publications/PDF/CSP-12-P_web.pdf
39. Dudder G.B. (2002): ITWG Round Robin Tests, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October; http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf
40. Janssens W., Daures P., Mayer K., Cromboom O., Schubert A., Koch L. (2001): Assisting Eastern European countries in the setting up of a national response to nuclear smuggling, IAEA Conference on Security of Material, 7 - 11 May Stockholm, Sweden; http://www-pub.iaea.org/MTCD/publications/PDF/CSP-12-P_web.pdf
41. Nilsson A. (2002): The role of nuclear forensics in the prevention of acts of nuclear terrorism, International Conference on Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21-23 October; http://www-pub.iaea.org/MTCD/publications/PDF/Pub1169_web.pdf

VI

Information Collection and Analysis

Determination of non-compliance relies on sophisticated analysis and evaluation of information collected by the various components of the verification system. Information is collected at the levels, national, regional and international. For effective use of the collected information synergies need to be developed among the three levels.

The Information Infrastructure of a Treaty Monitoring System

Nicholas Kyriakopoulos

1 Introduction

As treaties have evolved from simply describing obligations to requiring compliance and providing for sanctions in case of non-compliance, so have the requirements for the collection, analysis and evaluation of information. While the Geneva Convention [1] does not even mention the collection of information, the Comprehensive Nuclear Test Ban Treaty (CTBT) requires that "automated processing methods" be applied "on a routine basis" [2]. The resulting products, such as event bulletins, must be forwarded to the State Parties regularly and automatically. Considering that an event bulletin implies detection, transmission, analysis and evaluation of signals, it is clear that the generation of event bulletins within a relatively short time interval from the occurrence of an event has been made possible by the advances in sensing, computing and communications. Similar observations can be made for the current approaches to safeguarding nuclear facilities in near real time [3]. One could safely postulate that as the capability of the technology to transmit and process large quantities of data at faster speeds increases, treaty obligations will become more demanding and verification regimes more effective. An obvious corollary is that, at any given time, it is the available technology that determines the structure and operation of verification regimes and not vice versa. However, it should be noted that often, although the available technology is capable of increasing the effectiveness of a verification regime, political considerations impede its deployment. Some examples of limited use of available technologies are the slowness in deploying remote monitoring technologies in safeguarded nuclear facilities, and the lack of satellite surveillance as well as the limited use of hydroacoustic sensors in the CTBT.

Traditionally technology has been viewed in terms of instruments ranging from relatively simple, such as temperature sensors, to highly complex, such as spectrum analyzers and central processing units. The discrete nature of all instruments made their operation location dependent. Information was collected and used in the vicinity of the place where an instrument was located.

With the advances in remote sensing and communications, the constraints imposed by the location of the instrument on the generation and use of the information have been eliminated. A phenomenon occurring in one location is sensed by an instrument located somewhere else and the information about the phenomenon is analyzed at another location and the results of the analysis are used somewhere else. As a result, the processing of information is performed by a geographically distributed infrastructure.

Although the term infrastructure is being used rather loosely, it has a well defined meaning is if is associated with a specific set of functions or operations. Thus, in the context of a verification regime for a given treaty, one can construct an infrastructure to process all information necessary for verifying compliance, namely, an information infrastructure for the given treaty. It goes without saying that there may be differences among the information infrastructures of different treaties, because the types of information being processed and the desired outputs for verifying compliance may differ among them. Nevertheless, some fundamental concepts are common to all information infrastructures and independent of any particular treaty.

In this chapter we identify the major elements of a generic information infrastructure, their possible interconnections and some of the technical issues which may arise as a result of the international environment in which these infrastructures exist and provide their information services.

2 Major components of a treaty information infrastructure

The information infrastructure can be best specified as systems of interconnected components (see Avenhaus and Kyriakopoulos this volume). All information associated with a treaty falls into three categories: information supplied by sources, information provided to recipients (sinks) and information internal to the process. Some sources such as State Parties are external to the infrastructure. Others such as containment and surveillance devices used in nuclear safeguards, or inspectors collecting information, are elements of the infrastructure. In general, external sources and sinks are States Parties but not exclusively so. Treaties that specify verification regimes do not exclude the use of information available in the public domain. To improve the effectiveness of safeguards the IAEA may use open source information [4,5]. The CTBT provides for the use of the International Monitoring System (IMS) data for purposes other than verification of compliance. The two sets overlap but are not identical. The distinction between internal and external sources is necessary, because the connections between the infrastructure and the external sources and sinks define the boundaries of the infrastructure as shown in Figure 1. From a functional perspective, the purpose of the infrastructure is to provide information ensuring that the member States comply with their treaty obligations. A clear distinction needs to be made between the term information infrastructures and the communications systems that provide connectivity among instruments, computers and humans. The former refers to the flow and processing of information for the purpose of implementing a treaty, while the later refers to the means used to move and process the information.

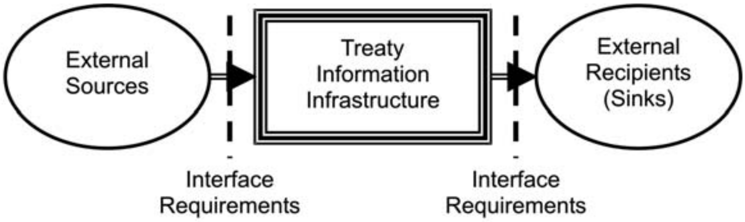


Fig. 1. The boundaries of a treaty information infrastructure

An information infrastructure is a network of nodes and links. A node receives and transmits information through links connecting that node with other nodes of the infrastructure. It also processes and stores information. Defining a node as a receptor, processor and transmitter of information allows one to consider each node itself as an infrastructure comprising nodes and associated links. At one level of abstraction, links are conduits that transport information. At another level, as communications networks they receive, process and transmit data. The information infrastructure for the CTBT is the set of information processing systems that are used to support the verification regime of the treaty. At the highest level it consists of four components defined by the treaty and one implied by the establishment of the Comprehensive Test Ban Treaty Organization (CTBTO). They are the infrastructure of the International Monitoring System, those associated with "consultation and clarification", "on-site inspections", "confidence-building measures" and a fifth one supporting the operation of the Technical Secretariat of the CTBTO. The information infrastructure of the IMS is fairly well defined in Article IV Section B and the Verification Annex of the CTBT. The flow and processing of information for "consultation and clarification", "on-site inspections" and "confidence-building measures" is described in Sections C, D and E, respectively. See also Kalinowski in this volume. Although the treaty does not specify the organizational structure of the Technical Secretariat, it is self-evident that for the organization to function effectively it also needs an administrative information infrastructure.

This example illustrates the first level decomposition of an infrastructure into component infrastructures as shown in Figure 2. The illustration also includes some sources and sinks for each Level 1 infrastructure. The characteristics of these sources and sinks as well as the quality and quantity of information associated with them are under the control of the infrastructure management system, while those of the external sources, shown in Figure 1, are outside the purview of the infrastructure. Consequently, rules of attachment to the infrastructure need to be established.

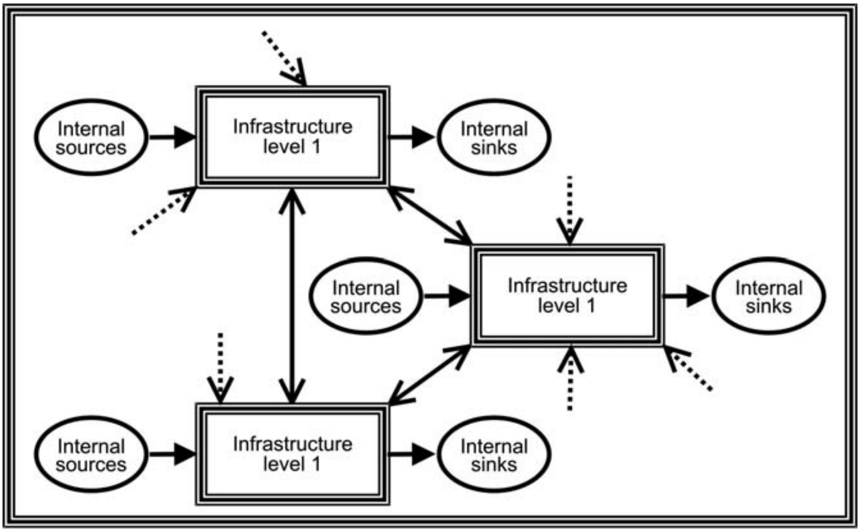


Fig. 2. Decomposition of an information infrastructure into first level constituent components

In order to analyze the performance of an existing infrastructure or to design a new one, metrics are needed for measuring information from the point of view of its use in a specified application. A commonly used term is *availability*, such as in system availability or data availability. However, these terms do not have a universally accepted definition and need additional qualifiers in order to be of practical use. Instead, for a treaty verification regime, the attributes *validity*, *sufficiency*, *integrity* and *timeliness* give a quantifiable description of the information used to measure compliance.

- *Validity* is a measure of the relevance of a unit of information to the verification objective and discriminates between relevant and extraneous information.
- *Sufficiency* is a measure of the amount of necessary information for making a decision with a desired degree of confidence. It specifies the minimum quantity of valid data to achieve a required degree of confidence.
- *Integrity* is a measure of the change in the information between the time and place of generation of a unit of information by an independent source, and the time and place of the use of the information by the decision-maker. Integrity measures the consistency (or, conversely, the changes) of

the information generated by a source and that available to the decision-maker(s) and attributable to the given source.

- *Timeliness*: Specification of the maximum delay for transferring the information from a source to a destination. Timeliness measures the elapsed time between the instant the information is generated and the instant it becomes available for use.

3 Sources and sinks of information

The sources, referred to earlier as external sources that could generate the information entering the infrastructure of a treaty may be put into three major groups: States Parties, international organizations and the public domain. For most treaties, States Parties are generally the sources and sinks of information. For some treaties such as the CTBT, information collected by the International Monitoring System may be made available to the public domain for scientific purposes and other uses. International organizations other than those associated with a treaty can be considered as external sources to the information infrastructure of that treaty, if they provide information to be processed by the infrastructure. For example, information from the World Meteorological Organization could be used by a Kyoto Protocol monitoring infrastructure, information from the World Health Organization could be used in monitoring the Biological Weapons Convention, etc. Individuals, non-governmental entities and the media may be considered as sources in the public domain.

Regardless of the specific terminology used in various treaties, the inputs to and the outputs from the information infrastructure may be in the form of data files or instrument measurements. Data files include declarations, reports, submissions, notifications, diagrams, images, messages, etc. They could be on paper, in electronic format, or, perhaps in oral form. These are discrete events that could occur periodically, e.g., annual declarations, occasionally, e.g., requests for clarification, or randomly, e.g., seismic event bulletins. Instrument readings may be analog or digital. They may consist of raw measurements, i.e., signals generated by sensing physical variables, or processed data, i.e., characteristics of the signals extracted from raw measurements. Although sensing of physical variables generates analog signals, the trend in instrumentation is to convert the analog signals into digital form as close to the sensing elements as possible. Advances in electronics have made possible the manufacture of analog-to-digital (A/D) converters with sufficient dynamic range to accommodate most signals used in treaty monitoring. From the perspective of information processing, the conversion of analog signals into digital data streams blurs the difference between data files and instrument measurements. In their elementary form, both are sequences of numbers transmitted to the infrastructure at some specified time interval. For example, annual declarations for the Chemical Weapons Convention (CWC) [6] are data records containing a given volume of data, as are the results of air sample analysis performed every twenty-four hours by the radionuclide stations of the International Monitoring System of the CTBT. In both cases, the records are digital, are transmitted periodically, but they differ in the volume of data they contain. Similarly, the primary seismic stations of the IMS generate a continuous stream of numbers at a typical rate of 40 samples/second. Every 10 seconds they convert the samples into a data record and transmit the record at the rate of 1 record per 10 seconds. The common characteristic of these three cases is the periodicity of generation and transmission of the records. In the case of the seismic signals, the transmission is said to be in real time, or more accurately, near real-time. Transmission in real time implies that each sample is transmitted as soon as it is generated, while near real time implies that there is a short delay between generation and transmission of a sample. These delays are in the order of seconds or less. Following the same logic one would characterize the transmission of the results of the analysis of air samples at radionuclide stations every 24 hours as real time or near real time because they are transmitted as soon as they become available. However, these terms are not used for such intervals. On the other hand, data files in the form of declarations, etc, may be constructed and stored in a database for some undetermined time interval before being transmitted to the treaty information infrastructure. In cases where human interference may be involved and the terms real time or near real time are inappropriate, the terms batch form or file transfer are sometimes used.

A major problem about the information provided by external sources is how to measure the integrity of the information. Is it possible for the treaty infrastructure to ascertain the veracity or authenticity of the information? The CWC requires the States Parties to submit annual declarations of commercial activities for chemicals not prohibited by the convention. The information is provided to the State Party by the enterprises under its control, aggregated and submitted to the Technical Secretariat of the Organization for the Prohibition of Chemical Weapons. The information may be distorted, intentionally or unintentionally, by the enterprise with or without the knowledge of the State, or by the State at the aggregation stage. In the age of electronic databases it is not difficult to have corrupted files, to alter records or maintain duplicate ones. Theoretically, the verification regime should be able to detect any distortions. In practice, it is difficult if not impossible [7]. On the other hand, the problem of ensuring the integrity of information generated by instruments is easier to handle. For instruments located within the realm of a State Party, one needs to make a distinction between those owned, operated and maintained by the State Party and those which are part of the treaty information infrastructure. Only the former are external sources and are susceptible to tampering with their operation by the State. In those cases, the design of the instrument must be such that the signal path from the sensing element to the digitizer (A/D conversion) needs to be protected so that the signal cannot be intercepted mechanically or electrically. After the signal has been digitized, coding techniques can be employed to either encrypt the signal or sign it with an electronic signature depending on whether the information contained in the signal needs to be protected or may be transmitted in the clear. For the infrastructure to rely on the integrity of the information generated by instruments not under its control, the physical protection of the signal path between the sensing element and the digitizer and the protection of the coder need to be under the control of the international authority managing the infrastructure.

By far the greatest challenge is how to handle the information generated by sources in the public domain. These sources may be instruments, publications (print, electronic), or broadcast. Instruments may be either earth-based such as weather stations, environmental monitoring stations, etc, or satellites. The common characteristic of these sources is that they are under minimal or no control by the State Parties to a treaty. The primary use of the information generated by these instruments is not for verifying a treaty but for other unrelated purposes. Thus, there is minimal incentive and decreased opportunity for someone to compromise the integrity of the information. Furthermore, as the number of independent users increases, there is a higher chance of detecting deliberate falsification. An example of information generated by such sources is the use of satellite imagery for improving the verification of the CTBT (See Jasani in this volume). The same cannot be said for publications or broadcasting. From the multitude of available sources, how does one decide which piece of information to accept and which to ignore? Even if, somehow, a criterion of relevance is established, the volume of data collected from such sources could easily exceed the capacity of the infrastructure to process the information. A solution might be to specify degrees of relevance, which brings up a more important question, that of information integrity. Even if relevance is determined by the use of some key words or phrases such as "chemical weapon", "nuclear explosion", "military aircraft", "biological agent", etc, one has no way of knowing whether the information generated by a particular source is true, partially true or false. For false or partially true information, there is the additional problem of distinguishing between innocent errors and deliberate distortions. Although data mining techniques can be used to screen the information for relevance on the basis of key indicators, it would be a daunting task to verify the integrity of the information generated by sources in the public domain for use in a verification system.

In addition to the external source, information sources can also be internal to the infrastructure. The most common are inspectors and instruments. The inspectors, as elements of the infrastructure, are trusted not to intentionally violate the integrity of the information they generate during inspections. Similarly, the international authority, having complete control of the instruments, incorporates into the design tamper-indicating and data protection features to ensure the integrity of the information generated by the instruments. Nevertheless, inspectors can make errors and instruments can generate erroneous signals. As errors, they compromise the integrity of the information, as do intentional errors induced by sources external to the infrastructure. There is, however, a major difference in their impact on the processing of information. The statistical properties of measurement errors are generally known and their impact on the uncertainty of the outcome can be calculated. The same cannot be said for deliberate falsification of data. For the latter case one needs to rely on the completeness of the verification regime to detect erroneous information introduced into the system.

4 Data networks

An information infrastructure, as an operational concept, refers to the flow and processing of information for the purpose of verification.Thus, infrastructures are associated with specific services, such as transmission of declarations, notification of inspections, generation and distribution of event bulletins, etc. For a given information infrastructure, one can evaluate its performance with respect to the services it is expected to provide by using the attributes of validity, sufficiency, integrity and timeliness. These services, however, are provided by another type of infrastructure comprising communications and computers. It is a major technical challenge to translate the service performance requirements into system design parameters. This section gives an overview of the relationship between services provided by the information infrastructure and the systems that provide them.

4.1 A networking framework

The information generated by humans or machines in the form of files or instrument data needs to be transformed into signals in order to be transported from one place to another through communications networks. The transformation takes place in a number of steps that take the information in forms understood by humans, convert it to signals that propagate through the communications networks and back to forms understood by humans. The initial steps utilize software, the actual transmission is by electrical conduction or electromagnetic radiation and the final steps again use software to transform the information into forms understood by humans. There are two networking frameworks for implementing these transformations, the Open Systems Interconnection (OSI) reference model and the Internet protocol (IP) stack [8,9]. The complete suite of Internet protocols is referred to as TCP/IP (transmission control protocol/internet protocol). Both OSI and TCP/IP are ISO[1] standards promulgated by the International Organization for Standardization. The protocols consist of seven and five *layers*, respectively. For the purposes of this discussion we will use the terminology of TCP/IP, because of the ubiquitous Internet.

[1] ISO stands for the first three letters of the word ίσος (isos) meaning equal.

The transport of information in a communications infrastructure can be described in terms of logical flow and the actual flow mentioned previously. Figure 3 illustrates the role of the Internet protocol layers in the flow of information between two users or hosts. These are typically desktop computers and are also referred to as workstations. The actual flow passes through all the layers, while the logical flow takes place between similar layers. Some of the functions performed by the five layers are:

- *Application layer*: File transfer, electronic mail, connection of servers to the Web, document exchange and other similar functions using protocols such as File Transfer Protocol (FTP), Simple Mail Transfer Protocol (SMTP), HyperText Transfer Protocol (HTTP), etc.
- *Transport layer*: Transfer of application layer messages such as flow control, error control etc, from one computer to another (client-server communication) using the TCP, or the UDP (user datagram protocol) for connectionless service.
- *Network layer*: Establishes the routes in the network through which messages (datagrams) in the form of data packets are transported between sources and destinations. These routes include a number of packet switches or routers.
- *Link layer*: Provides the network layer with a reliable information delivery service over a link. It performs functions such as error control and frame synchronization and it provides either a connection-oriented service or connectionless service. At this layer packets are converted into bits for transmission by the physical layer.
- *Physical layer*: Transports the bits from one physical node to another through a transmission medium by converting them into electrical signals. Protocols such as Ethernet, ATM and RS232 have physical layer components for twisted pair wires, coaxial cables and optical fibers.

4.2 Some common topologies

The networking framework provides the flexibility to define networks at different levels. The treaty information infrastructure can now be viewed as an application layer network with the users or hosts being the nodes and the logical connections at the application layer being the links. At the other end of the layer structure, there are the physical networks with transmitters, receivers and their associated equipment being the nodes and the communications channels either wired or wireless being the links. Regardless of the layer at which a network is defined, networks can have different topologies. Two of the most common topologies associated with treaty verification information infrastructures are the star topology and the mesh topology shown in Figures 4 and 5, respectively.

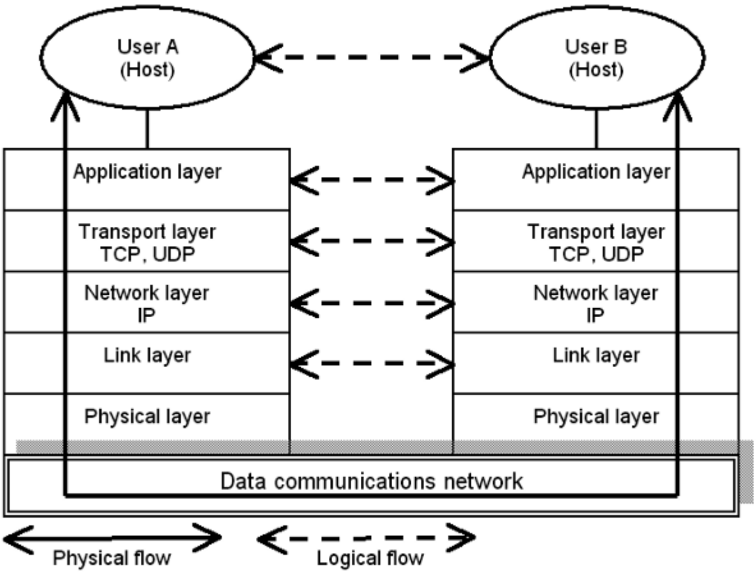


Fig. 3. Logical and physical flow of information between two users through the IP protocol stack

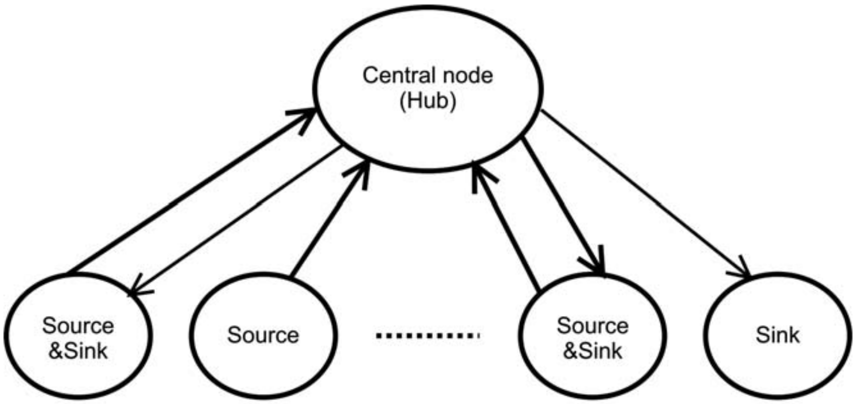


Fig. 4. Star topology indicating different types and capacities of information transport links

The star configuration consists of a central node and a set of remote nodes. Information passes only between remote nodes and the central node. Information exchange among remote nodes can only be done via the central node. Examples of star topology infrastructures are the CWC and the CTBT. In both cases, information is normally exchanged between State Parties and the

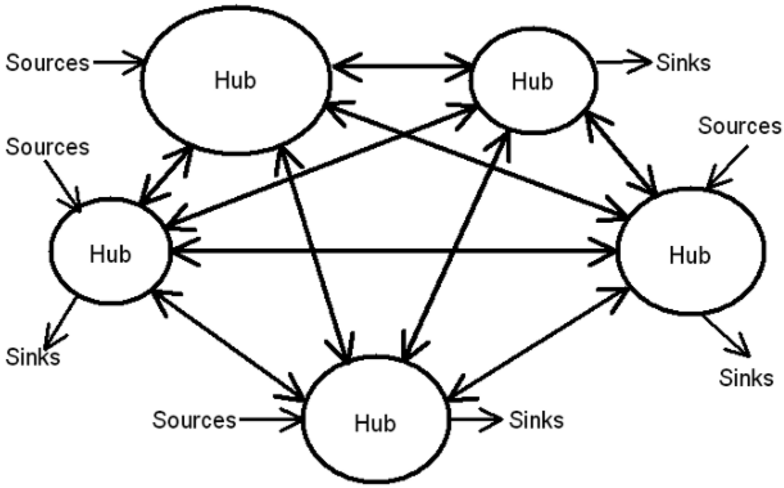


Fig. 5. Fully connected mesh topology including information sources and sinks at each hub

respective organizations although States Parties are encouraged to resolve ambiguities amongst them. Examples of star topology at the physical layer are surveillance systems with a central console and a collection of remote sensors, 10baseT and 100baseT Ethernet, and broadcast stations with remote receivers. Traffic in the links between each remote node and the central node may be unidirectional, bidirectional, balanced or unbalanced. For the CWC the traffic is bidirectional and unbalanced because the volume of data flowing from the State Parties to the central node is much greater than that from the central node to the State Parties. Similarly, the traffic in the CTBT network is also bidirectional and unbalanced, but for some links the volume of incoming traffic to the central node is greater than the outgoing traffic, while for some other links the reverse is true. The latter occurs when a State Party receives the raw data from all the stations of the International Monitoring System. A major concern for networks designed with a star topology is about reliability. Failure of one or more links between remote nodes and the central node will result in loss of information from those links. A more serious problem is the existence of a single point of failure at the central node. Degradation of performance, or failure, at that node will cause degradation of performance or failure of the entire system. The obvious solution is to introduce redundancies in all links and the central node.

In contrast to the star topology, the mesh topology maximizes the reliability of the infrastructure by providing full connectivity among all the nodes. The effects of failure or degradation of performance in one or more nodes or links can be mitigated by bypassing the defective components and distributing the information through the unaffected network. Reliable as the mesh topology is, it can be made more reliable by introducing redundancy in every link and node. In the final analysis it becomes a question of trade-off between reliability and cost.

A third type of topology encountered in a number of network implementations is the tree topology shown in Figure 6. An example is found within the information infrastructure of the CWC. Declarations for chemicals not prohibited by the Convention are submitted to the National Authority of each State Party for each facility covered by the Convention, aggregated into a national declaration and transmitted to the OPCW. The Authority becomes a hub between the industry facility nodes and the OPCW. At the physical layer, some local area networks are implemented in a tree topology with workstations (users) distributed among hubs in a hierarchical order. Tree topology allows the connection of additional users without disturbing the operation of the entire network.

More than one topologies can exist in a given information infrastructure. Under the treaty on Conventional Forces in Europe [10], annual declarations from each State Party are distributed to all State Parties without any intermediate processing, through the communications network of the Organization for Security and Cooperation in Europe (OSCE) resulting in a mesh topology at the application layer. In its original design, the network itself had a star topology where all message traffic was received by a central node and was distributed to the remote nodes without any intermediate processing.

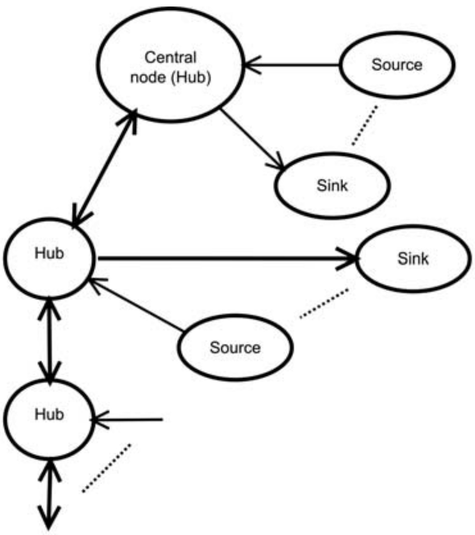


Fig. 6. Rooted tree topology in which the central node may represent the treaty organization, or the central computing facility, or the communications hub at the central facility

4.3 The role of the Internet

Information infrastructures increasing rely on the Internet as a data transport mechanism and the trend will continue as the quality of services offered by the Internet continues to improve. At the physical layer, the Internet is a collection of interconnected networks, shown in Figure 7, and referred to as service provider networks each managed and controlled by an Internet Service Provider (ISP). The service provider networks are interconnected at gateway nodes. Within a service provider network, the Internet protocol (IP) simply sends a packet with a final destination address from one node (router) to the next without expecting an acknowledgement whether or not the packet has been received. Thus, at the transport layer the sender has no way of knowing whether or not the packet has reached its destination. The TCP protocol offers reliable transmission by providing for acknowledgement of receipt for each packet and for retransmission of lost packets. The TCP, however, does not guarantee minimum transport delay and cannot provide a service that imposes a requirement for timeliness. Also, it cannot guarantee a given throughput rate, because the packet transmission rate is controlled by the congestion control mechanism of the TCP. These two limitations might not allow the application layer to satisfy timeliness requirements imposed by the users. For applications involving continuous transmission of data in real time, such as the transmission of infrasound, hydroacoutic and seismic data in the IMS, if the source data rate is greater than the throughput rate, a data queue will build up leading to system instability. As the Internet evolves and different classes of services are added these limitations are being slowly removed. Within a service provider network virtual private network services (VPN) are offered based on the differentiated services architecture [11,12].

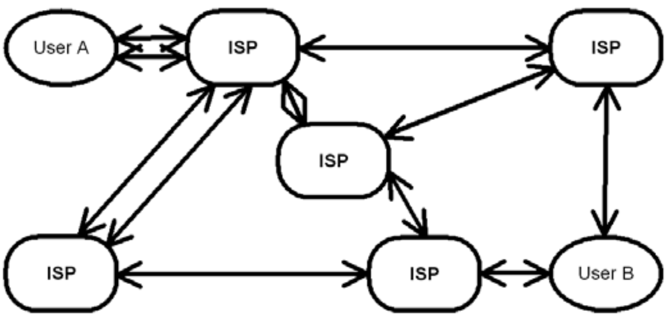


Fig. 7. Possible paths for the transfer of information between two users via multiple autonomous Internet service networks with redundant connections for increased reliability

The biggest impediment to the use of the Internet for treaty verification purposes is the lack of standards for specifying quality of service across the boundaries of service provider networks. The problem is particularly serious for applications relying on continuous transmission of data and on stringent timeliness requirements. The global coverage of the information infrastructures of multilateral treaties resulting in the transport of data at great distances may require the services of multiple cooperating ISPs for sending the data though the Internet. To offer the quality of service required by the application there is a need first to offer inter-provider quality of service, because measurements of quality of service differ among ISPs. To deploy inter-provider quality of service, standards are needed for service classes, performance metrics, measurement methods, routing methods and time references [13].

5 Anatomy of an infrastructure

We have seen that the transport of information from external sources to the processing nodes of an infrastructure involves a sequence of transformations. In this section we use the seismic monitoring network of the International Monitoring System of the CTBT to illustrate the processes involved in transporting signals within an information infrastructure for analysis and evaluation. We also outline a systematic approach for implementing these processes. The treaty verification requirements impose, in turn, requirements on the signals generated by the sensors and transported to the International Data Center for analysis and evaluation. These requirements are specified in a set of operational manuals still under development. Although the terminology is for a specific treaty, the underlying concepts apply to any monitoring system.

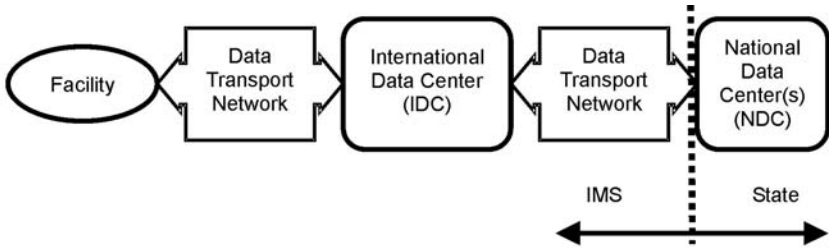


Fig. 8. The major components of the International Monitoring System information infrastructure

In the International Monitoring System there are three major components that form the path between the sensing elements and the computational facility where the data are stored, analyzed, evaluated and used to produce event bulletins. These are the remote facility where the sensors are located, the International Data Centre (IDC) in Vienna where the event bulletins are produced and the global communications infrastructure that transports the data from each remote facility to the IDC. See Figure 8. Information from the facilities is transmitted to the International Data Center, where it is used to produce event bulletins which are then disseminated to the National Data Centers of the States Parties. For seismic monitoring the information is contained in the signals generated by the sensing elements at each facility. The users of that information require only that the sensor data be available for analysis and evaluation where and when they are needed and in sufficient quantity to satisfy the verification objectives. It is the role of the system designer to build a system that should satisfy the performance requirements specified by the users. To do so, the system designer needs to decompose the four major elements of the seismic monitoring infrastructure through a sequence of mappings until the decomposition reaches the level of elementary components such as sensors, local area networks (LANs), software packages, satellite antennas, routers, etc. At each level of decomposition, the service performance requirements need to be translated into system performance specifications for that level. The challenge for the system designer is to derive the performance characteristics of these elementary building blocks from the requirements specified by the users. The following paragraphs describe a procedure for designing, building and operating such a system.

It has already been mentioned that information flows from source to sink in two forms, logical and physical. These two paths comprise, respectively, the logical and physical infrastructures of the International Monitoring System. The logical flow is implemented by the layered architecture of the Internet protocol stack, Figure 9, while the physical flow takes place through interconnected components of the physical infrastructure. In designing an information transport service, the user specifies the service performance requirements at the logical level by assigning values to the attributes of validity, sufficiency, integrity and timeliness. The system designer assembles and interconnects components to form a physical path for the data to flow between the users. At the highest level of decomposition, the physical path comprises the primary components shown in Figure 8. To relate service performance requirements and physical components specifications two parallel decompositions need to be done, one for the logical flow and the other for the physical flow. For the logical flow, the decomposition needs to reach the level where the elementary components are the changes of the signals generated by each sensing element. Correspondingly, for the physical flow, the decompositions need to reach the level where the physical path is formed by components operating on the individual sensor signals. Such a decomposition is a very complicated process and beyond the scope of this chapter. Figure 10 shows the second level decomposition from that shown in Figure 8. A third level decomposition would be that of the communications path and so on.

The relationship between application layer service performance requirements and component design specifications can be understood easier by going through the transformations undergone by signals generated by a seismic ar-

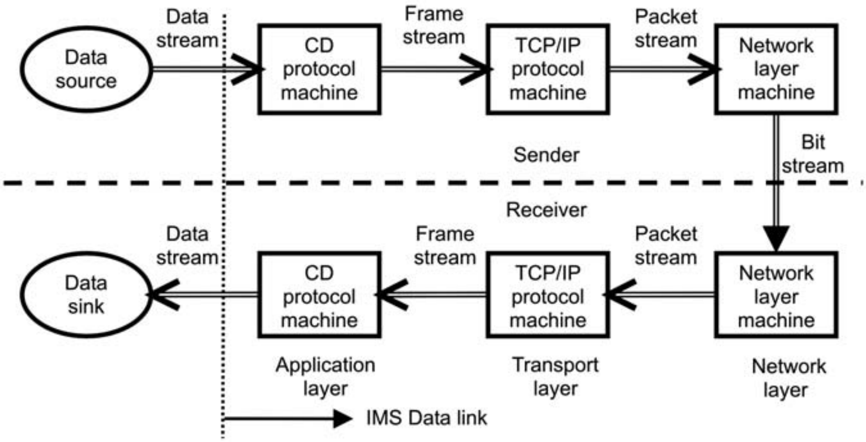


Fig. 9. Signal transformations from source to sink viewed from the perspective of the TCP/IP networking framework

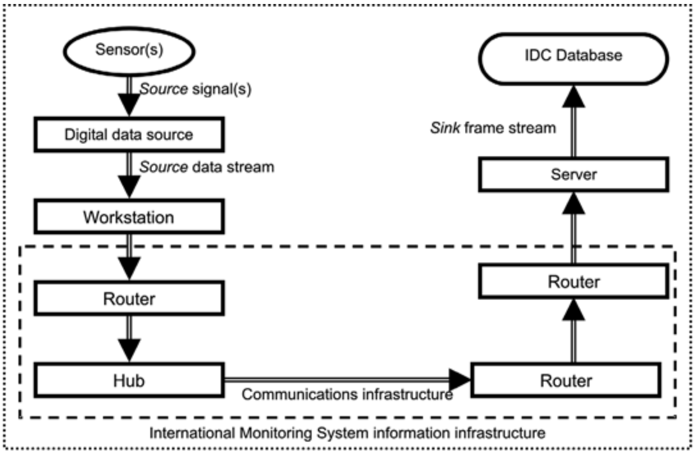


Fig. 10. Functional components of the data path between sensor(s) and the International Data Center database

ray until they are stored in the database of the International Data Center. Seismometer sensor arrays have, typically, 9-12 sensing elements. Consider the case where the analog output of each sensing element is sampled and quantized at a rate of 40 samples/second. Every 100 ms the streams of samples from all the elements of the array are combined to form a data subframe. To ensure the integrity of the information contained in each subframe an electronic signature is appended. Every 10 s the subframes are combined at the workstation into a data frame to which another electronic signature is appended. The resulting frame stream is transmitted via a communications infrastructure to the International Data Center where the frames are entered into a database and used to detect and locate seismic events. The sequence of signal transformations to form a frame is shown in Figure 11.

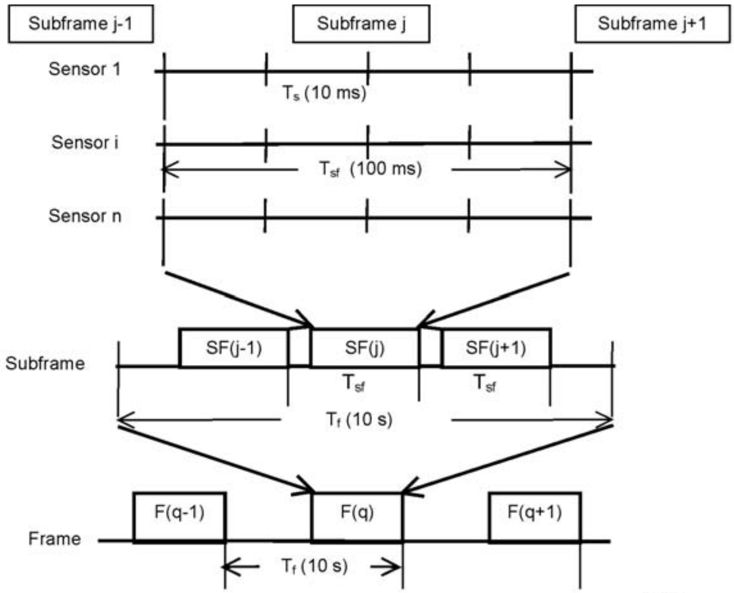


Fig. 11. Formation of application layer data frames from signal samples

Electronic signing is used to ensure that any violation of the integrity of the digitized sensor signals at the subframe level and above can be detected, while the information contained in the signals is available for anyone to read thus making the verification regime transparent. However, there is no mechanism for detecting violation of the signal integrity in the path between the analog sensor and the signing of the subframe. Physical protection of that section of the path can provide assurance that intrusion to violate the integrity intentionally can be detected. Within that segment of the path, the integrity of the signal can also be violated by equipment noise or malfunction of the sensing element. This type of problem is outside the realm of the data transport system and can only be addressed as a signal analysis issue.

The integrity of the transmitted information can be measured at three points of the data transport process, signal sample, subframe and frame. Figures 12, 13 and 14 show some possible patterns of corrupted samples, subframes and frames, respectively. The integrity of the information of the ith sensor is measured as the ratio of uncorrupted to corrupted samples over a specified time interval, in this case, the interval of a subframe, namely, 10 s. With some exceptions, such as spike noise, detection of a single corrupted sample in a sequence of uncorrupted ones is not an easy problem. On the other hand, a subframe is considered corrupted if the signature of the received subframe cannot be verified. As in the case of corrupted samples, the integrity of the information of the array for one subframe time interval can be measured as the ratio of uncorrupted to corrupted subframes over that interval. Similarly, the integrity of the information transmitted from a seismic station can be measured as the ratio of uncorrupted to corrupted frames as determined by the verification of the signature of the frames. The measurement of integrity can be refined by including the statistical distribution of errors at the three stages. For example, a pattern of alternating corrupted and uncorrupted samples may have less impact on the integrity of the information from a sensing element than a sequence of corrupted samples followed by a sequence of uncorrupted ones. What constitutes acceptable values of integrity at the three levels can be answered by analyzing the impact of these errors on the calculations for detecting, locating and classifying events.

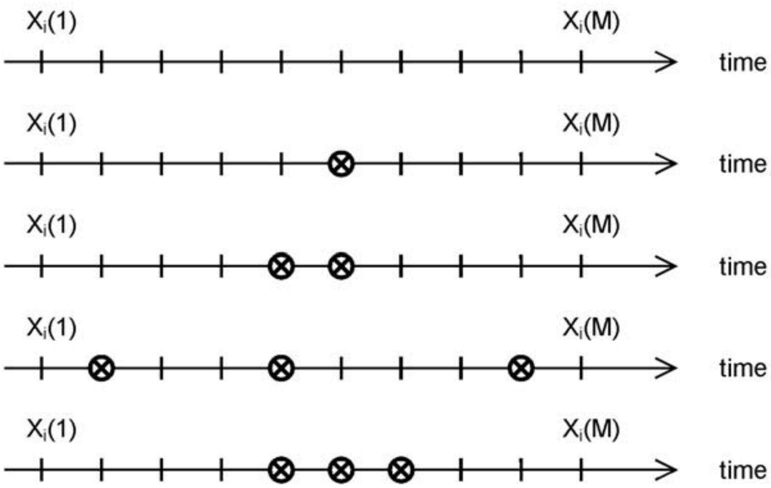


Fig. 12. Examples of temporal distribution of corrupted samples

For the information generated by the stations of the International Monitoring System, the questions of sufficiency and validity are moot, because the four types of monitoring stations and their locations have been, or should have been selected for their relevance to the verification regime and the adequacy of the information they generate for detecting and locating events and for discriminating between nuclear explosions and all other events. For other treaties, validity can become an issue. One of the functions of inspectors at facilities engaged in activities not prohibited by the Chemical Weapons Convention is analysis of samples using mass spectrometers. These instruments,

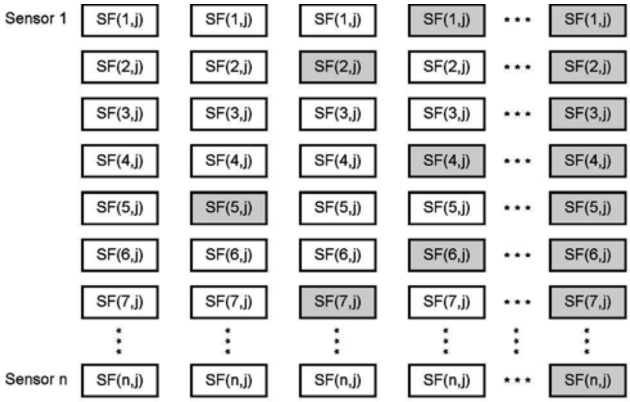


Fig. 13. Examples of spatial distribution of corrupted subframes (shaded) for a single frame time ranging for 0% to 100% error

however, can detect a broader range of substances than those covered by the convention. For the purpose of verification valid data are the spectra of only those substances which are subject to the verification provisions.

For this particular application, appropriate spectral filtering separates valid and invalid data. In general, for information generated by instruments validity can be ensured by proper design. Measuring validity and integrity is more challenging for information available in the public domain or provided by States Parties.

The measure of timeliness is related to the ability of the communication channel to transport a unit of information from a station to the International Data Center. At the application level, the unit of information is the data frame, because the event detection algorithms operate on the condition that the minimum length of transmitted signal segments is 10 seconds. At this level, timeliness can be measured in terms of the time it takes a signed frame to be transferred from the workstation at the station site to the database at the IDC. The elapsed time is measured by appending time stamps on each transmitted and received frame. One can then collect statistics of elapsed times for a frame sequence of specified length such as 24 hours, one week, one year, etc, and calculate the ratio of the frames received within a specified time window to the total number of transmitted frames for that period. If the verification regime imposes the more stringent requirement of specifying a minimum number of authenticated frames in order to reach a specified level of confidence in discriminating between nuclear explosions and other events, timeliness would need to be calculated by forming the ratio of the elapsed times for only those frames whose signature is verified.

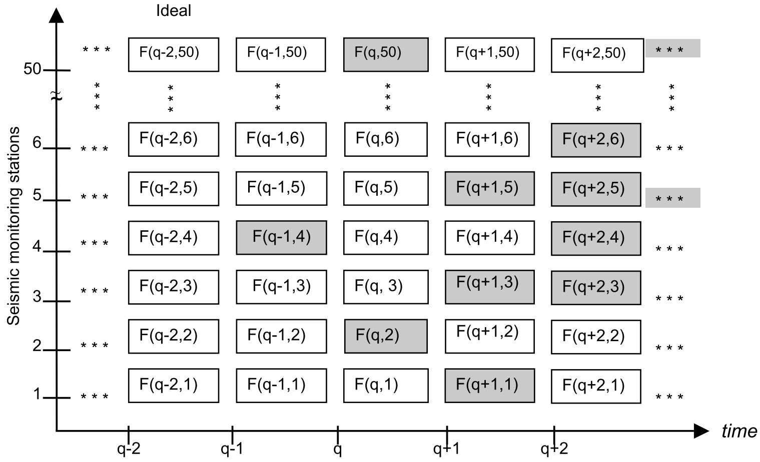


Fig. 14. Some examples of temporal and spatial distribution of corrupted frames

For sources generating data on a continuous basis, the data transport infrastructure must have enough capacity to handle the volume of information generated at each station. Equally important, the data throughput rate must be equal or greater than the source output rate. If throughput rate is defined at the application layer as the rate at which authenticated data frames must be transmitted in real time, the system needs to be designed to verify frame signatures on line. Frames failing authentication need to be re-transmitted. Figure 15 shows the functional decomposition of a path with the end point being the production of the first automated event bulletin. Other possible transport paths can be chosen depending on the intended uses within the infrastructure. For the purposes of this discussion, the information transport path begins at the source of the raw data and ends at the point where a frame with a verified signature is entered into the database of the International Data Center. One can then define quality of service at the application layer in terms of the ratio of authenticated frames entering the database to all generated frames over a specified time interval. For example, the signature of no fewer than 99% of all frames transmitted over each consecutive 24-hour period must be verified. Since the duration of each frame is 10 s, all the operations in the path need to be performed in less than 10 s, otherwise a queue will be formed at the source node. The task is to allocate efficiently the 10 s interval among the sequence of operations in the path. The two major components are the communications link and the in-line authenticator. In this particular case, the communications component does not present a problem, because the output data rate at the source is extremely low compared to the transmission rates achievable with existing technologies. The issue then is one of cost-effectiveness, i.e., determining the minimum transmission rate for the communications network required in order to maintain the desired quality of service. For this case, the problem although difficult, because the communications network comprises terrestrial and satellite networks, it is solvable. The broader challenge is to develop general metrics for specifying quality of service at the application layer and translating it into quality of service at the TCP layer. Translating quality of service at the TCP layer into performance specifications for the physical layer is a solvable problem. Similar reasoning can be used to develop performance specifications for the in-line authenticator. For each transport path, the signature authentication rate plus the channel transmission rate must be less than the frame generation rate. Since the channel transmission rate is higher relative to the frame generation rate, the dominant design parameter is the authenticator service time.

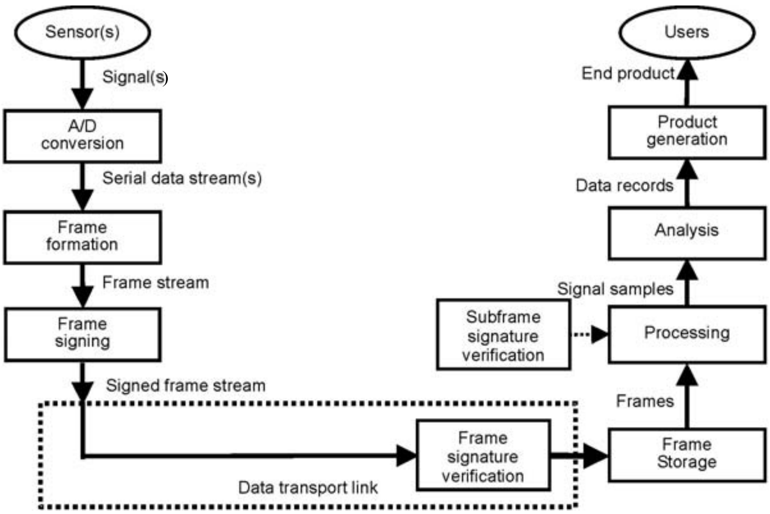


Fig. 15. Sequence of operations from signal source to end product for continuous data with in-line signature verification in real time

The logical and physical hierarchical decompositions create two sets of interconnected components. For each of these components to perform according to their associated service requirements so that the entire infrastructure will satisfy the application layer service requirements, their operations need to be coordinated through an infrastructure information management system. For the example at hand, the first level decomposition of such a system is shown in Figure 16.

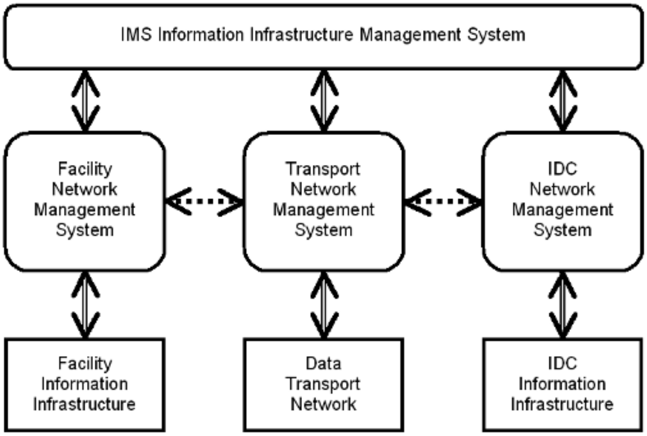


Fig. 16. A first layer decomposition for an information management system applied to the information infrastructure of the International Monitoring System (IMS) of the CTBT

6 Conclusion

The information infrastructures for arms control treaties are complex systems, because they are global and they generate outputs which may have major impact on the stability of the international security system. The information services they provide may make the difference between war and peace. Consequently, they need to be designed in such a manner that the quality of these services is commensurate with their importance. In this chapter we have identified the attributes of validity, sufficiency, integrity and timeliness to describe and measure the quality of the information services expected to be provided by a treaty information infrastructure. We have also presented the outline of a systematic approach for translating these service attributes into system design specifications. Essential to this approach is a properly designed infrastructure information management system. Without it one would never know whether or not the quality of services required by the treaty verification regime is, in effect, provided by the information infrastructure.

References

1. Geneva Protocol, (1925): *Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare*, Arms Control and Disarmament Agreements (1996 Edition), U. S. Arms Control and Disarmament Agency, Washington, DC, USA.
2. Comprehensive Nuclear-Test-Ban Treaty (CTBT), (1996): http://www.ctbto.org/treaty/treaty_text.pdf.

3. Japan Nuclear Cycle Development Institute (JNC); Joint Systems Analysis Studies of Near-Real-Time Accounting for a Mixed Oxide Fuel Fabrication Facility (JNC).
http://www.jnc.go.jp/kaihatu/hukaku/english/library/l-sg-coop-t3.htm
4. International Atomic Energy Agency (IAEA), (1997): *Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards.* INFCIRC/540 (corrected), IAEA, Vienna, Austria.
5. Bunn, Mathew (2004), "International Safeguards: Summarizing "traditional" and "New" Measures",
http://www.core.org.cn/NR/rdonlyres/Nuclear-Engineering/22-812JSpring2004/A88D2643-5744-4760-961C-D2859A1457A1/0/lec16notes.pdf
6. Chemical Weapons Convention (CWC), (1993): *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction*,
http://www.opcw.org/html/db/cwc/eng/cwc_frameset.html.
7. Lundin, S. J. (Ed), (1991): *Verification of Dual-use Chemicals under the Chemical Weapons Convention: The Case of Thiodiglycol*, (SIPRI Chemical and Biological Warfare Studies, no. 13), Oxford University Press, New York, N. Y., USA.
8. Halsall, Fred (1992): *Data Communications, Computer Networks and Open Systems*, 3^{rd} Edition, Addison-Wesley Publishing Company.
9. Kurose, James, F., K. W. Ross (2001): *Computer Networking: A Top-Down Approach Featuring the Internet*, Addison-Wesley.
10. Conventional Forces in Europe (CFE), (1990): *Treaty On Conventional Armed Forces In Europe*,
http://www.fas.org/nuke/control/cfe/text/cfe_t.htm
11. Internet Engineering Task Force (IETF) (1994): "Integrated Services in the Internet Architecture", IETF RFC 1633, June 1994.
12. Internet Engineering Task Force (IETF) (1998): "An Architecture for Differentiated Service", IETF RFC 2475, December 1998.
13. Jacobs, Philip, B. Davies (2005): "Technical Challenges in the Delivery of Interprovider QoS", *IEEE Communications Magazine*, June 2005, pp. 112 -118.

The International Level

Dirk Schriefer

1 Introduction

After the experience in Iraq in 1991 and with the difficulties verifying the initial nuclear material inventory for the Democratic People's Republic of Korea, the International Atomic Energy Agency (IAEA) recognized that additional steps were necessary to strengthen its safeguards system. Clearly, the interpretation of comprehensive safeguards agreements (based on INFCIRC/153 Corr. [1]) until that time was focused almost entirely on the verification of nuclear material, its accounting practices and inspections restricted to key measurement points only.

In the years after the revelation of Iraq's nuclear programme, the Agency's Board of Governors approved a number of new measures, as proposed by the IAEA Secretariat. There was little time to loose, and these measures were implemented speedily. One of them concerned the use of additional information, which, until then, was deemed to uncertain and unfocussed.

In 1993, "Programme 93+2" [2], the forerunner of the Additional Protocol, tasked IAEA staff to produce and test concrete and substantial strengthening measures, beyond the very early reactive measures. The Safeguards Department immediately undertook to determine the value of information from open sources, by systematically investigating what would constitute valuable information toward the safeguards goal. Hence, a group of staff began looking at what could serve as indicators relevant to early signs of States' interest in proscribed activities ("proliferation indicators").

When overhead imagery became commercially available, about a year later, and based on recommendations by the Standing Advisory Group on Safeguards Implementation (SAGSI), the Department began investigating the feasibility and usefulness of satellite imagery in support of IAEA safeguards verification. Satellite imagery became gradually, and with a great deal of help from Member States through their Safeguards Support Programmes and extra-budgetary funding, a regular safeguards tool.

In October 1997, the IAEA General Conference endorsed the Model Additional Protocol [3] as approved by the IAEA's Board of Governors in May 1997.

Currently (as of March 2005), the IAEA has 138 Member States; the NPT has 189 Contracting Parties, and there are 145 comprehensive safeguards agreements with 67 additional protocols in force (or otherwise applied).

2 Information for IAEA Safeguards

2.1 Comprehensive Safeguards Agreements: INFCIRC/153 Requirements

States entering into a comprehensive safeguards agreement, usually referred to as INFCIRC/153-type, with the Agency undertake to accept safeguards "on all source and special fissionable material in all peaceful nuclear activities within its territory, under its jurisdiction or carried out under its control anywhere " The acceptance of safeguards includes *declarations* of nuclear facilities and materials, and its inventories and flows; it also includes *access to facilities and nuclear material* for the purpose of verification by designated IAEA safeguards inspectors. Moreover, the States declarations must include *design, construction and operating details* of nuclear facilities, which will be verified by Agency inspectors in order to ascertain that the declared use and process quantities remain in accordance with the declarations.

As a result of this process, there is a multitude of information available to draw conclusions from, the main one under the comprehensive safeguards agreements being that no diversion of nuclear material has occurred.

While there are other safeguards agreements, which the Agency implements (INFCIRC/66-type and voluntary offer agreements), these all have a much more limited objective. For these agreements the undertaking is to ensure that (usually a limited set of) nuclear facilities, materials, services, equipment subject to safeguards are used in accordance with these agreements. These agreements are in force in the five nuclear weapon States recognized by the NPT, namely China, France, Russia, the United Kingdom and the United States (voluntary offer safeguards agreements) and the three States that have not accepted international safeguards subsequent to the NPT: India, Israel and Pakistan.

Of course, declared information under a safeguards agreement will be verified by IAEA safeguards inspectors. The verifications will provide data confirming the declarations (or not !) in many different ways, mostly in an indirect way, using radiation measurements and sampling on different strata, or using sealing techniques in a stable containment, and surveillance methods or radiation and motion detection - whatever is appropriate. All these techniques and technologies provide additional information to be interpreted, related and accumulated to enable the Agency to draw a conclusive statement about the declared nuclear material at facilities in a State.

2.2 Strengthening of IAEA Safeguards

As a result of missing links to detect the Iraqi nuclear programme, Member States agreed to provide additional information to the IAEA Secretariat to enable it to more effective analyze information relating to activities related to the nuclear programme. The Agency's Board of Governors authorized already in November 1991 [4] that "information may be obtained outside the safeguards system that suggests the possible existence of undeclared material or facilities in a State subject to a comprehensive safeguards agreement." At that time the Board also reconfirmed the Agency's right to "conduct special inspections" in accordance with paragraphs 73 and 77 of INFCIRC/153 and the value of the early provision of design information for nuclear facilities. In May 1992, the Board authorized the Agency to receive information from States on exports and imports of relevant equipment and non-nuclear materials [5].

In early 1993 SAGSI reported its findings on the use of additional information, e.g., results from environmental sampling, unattended surveillance and measurement systems, increased cooperation with States' systems, and access to and analysis "of all the available information on nuclear matters, including the information it obtains from Member States as a result of recent Board decisions" [6]. In November 1993 the Agency proposed Programme 93+2 and started implementation of those strengthening measures [2]. In 1997, the Additional Protocol [7, 3] replaced many of these measures (not quite all). At about the same time (early 1997) The Agency Secretariat assured States about the treatment of confidential safeguards information [8].

In addition to these new measures, which provided substantial additional data, there were other accompanying steps taken by Member States, a number of them as voluntary transparency measures, e.g., the reporting of policies (and annual amounts) regarding national holdings of separated plutonium in 1998 [9], the reporting (and related flow sheet verification) of neptunium and americium in 1998 [10] and the issues related to illicit trafficking with nuclear (and radioactive) material [11] and the strengthening of physical protection of nuclear materials [12]. Similarly, the guidelines by the Nuclear Suppliers Group first communicated to all IAEA Member States in 1978 [13] contributed to the definition of the annexes in the Additional Protocol in 1997, and, hence, to the overall strengthening process of the safeguards system.

2.3 The Additional Protocol: INFCIRC/540 Requirements

By February 2005, 90 States have signed the Additional Protocol; it has entered into force in 64 States. The Additional Protocol requests States to report to the Agency material, equipments and other items beyond nuclear material.

While the Protocol provides also for more physical access to IAEA inspectors, here we shall focus on the additional information it requires States to provide to the IAEA. It is essentially Article 2, which describes the type and quality of the new and additional reporting obligations, which States undertake when they sign up to the Additional Protocol. Article 3 describes the frequency with which the information is to be provided to the Agency.

Article 2.a.(i) calls for a general description of and information about the nuclear fuel cycle related R&D activities, which do not involve nuclear material. Article 2.a.(ii) provides an opportunity for the Agency to request information on operational activities of safeguards relevance at facilities and locations outside (nuclear) facilities (LOFs) where nuclear material is customarily present. Article 2.a.(iii) calls for a general description of each building on each site, including its use and, if necessary, its contents; a map of the site indicating details is to be included. Article 2.a.(iv) requests details of the scale of operations for each of the locations engaged in activities specified in Annex I of the Protocol. Article 2.a.(v) addresses the estimated annual production capacity of uranium (and thorium) mines and (usually co-located) concentration plants. In Article 2.a.(vi) source material not yet subject to the application of safeguards is addressed. Article 2.a.(vii) addresses nuclear material exempted from safeguards, its quantities, its use and its locations. The location or further processing of intermediate and high-level nuclear waste containing plutonium, highly-enriched uranium or uranium 233 is addressed in Article 2.a.(viii). Article 2.a.(ix) requires information on exports of items in Annex II of the Protocol and, upon a specific request by the Agency, on imports of such items. Finally, Article 2.a.(x) asks for the State's plans relevant to the development of the nuclear fuel cycle for the next ten-year period.

Article 2.b.(i) is similar to the requirements for information as in 2.a.(i); however, the information is limited to R&D in enrichment and reprocessing relevant activities by non-governmental entities. Article 2.b.(ii) does not require a declaration per se but calls for information to be provided upon request by the Agency about specific activities at locations to be specified by the Agency.

Article 2.c calls on the State to provide clarifications and amplifications upon the request by the Agency on any of the State's information provided. This is to ensure to facilitate implementation of the Additional Protocol and to assist the correct understanding, by the Agency, of the information provided by the State.

Article 3 defines the reporting deadlines for the declarations: 180 days after entry into force of the Protocol and updates each year by 15 May, for exports of certain equipment every quarter.

Article 4 (Complementary Access) stipulates that the Agency "shall not mechanistically or systematically seek to verify the information referred to in Article 2". However, complementary access is provided to the Agency inspectors to "sites", in order to perform certain activities as described in the protocol. These activities produce an essential set of information, which contribute substantially to the drawing of conclusions about the absence of undeclared nuclear material or activities in that State.

2.4 Integrated Safeguards

Integrated Safeguards can be implemented for a State only once the IAEA was able to draw the conclusion that *all nuclear material and all nuclear activities* in that State are under IAEA safeguards and remain in peaceful nuclear activities. In addition, the fulfillment of all other requirements from the Additional Protocol are necessary to "qualify" for integrated safeguards.

The aim of integrated safeguards is to provide the most efficient means to realize the full effectiveness of the strengthened safeguards system [14]. Given the additional assurances provided under an additional protocol, the need to avoid undue burden on States and facility operators, and the need for maximum efficiency in the light of the prevailing resource constraints, the new measures were to be integrated with existing ones. Effectiveness and efficiency have therefore each been given full consideration as approaches for integrated safeguards have been developed.

Integrated safeguards refers to the optimum combination of all safeguards measures available to the Agency under comprehensive safeguards agreements and additional protocols. The process of defining the optimum combination of all safeguards measures is being carried out on a non-discriminatory basis for all States that have comprehensive safeguards agreements and additional protocols in force. The integrated safeguards approach for a State sets out the safeguards measures applied in the State, including the general level and focus of complementary access activities to be conducted.

The objective of the measures and activities is for the IAEA to obtain sufficient information to be able to *draw conclusions on both the non-diversion of declared material ("correctness") and on the absence of undeclared nuclear material and activities ("completeness")* in the State. To meet this objective, an integrated safeguards approach is designed specifically for each State; it includes the State-specific features and characteristics, details for the application of safeguards at specific facilities and a plan for the implementation of complementary access at sites and other locations.

Under a comprehensive safeguards agreement with an additional protocol, the IAEA's ability to provide assurance of the absence of undeclared activities reduces the possibility that they may exist undetected. It therefore creates the potential for changes in the implementation parameters and reductions in verification effort for declared nuclear material. A positive conclusion of the absence of undeclared nuclear material and activities in a State-as-a-whole is a pre-requisite for the application of integrated safeguards. Comprehensive collection and evaluation of information for the State plays a key role in establishing and planning the activities to be implemented in the State. The ability, for the Agency, to continue to draw a positive conclusion about the absence of undeclared nuclear material and activities is an essential element and must be maintained under integrated safeguards by continuous and comprehensive information review and evaluation.

3 Information Assessment

3.1 Information on States-as-a-Whole and Its Evaluation

The assessment of the completeness and correctness of all information provided by a State party to a comprehensive safeguards agreement is the crucial measure to determine, whether integrated safeguards may be applied in this State. For this activity the existence of a "well performing" additional protocol is a pre-requisite. No major inconsistencies between declarations and all other information are permitted. For a comprehensive picture about the completeness of a State's declaration it is necessary to take a holistic picture of the State, considering all relevant aspects related to the State's safeguards undertaking. All relevant information is evaluated.

Cooperation between the Agency and the State is a pre-requisite for a meaningful implementation of international safeguards generally, but this is particularly the case for the implementation of additional protocols. Implementation of obligations under the additional protocol aims to provide a higher degree of assurances for the absence of undeclared nuclear material and activities, or the completeness of a State's declaration [15]. As an example, the level of cooperation between South Africa and the IAEA and, on the other hand, between the DPRK and the IAEA in the 1990's is frequently quoted.

For the evaluation of all available information for a State, there will be a consideration of all information relating to activities at nuclear facilities, primarily the inventories and flows of nuclear material. This consideration is based on characteristics of the nuclear fuel cycle components in a State, with special emphasis on enrichment and reprocessing. It is dependent on the amounts and types of nuclear material - and on the processing capacities and capabilities in the State. The resolution of inconsistencies and anomalous results is essential. Then, for the correctness of a State's declaration, the balance of material is considered at the facility level, then facility by facility, and, eventually, for the State-as-a-whole.

For the implementation of international safeguards under comprehensive safeguards agreements (without additional protocol in force), the planning and assessment of the non-diversion of nuclear material, a set of criteria is used to define the level of goal attainment for each nuclear facility. These criteria set out the frequency and intensity of inspections. They are based on the type of material and facility within the nuclear fuel cycle (Figure 1). The level of goal attainment reflects the Agency's capability to verify the declared quantities of nuclear material within a given timeframe (timeliness). These activities are based on the detection of a significant quantity ([1], paragraph 28) and to detect undeclared activities at declared facilities.

Under the strengthened safeguards regime, i.e. since Programme 1993+2 [2], the evaluation of safeguards information has been broadened to the State-level. Nuclear material flow and inventories are maintained and evaluated across the State, as are results from environmental sampling. The consistency of nuclear-related R&D work is compared with fuel cycle activities in the State; the history of anomalies, i.e., anomalous events in the course of safeguarding a nuclear facility, is considered over a long time period. Likewise, evaluations of material balances are established over time, to avoid leaving unacceptable trends undiscovered. The quality of State declarations, and their timeliness, plus the response to requests for further detail or clarifications are evaluated. It is important that the State meets all its undertakings for safeguards physical accesses (inspections, complementary accesses, visits, etc.).

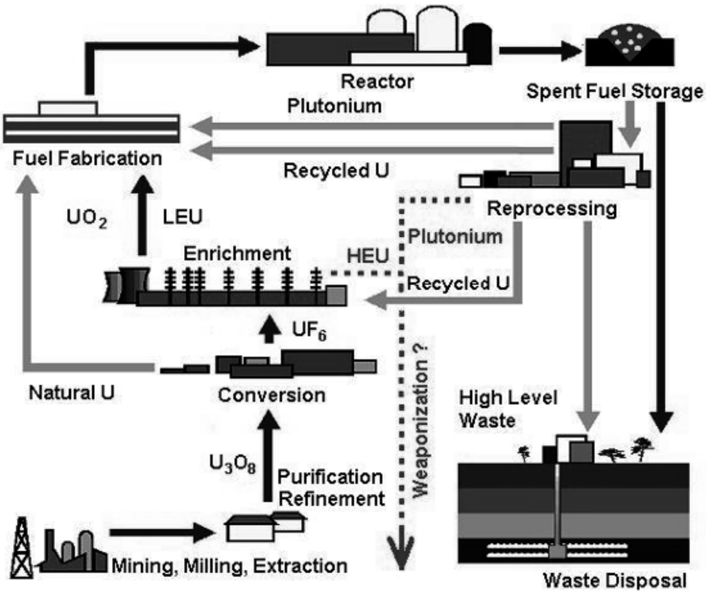


Fig. 1. Nuclear Fuel Cycle

Safeguards information on States has been traditionally presented to the Agency Board of Governors every June for the previous year. Since implementation of the additional protocol had taken place in the first States, the evaluation process of all information collected for States with comprehensive safeguards agreements has changed significantly. All information available to the Agency is considered in the process, be it States' declarations, information from verification activities, visits or complementary access, from open source, third parties or satellite imagery, and conclusions are drawn that "the nuclear material and other items placed under safeguards remained in peaceful nuclear activities or was otherwise adequately accounted for" - for States with a comprehensive safeguards agreement in force, but not an additional protocol - or that there was "no indication of the diversion of nuclear material placed under safeguards and no indication of undeclared nuclear material or activities" - for States that also have an additional protocol in force and the Agency has established sufficient information to make such a statement [17].

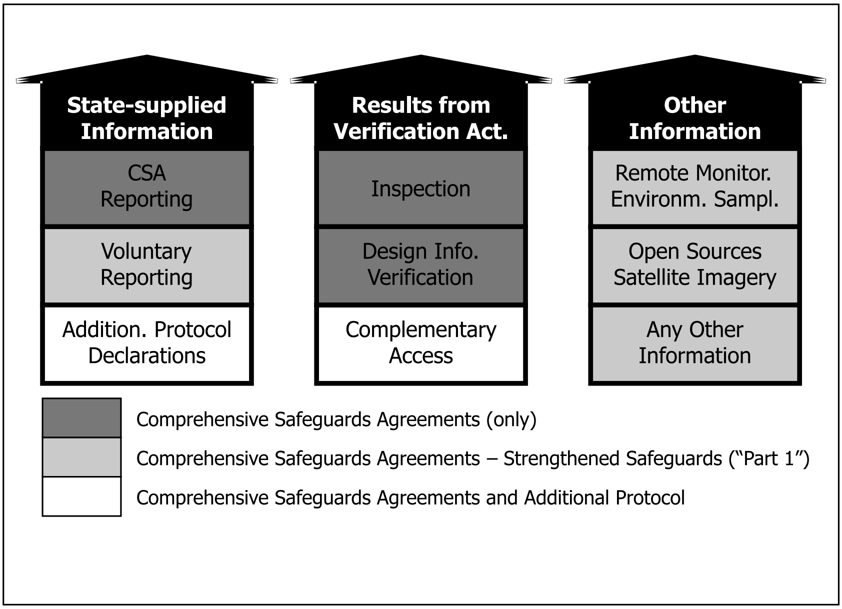


Fig. 2. Information of States as a Whole

For this assessment all information sources are being used: State-declared, inspection-generated, open sources and overhead imagery (Figure 2).

Declarations and other Information from States include the following:

1. Based on safeguards agreements, nuclear accounting reports and information from facility designs, as reported by States, are included;
2. Declarations under the Additional Protocol;
3. Reports transmitted to the Agency under the Universal (or Voluntary) Reporting Scheme [5];
4. Communications from States regarding their plutonium management policies and holdings of separated plutonium [9]; and
5. Reports on neptunium and americium [10].

Safeguards Information or inspection-generated information includes:

1. Reports on nuclear material from inspections and design information verification visits;
2. Results from measurements (e.g., non-destructive assay, material sampling, data from seals, surveillance and other devices, swipe sampling);

3. Reports from complementary accesses under the Additional Protocol; and
4. Results from inspectors' interactions with State and facility operator staff, and their field observations

3.2 Proliferation Indicators and the Physical Model

In the early 90's, shortly after the first strengthening measures were approved by the Agency's Board of Governors, the Safeguards Department constituted a small group of senior staff in the Department to look into what could serve as early indicators for nuclear proliferation. This was to help safeguards to find early possible signs of activities in States which might not be in agreement with the State's safeguards undertaking. Based on this set of indicators, which went through a number of significant improvements over the years, staff started to analyze safeguards-relevant information open sources, media, trade magazines, etc., to search for these indicators, so as to provide additional information for possible follow-up action.

During the implementation of Programme 93+2 a model for the evaluation of all available information was developed, which up to now is still called the "physical model". It attempts to describe in a very concise way the steps necessary to produce weapons-usable fissile material. It has two parts, one for the plutonium and, another, for the uranium route, from ore mining to the conversion of plutonium or highly-enriched uranium (HEU) metal.

These routes include mining, milling, conversion to forms suitable for enrichment (e.g., UCl4, UF6), or to uranium oxide or metal, then enrichment to HEU using any of the known technologies, and final conversion to metal; for plutonium production it includes fuel fabrication either for use in power or research reactors or in critical assemblies to produce suitable plutonium in sufficient amounts and qualities, facilities for storing the irradiated fuel and reprocessing, and, again, finally the production of plutonium metal. Storage facilities for waste and disposal are included. All stages of the model have a set of possible indicators attached. During the generation of a physical model for a State, facilities declared by the State are marked in a way to be able to distinguish production facilities from installations of research-scale only. In the process of examining all relevant information pertaining to the fuel cycle of a State, all elements pertaining to these facilities must be confirmed by the details of the State's declarations. Information found that cannot be associated with any of the declared facilities, give rise to further work and require clarification (Figure 3). The physical model has undergone many development steps. At the end of 2004, the model includes over 300 main indicators and search terms; more detailed indicators are available for refined analyses. The model is reviewed at least once per year, and it is adjusted to new safeguards requirements as necessary.

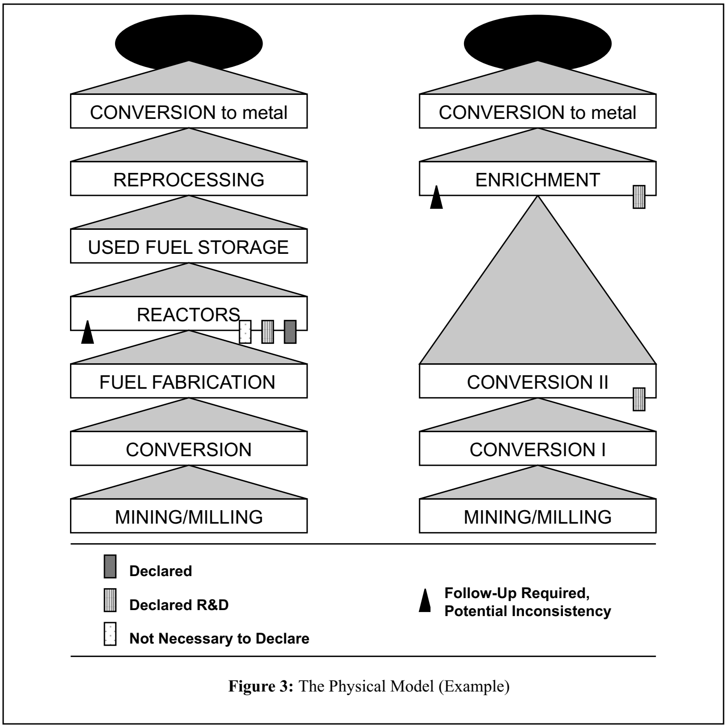


Fig. 3. The Physical Model (Example)

3.3 Trafficking in Nuclear Material

Since the early nineties, shortly after the break-up of the USSR, a sharp increase could be observed of incidents where persons, without appropriate authorization, removed radioactive and nuclear material from their designated locations. The motive was in many cases to sell the material, in other cases it may have been an inadvertent, but unauthorized, removal. At first sight, it may never be excluded that such removal may be used to harm other people, unintentionally or on purpose. For any State authority it appears necessary to follow-up on such cases, for States with a safeguards agreement the involvement of nuclear material requires a response, including the reporting of the movement of nuclear material to the Agency in a timely fashion.

In many cases media reported on such incidents first, sometimes wrongly. Based on requests from States, in 1993 the Agency started to collect information of such incidents in an illicit trafficking database. Since then, a regime has been established which enables the Agency to contact States for confirmation and more details of trafficking incidents. The readiness and ability of a State to respond to such an Agency request for further information has become another parameter in the evaluation information for that State.

Between 1993 and the beginning of 2004 the Agency registered 540 confirmed incidents of trafficking in both nuclear and other radioactive materials, 182 involved nuclear materials, approximately two thirds of which relating to natural or depleted uranium, or thorium. Several hundred additional incidents have been reported in open sources, but not confirmed by States. The Agency's Department of Safety and Security provides more details on all trafficking incidents [18]. The database is operated and maintained by the Department of Safeguards.

4 Open Source Information: Collection and Analysis

The objective to collect information beyond State-declared information and information generated from safeguards inspection-related activities is to provide both safeguards and Agency managers and other staff involved in safeguards verification activities with relevant complementary information.

With the collection and analysis of open (and other) sources the following tasks have been defined:

1. Establishment, maintenance and operation of the *Open Source Information System*, a computer-based system to store and retrieve formatted and unformatted information, its associated software, including tools supporting the work of information analysts, and the related training of staff;
2. The *compilation and maintenance of state portfolios*, relevant to safeguards assessments of States-as-a-whole and to participate in the State evaluation process;
3. The preparation, upon authorized requests, of *ad-hoc reports* on safeguards-relevant subjects, based on open source information;
4. The regular provision of *Open Source Highlights*, an e-mail news service, to IAEA internal only subscribers of daily safeguards and nuclear highlights; and
5. The operation of the *Agency's Illicit Trafficking Database* and the preparation and distribution of quarterly status reports within the Agency and to participating States.

The main purpose is to provide additional information to be able to determine that no inconsistencies remain during the State evaluation process, or that, in case of inconsistencies, follow-up activities for their resolution can be prepared.

It needs to be emphasized that analytical information must be protected; such information is regarded as confidential as any other detailed safeguards information [8].

4.1 Types of Information

During the comprehensive analysis the following types of information are considered: Declarations and other Information from States, Safeguards Information, IAEA information, open source and satellite imagery information.

IAEA Information describes all other information available inside the Agency, particularly information that is collected in other departments. Examples are:

1. Power Reactor Information System (PRIS);
2. Research Reactor Database (RRDB);
3. International Nuclear Information System (INIS);
4. Nuclear Fuel Cycle Information System;
5. Net Enabled Waste Management Database (NEWMDB);
6. Nuclear Data Services;
7. Requests and reports for technical assistance;
8. Fact sheets and country files compiled in the IAEA; and
9. IAEA staff travel reports.

Access to some of these databases is available to subscribers. Further information is available in [19].

Open Sources

1. Government and other official databases and publications; documentation from owners and operators of nuclear facilities;
2. Scientific and technical databases and related literature;
3. Specialized trade and export publications;
4. Publications from research and academic institutions;
5. Reports and material collected from non-governmental organizations;
6. Media and news reports from newspapers and magazines, radio and television stations;
7. Internet sources;
8. Commercial satellite imagery (see below); and
9. Other databases and publications, including information from other States and organizations.

Satellite Imagery is obtained, under contract, from commercial providers upon authorized request only, in order to

1. Determine the operational status of facilities or their parts, or to follow the progress of construction work - for declared nuclear facilities or sites;
2. Assist in the analyses of States' declarations during inspectors' preparations for specific inspections, facility design information verification exercises or complementary accesses; and
3. Monitor locations of interest or concern that were reported in open or other sources.

The use of an independent satellite imagery analysis capability has become desirable in the context of strengthening safeguards, after the experience with Iraq and, particularly, North Korea. Experimental use started soon; extra-budgetary funding was necessary to provide initially staff, workstations and imagery. In early 2002 a satellite imagery laboratory was finally set-up and integrated into the open source organization. Plans and initial results were reported in [20]. It took until 2004/2005 to provide regular budget funds for the laboratory, so that most imagery can now be purchased without extra-budgetary funds.

Overhead imagery has become a very much sought after complementary information source, which is open - as it comes from commercially available sources - yet more convincing and assuring than other open source information [22]. To understand and fathom the power of satellite imagery, see the examples published by Global Security using images of the enrichment plant at Natanz, Iran, both from Space Imaging, Middle East (Figure 4), dated 20 September 2002 and 29 February 2004 (below).

4.2 Collecting Information

Open sources accessed regularly include commercial new services, e.g., *Factiva*, which accesses 8,000 sources from 118 countries around the world, in 22 languages. It includes the BBC Monitoring Service, about 120 newswire services (Reuters, Dow Jones, AP, Itar Tass, etc.), many newspapers (Wall Street Journal, New York Times, Washington Post, Financial Times, The Globe and Mail, Handelsblatt, Les Echos, Straits Times, South China Morning Post, Sydney Morning Herald, Yomiuri Shimbun, etc.), magazines (The Economist, Fortune, Time, Newsweek, Finanz und Wirtschaft, Satellite News, etc.). Additional news media are available through *Lexis-Nexis*; it provides access to approximately 30,000 news, business and legal sources. Open source analysts have access to the *Foreign Broadcast Information System*, which is a world-wide monitoring system of TV reports, radio broadcasts, newspaper articles, and science and technology reports, with translations into English.

A number of *internet* sites are selected for daily review; this may vary slightly as relevant news change, new sites are discovered and current sources change coverage. Regular reviews of sites maintained by non-governmental organizations with non-proliferation interests take place. For ad-hoc requests internet sites of universities and their institutes, as well as research centres are searched to clarify specific questions.

From a number of sources certain information is loaded regularly into the Open Source Information System. This includes the Center for Nonproliferation Studies (www.miis.edu) and, among others, regional information provided by organizations in Russia (Kurchatov Institute, www.kiae.ru), the United Kingdom (King's College London, www.kcl.ac.uk), Japan (NMCC, www.jnmcc.or.jp in Japanese) and South Korea (KAERI Institute, www.kaeri.re.kr/english).

Fig. 4. Enrichment Plant at Natanz, Iran. Date: 20 September 2002 (top) Date: 29 September 2004 (bottom)

The *quality of open source information* depends on a number of factors, which are considered before using the information in a document to be passed on to any "end user" (Figure 5). How old is the information? Is it a recent update? Does it include recent information or is it reporting on historical facts? Is the entire text available or only in the form of an abstract or summary? In the latter case, is there a reference to the original document?

The *scope of open sources* may vary between direct focus on specific subjects and diffuse coverage of various subjects. Open source may provide a wide *spectrum of insight*; it may give facts about a very specific event or provide analytical opinion and suggestions for further investigations. Both may be useful. Sources may lie on a spectrum between general description and in-depth analysis. It is of particular interest for follow-up actions in safeguards that details are given (that can be verified) such as names of places and persons, times, background and technical details.

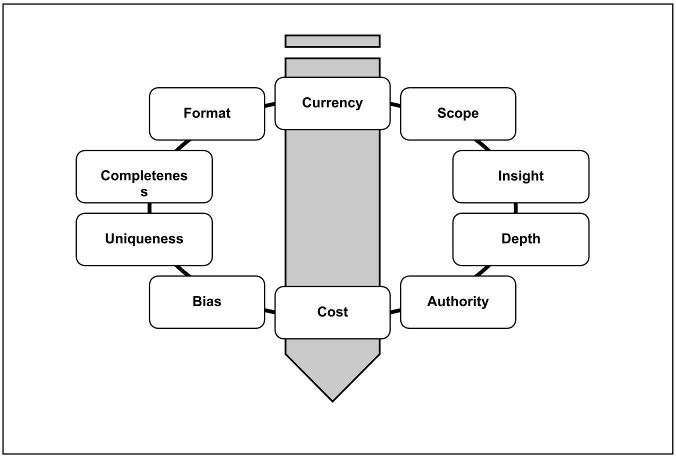


Fig. 5. Quality of Open Source Information

When *selecting new sources*, a choice may have to be made between sources easy to assimilate and others that require extensive work to utilize. The c*ost of making proper use* of a source may not only be defined by it purchase price, the source may be in a format or language difficult to use. It may have other restrictions attached, as, e.g., export constraints, or be generally complex and difficult, and "expensive in time" to navigate. Is a source *original and unique*, or does it generally tend to copy or report from other sources? If original, is the author cited? Is the method of investigation available? Are references complete? It is good practice to obtain, if feasible, the original source, as re-writes often take on their own facts and flavours, and conclusions. *Credibility and authority* are important factors for the quality of a source; authors should be well known and established experts in their area of reporting. Are they solidly well-informed, or are they just sensationalists? A bias - to deliver a predisposed point of view - is an attribute for many authors. It needs to be recognized; a biased article may still be useful, provided the reader is aware of the bias.

4.3 Analysis and Presentation of Open Source Information

As discussed earlier, the most important application of open source information is the assessment of a State-as-a-whole situation, in preparation of the annual Safeguards Implementation Report, as part of a State Evaluation Report, and in the form of ad-hoc report, which may deal with specific topics. Generally, the delivery of products from open source collection and analysis comes in the form of a report [21]. This will normally include geographic information in the form of maps and other suitable information in the form of tables, diagrams or pictures obtained from the sources.

The presentation of regular news flashes, as is currently done with the daily e-mail distribution of Open Source Highlights and weekly Illicit Trafficking Open Source News to internal subscribers is a much appreciated means of maintaining currency. Due to the recent developments, additional information is available in a similar way: daily Iran News and weekly Developments in East Asia, the latter attempting to provide up-to-date news on the situation in DPRK and other developments in Far East Asia. These may change as the situation and the demand for latest news changes. New regions may be covered with more effort, should this become necessary.

New tools are necessary to improve the speedy assimilation of results: more visualization and better graphical and integrated presentation of complex situations are required. Access to information in certain regional areas and languages may be improved upon. Software systems to help the trained analyst develop connections between relevant facts faster and easier, tools to extend his memory and simplify conclusions are required. Some of these systems may be available, but need to be simplified and adaptated, require more testing and training.

5 Resource Implications

Over the years, as work on open source information developed, staff with analytical training and experience was recruited. This happened in many instances only at the cost of other activities. Prioritization on the changing requirements from the strengthening of the safeguards regime made such changes inevitable. Today, the number of professional analysts is still small, and there is a clear need to expand the activities further. It is in step with the changes of the requirements of international safeguards - from nuclear material verification, to the larger scope of forward looking and examining signs which may indicate negative changes in States' readiness to comply fully with their undertakings from safeguards agreements. This will require the number of staff engaged in analytical safeguards work to grow, in order to be able to satisfy the requests for information analysis in support of safeguards implementation. The demand for satellite imagery analysis products has increased to such a level, that recruitment of staff over the next few years may see the doubling of the current staffing level.

Likewise, equipment and computer systems to support these activities will increase, both for professional analysts and for safeguards inspectors to engage productively in more information related tasks.

6 Future Developments

With the expected continuation of changes to increasingly information-driven processes in international safeguards, growth in analytical support appears to be natural and inevitable. As a prerequisite, only the highest standards of information safety and security will permit this continued growth. The introduction of new technologies, equipment and software systems will help. For success their value and robustness must be demonstrated. Recognized industry standards and the use of commercially proven systems, where available, will be a key objective for an efficient utilization of staff and financial resources.

Further developments of the international safeguards system will require the broadening of the scope of open source collection and analysis, they will also strengthen the need for more capacity for analytical products related to geospatial and other information.

New challenges will come from the "nuclear black market" issue, recently disclosed, where only parts of components for nuclear-related equipment are manufactured in one location, shipped along to another location, via different routes, until they may be turned into equipment or plants which will require reporting under safeguards agreements. The necessary technology appears to be available in many places. The "globalization of markets" is happening here, too.

Attempts of acquisition of nuclear weapons-capable materials by terrorists or other sub-national groups must be prevented at all cost. The strengthening of following all illicit activities involving nuclear materials is a priority task; the recognition of indicators to acquire or produce undeclared nuclear material, facilities or technology must proceed with high priority.

References

1. IAEA, (1972): INFCIRC/153 (Corr.): The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, June.
2. IAEA, (1995): GOV/2689: Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System: Report by the Director General on the Secretariat's Programme for Assessment, Development and Testing of SAGSI's Recommendations on the Implementation of Safeguards, 3 November 1993, and GOV/2784: Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System: A Report by the Director General, 21 February 1995 ("Programme 93+2"), and GOV/2807: Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System: Proposals for a Strengthened and More Efficient Safeguards System, 12 May.
3. IAEA, (1997): INFCIRC/540: Model Protocol Additional to the Agreements between States and the International Atomic Energy Agency for the Application of Safeguards, 15 May.

4. IAEA, (1992): GOV/2554: Strengthening of Agency Safeguards: 1. Special Inspections, 2. The Provision and Use of Design Information, 12 November 1991, and GOV/2554/Attachment 2/Rev. 1: Strengthening of Agency Safeguards: The Provision and Use of Design Information, 20 January 1992, and GOV/2554/Attachment 2/Rev. 2: Strengthening of Agency Safeguards: The Provision and Use of Design Information, 1 April.
5. IAEA, (1996): GOV/2589: Strengthening of Agency Safeguards: Universal Reporting of Exports and Imports of Certain Equipment and Non-Nuclear Material for Peaceful Nuclear Purposes, 18 May 1992 ("Universal Reporting Scheme"), and GOV/2629: Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System: Universal Reporting System on Nuclear Material and Specified Equipment and Non-Nuclear Material, 22 January 1993, and GOV/2767: Safeguards: Proposed Amendments to the List Being Used for the Reporting Scheme Endorsed by the Board of Governors, 19 October 1994, and GOV/2842: Safeguards: Proposed Amendments to the List Being Used for the Reporting Scheme Endorsed by the Board of Governors, 14 February 1996, and GOV/2842/Corr. 1: Safeguards: Proposed Amendments to the List Being Used for the Reporting Scheme Endorsed by the Board of Governors, 15 March.
6. IAEA, (1993): GOV/2657: Strengthening the Effectiveness and Efficiency of the Safeguards System: Report by the Director General on SAGSI's Re-Examination of Safeguards Implementation, 14 May.
7. IAEA, (1997): GOV/2885: Report to the Board of Governors by the Committee on the Strengthening the Effectiveness and Efficiency of the Safeguards System (COM.24) on its Second Session, 23 October 1996, and GOV/2893: Report to the Board of Governors by the Committee on the Strengthening the Effectiveness and Efficiency of the Safeguards System (COM.24) on its Third Session, 6 February 1997, and GOV/2914: Report of Committee on the Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System (Committee 24) to the Board of Governors, 10 April, ("Additional Protocol").
8. IAEA, (1997): GOV/2897: Safeguards: The Agency's Regime for the Protection of Safeguards Confidential Information, 13 February 1997, and GOV/2959: Safeguards: The Agency's Regime for the Protection of Safeguards Confidential Information, 14 November.
9. IAEA INFCIRC/549: Communication Received from Certain Member States Concerning Their Policies Regarding the Management of Plutonium, March 1998
10. IAEA, (1998): GOV/1998/61: The Proliferation Potential of Neptunium and Americium, October 1998, and GOV/1998/61/Corr. 1: The Proliferation Potential of Neptunium and Americium, November.
11. IAEA, (1995): GOV/2773: Measures Against Illicit Trafficking in Nuclear Materials and Other Radioactive Sources, 24 November 1994, IAEA GOV/2773/Add. 1: Measures Against Illicit Trafficking in Nuclear Materials and Other Radioactive Sources - Progress Report by the Director General, 6 March.
12. PHYSICAL PROTECTION: IAEA INFCIRC/225: The Physical Protection of Nuclear Material and Nuclear Facilities and IAEA INFCIRC/274: Convention on the Physical Protection of Nuclear Material, 30 September 2002
13. IAEA, (1978): INFCIRC/254: Communications Received from Certain Member States Regarding Guidelines for the Export of Nuclear, Equipment or Technology, February. Since 1992 as Part 1: Nuclear Transfers, and Part 2: Nuclear-Related Transfers

14. IAEA, (2002): GOV/2002/8: The Conceptual Framework for Integrated Safeguards, 8 February.
15. R. Hooper, (2002): The Changing Nature of Safeguards, IAEA Bulletin 45/1, June 2003 [16] IAEA Safeguards Glossary, International Nuclear Verification Series No. 3, Vienna, June.
16. IAEA, (2004): GOV/2004/32: The Safeguards Implementation Report for 2003, May.
17. IAEA, (2005): Illicit Nuclear Trafficking: Facts and Figures, in http://www.iaea.org/NewsCenter/Features/RadSources/Fact_Figures.html, May.
18. IAEA, (2005): Information Resources and Databases, in http://www.iaea.org/DataCenter/datasystems.html, May.
19. Chitumbo K., Robb, S. and Hilliard, J., (2002): Use of Commercial Satellite Imagery in Strengthening IAEA Safeguards. In Jasani, B. and Stein, G. (ed.): Commercial Satellite Imagery. A tactic in nuclear weapon deterrence, Springer.
20. Lepingwell, J., Nicholas, M., Braguine, V., (2003): Strengthening Safeguards through Open Source Information Collection and Analysis, Institute of Nuclear Materials Management, Annual Meeting, Phoenix.
21. Schriefer, D., Claude, F., Chitumbo, K., Huenefeld, J., (2003): The Use of Satellite Imagery for International Safeguards, Institute of Nuclear Materials Management, Annual Meeting, Phoenix

Open Source Information Collection, Processing and Applications

Louis-Victor Bril and João G.M. Gonçalves

1 Introduction

Much has been said about open-source information and its potential in various application areas. One thing is sure: the use of open-source information is not a new activity. Indeed, one can argue that libraries have been collecting open-source information for many centuries. Libraries, since their origin, have been always linked to the documentation, preservation and, till some extent, dissemination of knowledge. It is no wonder that libraries have been always associated to Universities or institutions for which the preservation of knowledge was important, e.g., religious organisations, including convents. Many governments made mandatory the registration of publications, e.g., France in 1537. Specific organisations, e.g., professional guilds, also played an important role in documenting their activities. The type of media used has always played a decisive role in how knowledge was documented, preserved, organised and transmitted. These two latter aspects determine the people, who could access knowledge, digest it and eventually increase it. The role of monks in meticulously preserving and copying, and hence transmitting, old documents and manuscripts illustrates the whole process of maintaining and disseminating knowledge. Today, we associate the type of media to specific technologies. It is possible to state that much of the interest about open-source is directly related to how easy it is to produce a document - please note that we are not considering the validity of its contents, to store it, to create exact replicas (or not!) and transmit them to the other side of the world. Another factor that is also important for the increased visibility of open-source information is the level of sophistication of our societies, including our governments, professional bodies and work organisations. The constant need for an increased efficiency of our societies requires rules and legislation covering many facets of our organisations (not to mention our lives!). Each organisation is thus extremely well documented from a multi-variable perspective. Examples of such variables are:

- identification;
- financial situation - including major stakeholders and description of financial flow;
- suppliers;
- clients;
- activities and/or products;
- environmental status, i.e., how does it interact with environmental rules;
- employees - including personal files, CVs, health records, social security obligations, reports, appreciations, etc.

Though each variable, i.e., a single descriptor, may not be confidential - and a valid question is who determines that - their combination, i.e., the multi-variable descriptor vector, will certainly be of classified nature, as it will may actively influence or determine the behaviour of third parties.

The two factors above, i.e., today's wide availability of information and the ease on how it can be accessed and transmitted, justify the increasing interest on open-source information collection and processing. The value of a specific piece of information is not the information itself but rather its potential to generate further knowledge. This knowledge generating process is mainly achieved by our ability to "putting things together", i.e., associating, linking, correlating, validating, corroborating sparse independent records and creating a new, stable information structure that is widely resistant to testing and criticism from others.

The objective of this chapter is to describe recent progress in open-source information collection and processing, including whenever appropriate application examples. Considering the authors' past experience in the field of nuclear safeguards, it is not surprising that application examples are oriented towards nuclear non-proliferation. As mentioned earlier, the processes of documenting and transmitting information, as well as creation of knowledge by simply putting things together are very much dependent on the technology and tools available at a given period of time. In this chapter we will concentrate on current, state-of-the-art technologies and tools. This justifies the emphasis on Internet based information collection. Indeed, the main advantage of the Internet is having established a de facto standard for information accessibility and exchange. This encouraged people in two ways: (a) letting the information available to others and (b) using the Internet as their primary platform and source for information search and exchange.

The chapter starts with some considerations on open-source information and what are the features that make it so attractive for information analysis. This is followed by a section on information collection and the attention that needs to be paid to validation of the content. This leads the discussion to information analysis and the need for automated tools to process, augment and assist the analyst in her/his work. The last section discusses the use and limitations of open-source information and hints future research lines.

2 Open-Source Information

Open-source information is information accessible to anyone, with or without conditions. These conditions may be of financial nature, e.g., the cost of a book or journal, or the on-line subscription to receiving a newsletter or accessing a newspaper website. They can also be of linguistic nature in the sense that an original text is written in a language unknown to the reader. Whatever the cases, it is meant that these conditions are not insurmountable.

In this respect, open-source information should be opposed to private and commercial information, generally generated for non-public uses. In the cases of interest for the present chapter, it should be considered opposed to intelligence and commercial information. By ’commercial’ we refer to technical or financial information shared by two (or more) partners in the frame of an exchange of goods and/or services.

Within the context of this book on treaty monitoring, it is important to have access to all available information at the time of the analysis. This is not to say that only the most updated information is to be used. Indeed, from an analysis perspective the correlation between old and new information can be extremely useful, as it may lead to the detection of changes, but it may also indicate omissions, i.e., activities or items once reported and no longer mentioned. As it is often said "the past may help explain the present". From a practical point of view, one can have two independent tasks running in parallel: (1) Data Collection - continuously searching for items of interest and registering their whereabouts (e.g., web links or URLs - Uniform Resource Locator) and time stamps and (2) Analysis - normally made at given instants of time depending on the needs. The two tasks are not totally independent, as feedback from the analysis will help configure future data collection (e.g., updates on keywords). A third, highly objective oriented, task on information processing is also necessary as it will help selecting and preparing the collected information before being submitted to the expert analysis. Sections 3, 4 and 5 detail these issues.

2.1 Accessibility

A major feature of open-source information is that it can be independently verified. Anyone can verify the information provided by an open-source. This does not mean that the information contents can be verified, but only its reporting, i.e., the fact of its own existence as well as the description used. This verification practice definitely allows the reader to corroborate the sources of information, validate the reasoning leading to conclusions, and definitely increases the trust the reader assigns to a specific reading. One can make an analogy between the importance of independent verification and the scientific method: knowledge is valid unless proved (and verified) otherwise.

Examples of open-source information are numerous, including most newspapers, journals and press reviews: anyone can subscribe a newspaper and will receive it at home or on a personal computer. Newspaper consultation, either partial or total, is usually free on the Internet. Many databases can also be freely accessed. Consultation of scientific papers is also possible in some on-line libraries or professional societies. Much administrative information is also freely available (from nuclear regulatory authorities, legislative bodies or independent auditing organisations). One should note the declassification policy of some states ensuring free access to administrative information after a legally defined period of time or for specific communication purposes. This information sometimes includes highly technical reports.

Non open (or closed) sources can be of administrative nature, e.g., "for official use only" or "classified". Commercial information is normally protected, e.g., physically, access control or by copyright and intellectual property rights. Highly technical information is, of course, rarely made accessible to the public.

2.2 Features of today's open-source information collection and processing

Some technological features of today's media justify the major "boom" in Internet based open-source information collection. The most important features are:

- All information is in digital format. This eases the storage, retrieval, transmission and processing of information;
- Information collection is easily automated. Search engines can be set-up to retrieve information sharing a common characteristic (normally a combination of keywords).
- The amount of information on line is huge, all of which available from the user's computer [single "door" access rather than multiple visits to different libraries]. Information includes news agencies, newspapers - past and present, books, reports from government agencies, companies advertisements, maps, satellite imagery, etc.

Most of the information present in the web is in English. On one hand, this allows for greater access. On the other one should keep in mind that many valid documentation and reports can be found written in languages other than English and in alphabets other than Latin. Taking as an example nuclear non-proliferation, it would be highly reductive to focus information collection only in documents written in English, considering there are too many major actors in that field communicating in their own national - non-English - languages.

Though many information collection and processing tools have been developed and are operational for English texts, there is still much to be done in other areas. This topic will be dealt with further on in this chapter.

Generation of knowledge based on open-source information is mainly the result of an exercise of combination of information by associating, linking, correlating, validating, corroborating sparse independent records. A key factor to the success of such exercise is expert knowledge. New, high performance tools can definitely contribute to the role of the expert when producing an analysis. These tools can boost and enrich the data (rough or semi elaborated) that is to be used by the experts, but they will not replace her/his previous knowledge, intuition and analysis capabilities.

3 Open-Source Information Collection

Open-source information collection aims at creating a set of indexed references about documents that are thought to be useful in future analysis exercises. It may happen that when the information is collected little is known about future analysis exercises. This may create difficulties in selecting: (a) the references to record and (b) optimised indexing schemes.

Taking the Internet as an example, one might expect that once an information is posted, it stays always accessible, as in classical libraries. This is a major error of judgement as Internet information can be quite volatile. A few examples:

1. News agencies or newspapers articles are normally available only during a limited time-window, i.e., while the information is considered "breaking news". This means that the reference to an interesting piece of news may no longer be valid one week later.
2. Scientific papers or reports posted by a university or other research institution may be considered outdated and may no longer be accessible on line.
3. Commercial information also changes depending on a company's marketing policy. Companies merging, acquisitions, or bankruptcy, lead to major changes in the information available on-line.
4. Political decisions, international events or simply new regulations can influence governments or organisations to revise the document publication policies. This may restrict the classification of some previously available documents.

The above examples illustrate one of the major difficulties in open-source information collection, and indexing. In the case of (a) news agencies or newspapers, the information can still be available on-line under a new URL, and probably accessible after paying a subscription or small fee. A solution to the case of (b) scientific papers or reports is simply contacting the authors or university library, though there is no guarantee for success. Solutions to (c) and (d) above are more difficult to find.

Of course, once a relevant document is found the best thing to do would be to copy it (i.e., download) to a local system. Indeed, this helps solving the volatility problem. There is one aspect that needs attention: intellectual property rights including copyright. The fact that a document is "freely" available in the Internet does not mean that it is not protected by some copyright. Some usage restrictions, e.g., freedom to copy, distribute and/or use, may apply. To avoid unpleasant surprises, this issue needs to be investigated and ascertained on a case-by-case basis.

3.1 Data Collection

Most of the efforts in open-source information collection concentrate on textual information. To collect these data it is possible to devise two approaches:

- *General*: The search criteria are based on a set of selected keywords, and a search engine retrieves the documents matching those keywords, using as search-space the whole Internet.
- *Targeted*: A search engine looks for documents matching a set of predefined keywords in a reduced search-space, containing a user-defined set of sites where relevant information is most likely to be present.

From a data collection point of view both approaches are useful, as they complement each other. With the *General* approach exhaustive searches are made. It is then possible to find unexpected sources. This type of search is more appropriate to sites that do not frequently change their contents. Recently posted documents may take a few days to be detected by the search engine, as this thorough search takes longer to be executed. *Targeted* searches use a known set of credible sources. As such the search process becomes optimised. This type of search is a good solution to sites with highly dynamic contents, as is the case of news agencies or newspapers. *Targeted* search can be configured in terms of search frequency. Typical values range from some tens of minutes to a few months.

3.2 Data Validation

The main advantage of open-source information lies in the fact that the existence of the source document is verifiable. In terms of the analysis, the validation of the information contents is of great importance. Failure to validate the information contents can lead to wrong conclusions, embarrassment and waste of resources. Different questions may arise:

1. Reliability: is the information to be trusted? Completely? Partially?
2. Suitability: till which extent is the information appropriate to detect anomalies?

The correlation of information from multiple sources may help answering to the first question. However, one should bear in mind the way press news are generated - it is not infrequent to have newspapers editing the texts from others and presenting those texts as their own. In the end multiple sources would be reporting on the basis of a single origin, reducing therefore the capability to have independent verification.

The IAEA reported recently on the pitfalls of inaccurate information from open-source media in the field of illicit trafficking of nuclear and radiological materials and the efforts engaged, together with relevant State authorities, to ensuring their credibility [1]. This test-case is a good example of the difficulties of the information validation issue and of the approach taken.

In democratic countries, reports from administrative sources (e.g., governmental, international organisations) contain, in general, precise and verified information. This information is generally made official and public and is beforehand made very reliable. Non-verified or non-certified information is usually not included in such reports.

It is possible to say that some sources are more suited than others to issuing sensitive reports. Indeed, the political weight behind some administrations is such that they simply cannot afford to make a mistake, or ignore a major fact. Some civil organisations, instead, such as NGOs - Non-Governmental Organisations, have more reporting flexibility, as they are doing what is expected from them, with less political consequences attached. Newspapers also show reporting flexibility as the objective to inform in due time may compensate for a few inaccuracies. The situation depends very much from a country to the next and is quite influenced by the accepted codes of practice.

3.3 Satellite Imagery

Satellite imagery produced from commercial companies can be also considered to pertain to the category of open-source information, as anyone with a minimum budget can acquire such images. It is often said, "a picture is worth one thousand words" or "seeing is believing". These sayings apply quite well to the use of satellite imagery in treaty monitoring activities. Many worldwide national and international security agencies use satellite imagery for their investigation purposes [2,3]. Images can be optical, infrared, multi-spectral, radar and, more recently, hyper-spectral. The main application of optical imagery is to infer what is going on at a particular site based on the interpretation and analysis of the ground activities as described by the image itself. Often, the analyst is interested in the detection of changes and as such bases her/his work on the time analysis of a sequence of images taken at different time intervals.

Infrared imagery is most useful to detecting changes of temperature at the ground level, e.g., detection of industrial discharges ("plumes") in a nearby river. In optimal conditions, radar imagery can detect changes in the dimensions of structures and in ground elevation. This helps monitoring mines as well as the stabilisation of recent, heavy loads on the ground (i.e., terrain settling). Multi-spectral imagery can be used for indirect purposes, i.e., detecting side effects of illegal activities, e.g., vegetation stress. More recently, much research and development effort has been put on the use of hyper-spectral imagery hoping that better spectral discrimination data can be more assertive in detecting undeclared activities.

3.4 Multi-lingual Information Collection

From an information gathering perspective, it is important to collect as much as possible data relevant to a specific topic, irrespectively from the web source. This includes information written in languages other than English, or other non-European languages. From a technical point of view, there are no problems in making searches using other languages and/or alphabets, as most search engines can be easily configured.

The difficulties associated to multi-lingual documents derive from the fact that not all organisations have the internal or trusted means to make a thoroughly expert analysis of the documents retrieved. Some alternatives will be considered later in the next section.

4 Open-Source Information Analysis

The main objective of the information analysis is to build knowledge from the documents available. To achieve this, these documents need to be assessed by people with expert knowledge on a particular field. Ideally, one can think of a team of analysts working independently, comparing and confirming conclusions, as well as making their best to resolve inconsistencies and clarify the points for which less evidence exists.

In one way the analysis can be a logical exercise, based on deductive reasoning and on the validated evidence provided by the information. This approach is seldom applicable, as not always will the analyst be able to validate the information contents. At this point, the analysis may become investigative or speculative. In these cases some working hypothesis or scenarios are laid. Most of the work will then consist in validating those hypothesis or scenarios based on the evidence available and within a given degree of confidence.

Given an important topic, one cannot say that the analysis phase has an end. Indeed, it is more structured as a sequence of analysis exercises, the next one being influenced by the results (or absence) of the previous exercise. The conclusions or, to be more precise, the working hypothesis or scenarios that score better in terms of credibility, will likely determine new searches, i.e., new data collection with probably a different, more (or less) focussed set of keywords, or the gathering of other types of data, e.g., satellite imagery, environmental data, etc.

4.1 Nuclear Non-Proliferation

Nuclear non-proliferation is a major user of open-source information analysis. Indeed this field of application is very complex covering the production, transportation and usage of nuclear materials, including all associated technologies - seen in its broadest perspective of who designs, produces, sells and distributes the relevant technologies to whom. Different bodies, treaties, arrangements and agreements cover the various aspects of nuclear non-proliferation. Table 1 summarises the legal means, some of which not yet enforced, to preventing the construction of nuclear weapons as well as detecting nuclear tests.

Table 1. Summary of Nuclear Non-Proliferation legislation.

Objective	Legal instrument
Control of conformity with declared use of materials	EURATOM Treaty [1958]
Control of finality (no nuclear weapon production)	Non-Proliferation Treaty NPT [1970]
Detection of undeclared facilities and activities	Additional Protocol to NPT - IAEA INFCIRC 540 [1997]
Preventing the production of weapon grade nuclear material	Fissile Material Cut-off Treaty FMCT*
Detection of nuclear device testing	Comprehensive Test Ban Treaty CTBT*
Control of exports of dual-use items and technology to preventing the build up of the industrial capability to producing nuclear weapons	IAEA INFCIRC 254 [1978 .. 2005] EU Regulation 1504/2004 [2004]

*Treaty not yet enforced

The ultimate goal of nuclear non-proliferation is to prevent a country or group to "*manufacture or otherwise acquire nuclear weapon or other nuclear explosive device*". The Non-Proliferation Treaty (NPT) establishes the legal framework for ensuring that all declared nuclear materials, facilities and activities are kept under Safeguards measures to be implemented by the International Atomic Energy Agency (IAEA)[4]. Other treaties may apply at a regional level, such as the European Union's EURATOM treaty, enforced in 1958.

The Nuclear Suppliers Group (NSG)[5] contributes to "the non-proliferation of nuclear weapons through the implementation of [internationally agreed] guidelines for nuclear exports and nuclear related [technology] exports".

4.2 Export Control of Goods and Technologies

Export control regimes do also contribute to the prevention of nuclear non-proliferation. Generally speaking, export control regimes pose restrictions on the trade of items, which can contribute in any way to manufacturing chemical, biological or nuclear weapons or other nuclear explosive devices. Control regimes require exporters of these items to obtain a license from national authorities before the actual trade can take place. The license is awarded taking into account various information to be provided by the exporter, like the intended use of what is traded, who is the end-user, etc.

More specifically, and within the context of nuclear non-proliferation, the Nuclear Suppliers Group (NSG) authored a set of guidelines - published as IAEA's INFCIRC/254 [6], for the export of nuclear material, equipment and technology as well as dual-use equipment, materials, software and related technology. These guidelines enumerate items of interest to nuclear proliferation (the so called '*trigger list*') and state that '*suppliers should authorize transfer* *of items or related technology identified in the trigger list only upon formal governmental assurances from recipients explicitly excluding uses which would result in any nuclear explosive device*'. The trigger list is regularly updated to reflect advances in nuclear technology.

At European level, the NSG guidelines have been incorporated as part of the EC Council Regulation No. 1504-2004 [7], which sets up a community regime for the control of exports of dual-use items and technologies. This regulation established a common list of items to be controlled across all member states of the European Union. Consequently, there is a growing need to identify multiple and independent sources of information that would allow crosschecks and the verification of the implementation of this regulation. Again the use of open-source information, in particular the use of international trade databases including those related to transportation of containers, can help monitoring the application of such agreements and regulations.

4.3 Nuclear Profiles and Studies

Many organisations, both public and private, have been active in analysing open-source information to preparing nuclear country profiles. For example, valuable country profiles can be found in the websites of the International Atomic Energy Agency [8], Stockholm International Peace Research Institute (SIPRI)[9] or Nuclear Threat Initiative (NTI)[10]. These reports aim at describing specific countries in terms of their energy situation, including the existing internal resources and all the aspects related to nuclear industry and activities. It is quite accepted that nuclear proliferation is the result of a country's long-term strategic decision. To implement this strategy, a country needs to create or enhance its own internal potential, in terms of required facilities, available materials and, probably less visible but equally important, the human scientific and technical capabilities.

Material originated from open-sources, both textual and satellite imagery, can be correlated with officially declared information (e.g., IAEA list of nuclear facilities). From this analysis by nuclear experts, it is possible to create accurate descriptions of the activities related to each phase of the nuclear fuel cycle. It is also possible to investigate, within a given degree of confidence, non-official scenarios related to the potential of future activities.

This type of expert analysis helps describing the nuclear activities of a country, and can hint on some worrisome potential, undeclared activities or intentions. This analysis is also useful to describing new types of threat as nuclear proliferation networks - activities led by a group of people with no support from state(s)'s authorities. Information from open-sources can document and pinpoint the resources available - including financial flows, the cooperation between groups of people, relations with some states, transportation of materials and equipment, scientific and technical background of those involved, etc.

5 Open-Source Information Tools

In previous sections we highlighted the use of open-source information in the context of treaty monitoring. This section is more application oriented in the sense it describes some of the needs felt when analysing information. These needs reflect the abundance of information, each piece describing only a partial aspect of reality, and the final objective to "put things together", i.e., to provide the analyst with a description as comprehensive as possible of a given situation.

As for many tasks, specific tools need to be developed taking into account some repetitive activities. One should note that given the potential sensitivity of the analysis exercise, it is important for the analyst to have at any time direct access to the source documents as well as to the description of the outputs of the different tools. Indeed, it may very well happen that one important conclusion is associated to a critical path of information. If this happens, the analyst should be aware of that, and should be capable to trace back her/his conclusion to the sequence of operations and processing steps made during the analysis process, including the associations made to other types of data. This allows for the confirmation of the conclusion but also enables independent auditing of the process and procedures. The above concern justifies the need for high-level analysis management tool, capable of recording all the steps made, including assessment of the quality of the results in each step.

This section describes some of the most used tools and procedures for indexing, processing and analysing documents. One should bear in mind that the final result of any tool needs to be validated by a qualified human expert. Tools are here to assist the analyst, not to replace her/him. At the end of this section some details on the practical work and tools developed within the European Commission's Joint Research Centre, Institute for the Protection and Security of the Citizen - JRC-IPSC.

5.1 Data Collection Keywords

Before a search is organised in the Internet, whether general or targeted, a list of qualifiers - normally keywords - needs to be setup to help distinguishing what is relevant information. For each search topic, a list of relevant keywords is drafted and a weight assigned to each one. For each article, the occurrence of each keyword is then screened and a simple algorithm computes a score value for that article. A threshold is determined by trial and error. All the articles scoring above the threshold are then selected (an their Internet link recorded). The list and weights of the keywords can be easily reviewed to fine tune the search for each specific topic of interest.

A classical problem is to limit the number of false articles. An article can indeed be selected, but having nothing to do with the topic of interest. As an example, the word "defence" can be used for football, as well as for justice court or military purposes. A refinement of the use of keywords, e.g., algorithms with "negative keywords" could easily block such occurrences.

5.2 Data Indexing

Data indexing is a key aspect to successful information retrieval and analysis. Indeed, if a document, be it a newspaper article, a technical report, someone's CV (Curriculum Vitae) or simply a satellite image, is not properly indexed, i.e., described by means of one or more qualifiers, it becomes virtually impossible to retrieve and use in an efficient and appropriate way. Many studies proved that different people index the same document differently. Moreover, in time, the same person will likely use different indexing keys for the same document. This means that it is difficult to assign a consistent representation to a document.

Automated tools may assist in this problem by making some measurements on the document's contents. Examples of such measurement can be: (a) presence of keywords from a given list; (b) frequency of such keywords; (c) association of keywords taking into account how far apart they are in the text. These simple, statistically based tools help in providing a more consistent classification of the documents.

Alternatively, some topic-specific tools may be written to analyse the document and infer its contents. These latter tools depend heavily on a specific language as they are based on syntax and grammatical aspects.

5.3 Document Augmentation

The objective of document augmentation is to automatically associate to a single document external relevant references that might be useful during the analysis phase. Table 2 illustrates the type of information that may be added to the original document.

Table 2. Document augmentation: some examples

Document contains:	**Extra information to add:**
- Name of a person	· List of alternative spellings · Persons curriculum vitae or rsum or web site, photographs · List of references where the name is mentioned · List of people, places and dates associated with the name
- Name of a place	· List of alternative spellings · Geographical coordinates, web sites, maps · List and description of known facilities within a given distance · List of references mentioning the place, including list of visitors
- Name of a facility	· Description of the facility · Associated country profile · List of related articles and reports · List of people and/or companies associated to the facility

5.4 Dealing with other languages

Many text-processing tools have problems when operating outside the English language. If the use of keywords is easily transferred to another language, both in terms of ease of translation and in terms of efficiency - considering the differences in syntax, then the use of tools in a second language (or alphabet) do not seem at all impossible. There are basically two approaches when dealing with a new language:

- *Translate the documents* into a known language, e.g., English:
  Advantages: previously established tools can be used and the analysis is done also in the final language.
  Disadvantages: it may be difficult to thoroughly translate all the documents needed, either by human translators with limited topic-specific expert knowledge, or by automated tools.
- *Translate keywords* from English to the other language.
  Advantages: it is possible to apply equivalent text-processing tools and/or methodologies. As such it is possible to identify duplicate documents.
  Disadvantages: Without expert readers, there is the need for translating some selected documents.

A major advantage of the second method is the fact that the comparison of documents written in different languages becomes possible, as they share the same keywords.

Once the list of keywords is established in a reference language, e.g., English, the translation into other languages may use commonly accepted and tested documents, such as legal texts. The European Union Council regulation on dual use items (1504/2004) [7] is a good example of such common text as it exists in all 21 official EU languages. In its nuclear part, regulation 1504/2004 is directly derived from IAEA's INFCIRC 254 [6] that exists in three EU languages (English, French and Spanish) as well as in other official languages of the IAEA such as Russian, Arabic and Chinese. For other non-EU languages, there is no alternative but to translate them classically, with the assistance of a native speaker.

5.5 Research at JRC-IPSC

For many years the European Commission's Joint Research Centre - JRC, has been working in the area of Nuclear Safeguards and has provided scientific and technical support to both the European Commission's DG-TREN - responsible for implementing all nuclear safeguards derived from the EURATOM treaty, and to the International Atomic Energy Agency. Other JRC projects covered the fight against fraud in their various angles. Within all these projects many tools were developed to assist the collection, processing, analysis, organisation and presentation of data and results. The rest of this section describes some relevant open-source information tools developed at the JRC. All the tools described are now used both inside the JRC for the execution of internal projects, and outside in collaboration with external institutions and partners. The scope of the presentation is to illustrate concepts and ideas developed in past sections.

Data Collection - EMM

The EMM (Europe Media Monitor) [11] main objective is to provide the European Commission services with targeted, updated information selected from a wide variety of Internet sources [12,13]. The number of web sources monitored by EMM reached 700 sites, most of them newspapers. EMM offers a complete interface in all 21 languages of the EU. All interfaces have been translated and implemented, and all native language news sources from every country have been added. Today EMM also operates in Farsi after the translation of the English nuclear non-proliferation keyword list.

The EMM alert system exploits a JRC developed parallel state algorithm for identifying keywords across multi-lingual texts. It processes in real-time the full text of any article against 8000 keywords from 350 subjects. EMM alerts are fine tuned to each user-defined topics of interest. Statistical indicators for various global themes can be derived and plotted versus time and geographic location.

An extension of alerts is being prepared to cover data originated from other set of sources, such as scientific newspapers, NGOs, governmental, professional organizations, etc. The screening periodicity is adapted to each source and ranges from a few days to one month.

Language Engineering

The number of documents to be potentially used in analysis is very large. This excess of information may hinder the advantages of open-source information. Indeed, it is difficult without appropriate means, to select the most important documents to consider for analysis. The excess of information creates different problems, such as:

1. What are the best keywords (or combination thereof) to index the document?
2. From a set of documents, are all of them independent from each other? Which ones cover the same subject?
3. If many documents cover the same subject, which one is the most representative?
4. What about if the different documents are written in different languages?
5. Is it possible to assist the analyst by automatically providing extra information related to a document? Examples: (1) an updated map of the places mentioned in the document; (2) the biography of someone mentioned in the document; (3) the technical description of an installation cited in the document; etc.

All these questions require specific tools to help the analyst. In the past years, JRC's Language Technology group has been developing some tools to assist the information analysis process [14].

Keyword Extraction
Indexing well a document is important as it may determine how easy and accurately the document will be used. A tool was developed to automatically identify within a document the most representative keywords including their relative importance - the *keyness* of each keyword [15]. Keywords are extracted by measuring the frequency of occurrence of each word in the document and establishing a comparison with the average frequency of that word in a normal, average text. The words presenting a significantly higher frequency of occurrence become the *extracted keywords* for that document.

A combined approach involving the mentioned extracted keywords together with other indicators improves document indexing and description. The extra indicators are the output of filters looking for names of people, organisations, facilities, places, countries, etc. This variety of names together with the group of extracted keywords creates a multi-variable vector representing the document. This vector can be used both for indexing as well as for comparing documents or ranking their relative importance.

Removal of Duplicates
When analysing a large collection of documents it is not excluded that some of these documents are copies or adaptations from others. This is most frequent when analysing news articles, as the independent sources are normally very few - the news agencies. The existence of duplicates can be quite annoying as this may correspond to a waste of the expert analyst's time. Tools have been developed to detect documents that are almost identical, i.e., containing an equivalent level of information [15]. Some tools use as discriminating feature the frequency of pentagrams - a sequence of five consecutive words. If more than a certain percentage of all pentagrams are identical (e.g. 50% or more), this is flagged to the user and the duplicate documents are automatically put aside. The tool thus identifies whether entire texts or some text passages are identical between two documents. By doing this, multiple readings of the same text can be avoided, increasing therefore the efficiency of the analysis.

Document Clustering
It is useful for analysts to know which documents are topic related in order to either concentrate effort on them or have all of them discarded - should they lack relevance. A document-clustering tool was developed to group, in an automated way, the documents referring to a specific subject. The tool is based on the computation of a similarity measure between each pair of documents. All those document pairs with a similarity above a user-defined threshold are then grouped into a single cluster [16]. Within each cluster, the

most "representative" document can be identified as the one, which is closer to the centroid of all cluster documents in the vector space.

Data Indexing: Topic Trees

In 2000, the Joint Research Centre started an Information and Analysis Centre (IAC) with the purpose of studying information about Nuclear, Chemical and Biological Non Proliferation, Disarmament and Weapons of Mass Destruction, as well as producing technical studies on related subjects [17].

Due to the large number of documents with similar information content, it is often difficult to identify the original source. It is also difficult to use such information, as little is known how reliable it is. Therefore, the information is analysed by experts in a given field who produce, on a regular basis, internal documents on subjects of interest. A document-managing tool was selected to handle the large volume of documents in a variety of formats, performing efficient indexing, searching, retrieving and displaying of textual information [18].

This tool uses an advanced technology that allows the user to search for concepts in documents, rather than individual words or phrases. This technique considers the existence of specific words and phrases in a document as evidence of the presence of a concept. Keywords describing the concept are encapsulated in an entity called "Topic-Tree" (TT). The organisation is recursive in the sense that each concept can incorporate other sub-concepts. This leads to the construction of a tree-like structure. Simple operators - logical, proximity, evidence - are used to create the topic-tree. Therefore, a topic-tree is a set of information describing a particular concept and structured as a predefined query that supports very efficient searches [19]. The result of a query is a list of documents with an associated score. Experimental results showed that topic-tree searches produce a set of fewer, more targeted documents.

Integration of data from multiple sources

Efficient information analysis requires to have all the important documents readily available, and if possible organised in such a way that they can relate to each other. In other words there is a need to "put things together" and see "the whole picture". This creates many challenges on how to organise heterogeneous information derived from multiple sources, different media, generated at different instants in time and collected at different time intervals. Two needs are present: (1) to make an in-depth analysis of each document and to do this specific tools will certainly be used and (2) to have the possibility to relate all information and partial analysis results and make unexpected associations. Assuming the information was properly indexed, the analyst should have the capability to retrieve and visualise all the information in a seamless and "natural" way.

The application of the Additional Protocol to the Non-Proliferation Treaty (NPT) gave a new role to satellite images as they are used for the verification of the layout of declared sites as well as for supporting the evidence about hidden nuclear activities or undeclared sites. Currently, each type of data requires its own independent tool. The analysts perform the final integration of the data manually. For example, satellite data are analysed by using dedicated tools (e.g., ERDAS Imaging), Internet documents are retrieved with standard or advanced search engines, 3D models of the area are visualised using stand-alone applications, etc.

Users have to verify manually the consistency of the results from the different and separate processing phases. The Joint Research Centre is designing and implementing a platform based on GIS (Geographical Information System) technology for integrated data visualization and processing. This platform integrates tools for the collection, joint analysis, and effective visualisation of heterogeneous data. Examples of data to be integrated in the GIS are:

- Satellite image analysis tools: e.g., data fusion between images from different sensors, detection of scene changes, satellite image classification, etc.
- Text search and processing tools (language engineering tools): e.g. automatic keyword generation and document cataloguing, duplicate removal, multi-language tools
- 3D tools: e.g. modelling, visualisation, 3D change detection [20]
- The NUMAS geo-database (see below)

The usefulness of a GIS-based solution for integrated data analysis has already been validated by a pilot study combining the analysis of documents related to Non-Proliferation issues with information from the NUMAS database [21].

NUMAS Geo-Database

NUMAS is a geographical information system containing open-source information describing nuclear facilities covering the complete nuclear fuel cycle (i.e., from mines and milling to waste repositories). Data include the geographical coordinates, country name, site name, associated maps and satellite images, plant type, process type, material used, production capacity, status, start-up and closed down date. The initial contents of NUMAS originates from official sources (IAEA-NFCIS [8], WANO [22], INSC [23]) and many other Internet open sources. NUMAS contents are updated with both new information and the results of previous studies.

NUMAS allows the user to perform spatial queries using the content of the database as search-keys. A spatial query is a request whose result is represented by a new, dynamically generated map. Spatial queries can find, say, the spatial distribution of locations containing a given type of facility, process or material in a predefined geographical area.

Clicking on an object of the map all the information from the database is displayed. Specific words in the NUMAS database are used to automatically query the Information Analysis Centre database (IAC) by triggering the relevant topic-trees. The result is a list of selected documents targeted on the topic of interest and ranked by decreasing score of relevance.

6 Discussion

The previous sections described the wide availability of open-source information, how the information can be collected, processed and analysed. There are some points that need some detail, as they will likely influence the availability of future's open-source information.

Since its origins, Internet has been much inspired by the desire of the academic and research communities to exchange information and data. The organisation behind the availability and exchange of data is extremely simple: someone publishes information at a [server] computer, another computer sends a request, and the information server sends a copy of the information to the requesting computer. No questions asked, no questions answered!

As any other "society", Internet's success depends on the behaviour of its "citizens", or in other words, the sustainability of the Internet depends basically on its users and their willingness to share information, even if some access or subscription fees are required. After the initial years, there was a strong effort from people and institutions to publish information that, previously, was accessible only upon request. Most countries made public all their legislation including all administrative decisions. On the commercial side, almost all companies see the Internet as a platform to have their products and activities known. The new communication media changed the way, or at least introduced alternative ways, to do business, making, electronic commerce a reality. Many companies aiming at improved services or increased efficiency, made their databases available on-line. The scientific and technical communities also took advantage of the new media, created open discussion fora, and made available on-line the most updated scientific information - or at least accurate references to the latest publications. Indeed, information such as who (working for whom) published what at a specific conference, what are today's "hottest" research topics or, simply, the list of the latest reports issued by an organisation, is readily available at our fingertips.

The 2001 September 11 events triggered many discussions on security aspects, i.e., what should and should not be readily available on-line for anyone's free usage. As a consequence, in recent years much on-line information was either removed or shortened. Moreover, increased commercial competition and the need not to divulge business practices made companies to restrict the access to their on-line databases. It is possible to say that all the information posted on-line today is heavily screened, and subject to high-level decisions within each organisation.

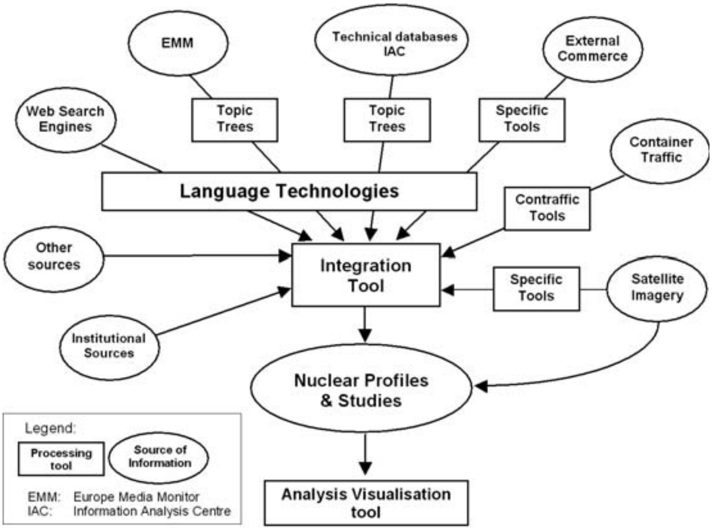


Fig. 1. Proposed architecture for JRC's open source information and analysis applied to nuclear non-proliferation

As a coincidence, or perhaps to "compensate" for stricter publication rules, the Internet community engaged recently into a new communication tool: Blogs - a web-based publication updated on a daily basis, and normally containing the diaries of the individual owner. Blogs can also be used for political campaigns. They range in scale from the writings of one occasional author, to the interactive collaboration of a large community of writers [24]. The information contained in Blogs, written either by the Blog owner or by visitors can be of high quality, and should also qualify as open-source.

6.1 Monitoring who accesses the information

Information owners are often interested in keeping track of who accessed the information and make some internal analysis justifying the interest in specific documents, e.g., reports. In the Internet, this tracking can be as simple as:

1. asking the user to register before been given electronic access to a requested document
2. asking the user to provide an electronic address for a document to be sent
3. asking the user to provide a physical address for a document to be sent by normal mail
4. translating back the user's Internet Protocol (IP) number to an organisation and/or individual

Should there be the need, the information owner can engage into more in depth verification and analysis studies. Needless to say that all the tracking mechanisms mentioned above can be easily cheated with currently available Internet tools.

6.2 Future Research

These new facts do not diminish the interest on open-source information. Rather, they put pressure on innovative ways to look for the information beyond the generic, high audience search engines, e.g., Google, Yahoo, MSN. These engines are extremely important tools, they have access to so much information [25], but have not been designed to meet the requirements for highly specialised, treaty monitoring oriented searches. These are niche applications and special, highly targeted tools, such as EMM, will still be needed. Section 5 described a few examples of open-source information tools and presented ideas on the way ahead.

Much research and development work is progressing towards innovative document augmentation techniques, as well as to improved ways to relate existing information. One likely possibility for the future is to have search engines automatically tuned by the requirements of previous analysis. Such engines will take a few, validated documents as sources, and will autonomously gather extra information to augment or corroborate the previous information. After a few hours, the analyst would have a complete file to study, where proven and hypothetical (i.e., in need of expert confirmation) associations between documents are signalled.

Figure 1 shows a tentative architecture for an open-source information analysis system applied to nuclear non-proliferation. It can be seen that the analysis is the result of putting together information originated from multiple sources. Future research will determine: (a) how the different sources of information and processing blocks relate, (b) what are the fluxes of information and control (i.e., procedures) between blocks, (c) how the different blocks will be partitioned or grouped, (d) what are the levels of direct human intervention, etc. Similar architectures can be easily developed for other monitoring activities.

6.3 Final Considerations

There is a strong value in open-source information. Indeed, even with current cautious practices to post information in the web, the value and the potential of open-sources is immense. Two final words of caution though:

1. Open-sources do not replace other sources of information such as those resulting from effective intelligence work.
2. Analysts need to be careful and avoid errors derived from wrong or non-validated information.

Acknowledgment

The authors express their gratitude to various colleagues for the informal discussions that contributed to this text. Special thanks are due to F. Bellezza, S. Contini, C. Ignat, A. Poucet, R. Steinberger, E. Stringa, A. Ussorio and C. Versino.

References

1. Satterfield, J., (2005): *The International Atomic Energy Agency (IAEA) Illicit Trafficking Database*, Proc. 46th INMM (Institute for Nuclear Materials Management) Annual Meeting, Phoenix, July 2005.
2. Jasani, B. and Stein G. (ed.), (2002): *Commercial Satellite Imagery. A tactic in nuclear deterrence*, Springer, Berlin Papers.
3. Jasani B., Hofmann P., Lingenfelder I., (2005): *Classifying nuclear power plant facilities using an already developed 'key'*, ESARDA 27th Annual - Symposium on safeguards and nuclear material management, London.
4. IAEA - International Atomic Energy Agency: http://www.iaea.org
5. NSG - Nuclear Suppliers Group: http://nuclearsuppliersgroup.org
6. IAEA-INFCIRC 254: IAEA: http://www.iaea.org/Publications/Documents/Infcircs/2005/infcirc254r7p1.pdf
7. EC-1504-2004, (2004): *European Union Council regulation 1504/2004 setting up a Community regime for the control of exports of dual-use items and technology*: http://europa.eu.int/eurlex/lex/LexUriServ/site/en/oj/2004/l_281 /l_28120040831en00010225.pdf
8. IAEA-NFCIS: International Atomic Energy Agency - Country Profiles: http://www.iaea.org/DataCenter/datasystems.html
9. SIPRI - Stockholm International Peace Research Institute: http://www.sipri.org
10. NTI - Nuclear Threat Initiative: http://www.nti.org
11. JRC-EMM - EC-JRC Europe Media Monitor: http://emm.jrc.org
12. Best C., van der Goot E, de Paola M, Garcia T, Horby D., (2002): *Europe Media Monitor* - EMM, JRC Technical Note No. I.02.88.
13. Best C., van der Goot E., Garcia T., Horby D., (2003): *Europe Media Monitor*, EC Bulletin Informatique.
14. JRC-LT - EC-JRC Language Technologies Group: http://www.jrc.cec.eu.int/langtech/index.html
15. Ignat C., Steinberger R., Pouliquen B., Erjavec T.: *A tool set for the quick and efficient exploration of large document collections*, ESARDA 27th Annual - Symposium on safeguards and nuclear material management, London, May 2005.
16. Pouliquen B, Steinberger R, Ignat C, Ksper E & Temnikova I., (2004): *Multilingual and Cross-lingual News Topic Tracking.* In: CoLing'2004 proceedings, Vol. II, pp. 959-965. Geneva.

17. Bril LV., Cuypers M., Meloni U., Mousty F., Poucet A., (2001): *European Non Proliferation Information Management and Analysis Center*, ESARDA 23rd Annual Meeting - Symposium on safeguards and nuclear material management, Bruges, May 2001.
18. VS97 - Verity- http://www.verity.com
19. Ussorio A., (2004): *Development of an Information and Analysis Centre, JRC internal report*, contract 18867-2001-11 P1B20 ISP
20. Sequeira V., Bostrm B., Fiocco M., Puig D. and Gonalves J.G.M., (2005): *Outdoor Verification System*, Proc. 46th INMM (Institute for Nuclear Materials Management) Annual Meeting, Phoenix, July 2005.
21. Contini S., Bellezza F., Mousty F., Ussorio A., (2005): *GIS-based System to Support Open Source Information Analysis*, ESARDA 27th Annual - Symposium on safeguards and nuclear material management, London, May 2005.
22. WANO - World Association of Nuclear Operators:
http://www.wano.org.uk
23. INSC - International Nuclear Safety Center:
http://www.insc.anl.gov
24. WIKIPEDIA - On-line Free Encyclopedia:
http://en.wikipedia.org/
25. CNN, (2005): *How much does Google know about you*?:
http://www.cnn.com/2005/TECH/internet/07/18/google.privacy.ap/

The National Level

Michel Richard and Bernard Chartier*

1 Introduction

Since the end of the cold war (1989), a series of events which occurred in the late eighties and early nineties have stressed the importance of information collection and analysis in assessing the level of the threat posed by the proliferation of weapons of mass destruction (WMD) to the international and national security; in particular, the threat posed by States of concern regarding non-compliance with their non-proliferation commitments in the context of regional instabilities and terrorist groups acquiring such weapons.

Information collection, analysis and assessment have always played a major role in strategic planning by governments. They are essential elements for evaluating possible alternative paths along which international crises might evolve and on possible responses to resolve them as demonstrated the Cuban missiles crisis (1962), to mention just a major one. A number of incidents in the early nineties, such as those which occurred in the course of the implementation of the Nuclear Non-Proliferation Treaty (NPT) by the International Atomic Energy Agency (IAEA) in Iraq, North Korea, South Africa, exposed the weaknesses of the non-proliferation regime as a whole and, in particular, the nuclear non-proliferation regime. These events highlighted the urgent need to strengthen the NPT and similar treaties, and to give to the organisations in charge the capability to deal not only with known situations, such as the correctness of the declarations by the States, but also with the unknown factors such as the completeness of declarations [1].

To accomplish this and similar objectives information management, i.e. collection, analysis, assessment and knowledge building, has become an essential tool of international organisations such as the IAEA, the OPCW, future CTBTO, multilateral organisations such as the European Union, NATO or G8 and national governments. Through information management, the diverse

* The views expressed herein are those of the authors and do not necessarily reflect the views of the CEA or the French Authorities.

organizations could collaborate by sharing information in order to eliminate the threat of the proliferation of weapon of mass destruction and their means of delivery and to provide assurance that international peace and security will not be endangered by a State or a group of States or some terrorist group [2], [3].

In the aftermath of the first Gulf war, when the IAEA inspections discovered the large clandestine nuclear weapons programme of Iraq only a few experts were venturing guesses about possible clandestine activities there. At the same time, the IAEA while facing obstacles in verifying the initial declaration of North Korea, discovered a hidden comprehensive plutonium production facility consisting of a large reprocessing laboratory associated with a 25 Mw_{th} natural uranium gas graphite reactor with the help of satellite imagery provided by an intelligence agency of a member State. After the decision of the South African Government to give up its nuclear weapons programme and join the NPT, the announcement that South Africa had already possessed and had destroyed seven nuclear weapon component parts, the international community realized that it had been oblivious to what was really occurring in some countries. As a result, it became imperative to develop legal and technical means to detect nuclear proliferation activities in concealed facilities at the earliest possible stage. The strengthened nuclear non-proliferation regime (see Cooley and others in this volume) relies heavily on information collection, analysis and assessment processes. At the outset of the new century, the emergence of new crises has confirmed the central and vital role information processing plays at each levels of the international community, international, multinational and national.

- First crisis: The awful terrorist attack against the USA on September 11^{th}, stressed the need to set up specific legal and technical means to prevent and respond to such criminal acts, in particular to the use of weapons of mass destruction by terrorist groups. All these mechanisms are mainly based on information processing.
- Second crisis: In 2002-2003 strong suspicions arose that North Korea had developed enrichment capabilities. In the same period, Libya abandoned its weapons of mass destruction programme. The disclosure of its nuclear weapon project brought to light the A.Q. Khan nuclear black market was organized and managed from Pakistan by the scientist A. Q. Khan, the "father" of the Pakistani atomic bomb and the head of A. Q. Khan laboratories. Iran, has come under strong suspicion that it is developing a nuclear weapon programme based on highly enriched uranium and thus has breached its commitments under the NPT.
- Third crisis: In June and September 2003 an Iranian opposition group released information that Iran was building a large underground nuclear related facility at Natanz and a heavy water production plant at Arak which it had failed to declare. IAEA inspections revealed the existence of

other undeclared activities and equipment leading to the suspicion that Iran was conducting a secret nuclear weapon programme [4].

- Fourth crisis: While investigating the past nuclear programme of Libya, the IAEA discovered the existence of A. Q. Khan black market network of sensitive nuclear items such as centrifuge technology and know-how, centrifuge components and Pakistani drawings of nuclear weapon design. It was subsequently discovered that this network, the existence of which has been confirmed by the Pakistani government, extended across Africa, South Asia, the Middle East, many countries including several from Europe and it involved individuals and companies in these countries. Moreover, it emerged from the investigation that not only Libya and Iran but also North Korea and possibly other countries had benefited from the transfers through the network. Also, Libya may have given weapon design drawings and manufacturing instructions to other countries in the network. The ramifications and the nature of the transfers have not been fully investigated.

The investigation of these issues relies heavily on both **open and confidential information**. To provide evidence of breaches and of non-compliance, to highlight the threat to the international peace and security from those countries, and eventually to resolve these crises, strong cooperation is needed among responsible States, and multinational and international organisations. Such cooperation involves mainly exchange of information, analysis and assessment. Of significant value is the information from member States that possess national technical means and intelligence agencies to obtain, analyse and assess it.

The three previous articles of the section on "Information Collection and Analysis" are dealing with issues of the information infrastructure of a treaty [5], and issues of information collection and analysis at the international level [6] and the multinational level [7]. This chapter describes the process of information collection analysis and assessment at the national level in the context of nuclear proliferation watch as it is managed in France in order to assess threats to its national security or to the global security and to propose ways to monitor and redress the situation. This article deals only with nuclear non proliferation. The issues related to activities against nuclear terrorism will not be discussed because most topics are confidential. Nevertheless, the overall approach is, in general terms, similar to that dealing with nuclear proliferation.

The situation of France regarding nuclear issues is a special one. France is one of the five NPT nuclear-weapon States and a member of European Union. France, with a long history of nuclear achievements both in the civilian and military sectors, runs large scale advanced civilian nuclear facilities and has acquired recognized expertise in all steps of the civilian nuclear fuel cycle. From the development and maintenance of its nuclear deterrent, France acquired expertise in the design, manufacture and testing of nuclear weapons as well as on issues related to safety and security. In this context, France's national assessment of nuclear proliferation information based on this set of knowledge is unique. Nevertheless general features regarding national information collection and analysis could be extracted for wider applicability to both nuclear-weapon and non-nuclear-weapon States.

This chapter discusses the essential components of the information management process at the national level. These are: types of data/information, the nature of the information and that of its sources, raw and processed information, internal to the State or external, confidential or in the public domain. It also describes the sequence of steps through which raw data are collected, processed, analysed, merged, evaluated and assessed in order to extract information, transform it into knowledge and synthesize into a form that will guide the French authorities to formulate policies for action. The information is discussed at interdepartmental meetings to balance differing views and to allow high level assessment of the important issues.

2 National information collection within international context

The review of information collection, analysis and assessment at the national level is done in the context of the evolution of verification under the nuclear non-proliferation regime and the national support to international verification activities.

2.1 National information supporting multinational treaties implementation

Knowledge has always been a fundamental asset in the establishment and maintenance of personal or territorial power of leaders and nations by monitoring either the capabilities and intentions of adversaries or compliance of subjugated ones. With the birth of global security needs awareness, instruments to secure it were established which called for the development of international verification to enforce compliance with international obligations. As a result, information collection and analysis started to be an essential element of the security of the international community, in particular nuclear security and international safeguards as implemented by the IAEA under the NPT.

The principle of international verification of the commitments by the States to abide by the terms of agreements and not to engage in violations thereof is a post-Second World War novelty [8]. Until the early fifties, collection and analysis of information mainly by national technical means was confined to the national level, in response primarily to domestic or allied countries concerns. During the second half of the last century, the international community had to deal with threats due the huge arsenals of the United States and the Soviet Union and the risks posed by the accumulation of large stocks of weapon-grade fissile materials. The fear of nuclear weapons and their huge destructive power raised the vital need to stop their proliferation and to control the spread of nuclear technologies and fissile materials required to make these weapons. The awareness of this danger inspired the speech of President Eisenhower "Atom for Peace" fifty years ago (December 8, 1953) and gave birth to the IAEA (1957) and the first verification system. It paved the way to the Treaty on Non-Proliferation of Nuclear Weapons (1968).

Initially, only very light verification activities [9] were accepted by the Member States. But, facing the increasing risk of a nuclear war due to the uncontrolled proliferation of nuclear weapons with possibly up to 20 or 30 States possessing nuclear weapons at the end of the century, States, balancing benefit in security with loss of sovereignty, agreed on the NPT and, for all except five, undertook the obligation to forego any nuclear weapon ambition. Pursuant to the treaty, they have to conclude with the IAEA a Safeguards Agreement (INFCIRC/153), the scope of which is much wider than the previous ones [10].

Under the Comprehensive Safeguards Agreement, the IAEA has the right to verify all the declared fissile material and the facilities which contain them. For the first time in the history by joining the treaty, States parties agreed to relinquish a part of their sovereignty and to permit international inspectors to come into their territory and to move about freely in what they considered as their most advanced and sensitive research and industrial facilities in order to verify that the inspected State complies with constraining undertakings. To agree to inspections on their territories, States had to balance the breach to their national security against the benefit of an increase of the international security with the ultimate result of an increase of their own security. Some States were distrustful of on-site "intrusive" inspections which, in their view, could threaten the confidentiality of their sensitive and proprietary information[2].

Then, information collection, analysis and assessment at national level became an important element of State policies for enhancing both national security and international security through support of organisation like IAEA. Since the sixties, security issues have become the main global concern that has lead to the development of these multinational agreements which, in turn, expanded the uses of the information collected by National Technical Means and other national means [11]. The information was not only collected for domestic purposes, but also to support to some extend the activities of multinational or international organizations charged with verifying compliance with various treaties and agreements. Examples of such use of national information are the International Atomic Energy Agency safeguards [12], the Organisation for the Prohibition of Chemical Weapons [13], a future Comprehensive Test Ban Treaty Organisation [14], and the United Nations Security Council resolutions establishing the United Nations Monitoring, Verification and Inspection Commission [15] and the Iraq Nuclear Verification Office [16].

[2] See [8]: The Novelty of International Inspections.

2.2 The age of verification and monitoring: global security calls for more information

Now at the dawn of the 21^{st} century, the world has also to cope with the emergence of multiform and elusive terrorist threats from sub-state groups. To face up all these threats, numerous bilateral or multilateral agreements on disarmament, arms control and proliferation of weapons of mass destruction have been set up in every domain, nuclear, chemical, biological, and missiles, from the mid sixties as the Tlatelolco Nuclear Weapon free Zone Treaty (1967) to the Treaty of Moscow (2002) [17], the United Nations Security Council Resolution 1540 [3] and the Proliferation Security Initiative [18]. Most of them include dispositions allowing for verification of compliance [19].

In the early nineties, the discovery of the clandestine nuclear programme of Iraq, the difficulties of the IAEA to verify the initial declaration of North Korea and the discovery of undeclared plutonium production capabilities and the termination of South Africa nuclear weapon programme exposed the weaknesses of the traditional NPT safeguards to verify compliance. In order to achieve the disarmament of Iraq and prevent any resumption of prohibited activities, the IAEA, as the United Nations Special Commission (UNSCOM), set up under the Security Council Authority a very intrusive Ongoing Monitoring and Verification Plan. As a result of the failures of the initial safeguards system, the IAEA and the member States developed and adopted an ambitious programme, the Additional Protocol [20], to strengthen the safeguards The measures contained in the Additional Protocol to the Agreement between State and the IAEA, the spirit of which has been drawn from the experience of the IAEA in Iraq, give the IAEA extended rights of verification[4].

One of the most profound changes is the way in which information from a wide range of sources is collected and evaluated; it includes information from the declarations of the inspected country on facilities, fissile materials, nuclear related research and development, facility project, import-export, information from open sources such as media, commercial satellite imagery, information from "third party" such as member States, governmental and non governmental organisation. All information put at the disposal of the IAEA is used to determine the "correctness" and especially the "completeness" of State declarations, to verify the absence of indications of nuclear material diversion and undeclared nuclear material and activities, and to draw safeguards conclusions.

2.3 Are the strengthened safeguards strengthen enough? More information needed

In the beginning of the 21^{st} century, the recent crisis of the nuclear non-proliferation regime, North Korea again, Libya, Iran with the undeclared past

[3] See [3].
[4] See [1]: Introduction.

nuclear activities and the role of the A. Q. Khan network has highlighted the increased importance of collecting and validating information from all available sources; it also identified the need for good analysis and validation of the information in a global context.

All relevant information, including declarations from the States, results obtained from the verification activities of the IAEA, and from open sources and other ("third party") sources need to be evaluated in order to determine whether there is overall consistency in the available information about the State's past, present and planned nuclear programme and known technological and industrial R & D. Under the Additional Protocol, Safeguards conclusions must be based on the results of the "Evaluation of a State as a Whole". Henceforth, State evaluation is a continuous process through which all relevant information available to the Agency is analysed" [21].

Drawing lessons from the difficulties the IAEA has faced in implementing nuclear safeguards in Iran, the Director General has admitted that "even if Iran is acting as if its additional protocol were in force" [22, para.35] and if the IAEA is implementing measures under strengthened safeguards, i.e. measures under Comprehensive Safeguards Agreements plus measures under the Additional Protocol, the ability of the IAEA to verify the correctness and completeness of the statements made by Iran (that is to say, the ability of the IAEA to detect undeclared activities at undeclared sites) has reached its limits and that "Iran's transparency should go beyond those measures, including access to individuals, documentation related to procurement, dual use equipment, certain military owned workshops and research and development locations" [22, para. 50]. The Director General of the IAEA had already addressed the question of the bounds in the capabilities of the additional protocol. He has stressed the need for the verification system to be supported and supplemented by the sharing[5] of more "*actionable information*" in particular from an export control system as well as intelligence information in order to be able to detect low level clandestine nuclear activity [23]. The question then is: Should the safeguards system be strengthened further with the provision of more information and by moving to more stringent measures resembling more those used in Iraq? This issue has already been raised and is under discussion.

The collection, analysis and assessment of information at the international level, e.g., as required for an efficient implementation of IAEA safeguards[6], and at the national level, e.g., as required for a member State like France, are closely related. With the extension of the range and type of information collected by an international organisation like the IAEA, there are few but significant differences between the national and the international information systems. States have the capability to rely upon intelligence and national

[5] Editor's note: from member States and organisations like National Suppliers Group, EU,..

[6] And at multinational level as for the European Union (European Security and Defence Policy) or Nuclear Suppliers Group (NSG).

technical means not available to the international system to get sensitive "national" information. International organisations, such as the IAEA, have the capability to collect sensitive information including state's declarations, fissile material accountability and facility design information, inspection reports, sampling results, etc.., which are all confidential and have to be protected by the organisation.

Relying on their own information, member States could make their own assessment of a situation and support the work of international organisations by providing adequate and validated "national" information. The cross correlation of organisation information and analysis with that provided by member States will enable the organisation to enhance the quality of its evaluation of a given situation and contribute to maintain the international security.

3 National level process

Examining the process of information collection at the national level on nuclear security issues raises the following questions:

- What is the motivation for a State to acquire and maintain an independent national capability for evaluating information regarding security issues?
- What is the specific role of France regarding nuclear issues?
- What types of data should be collected and how should they be analysed?
- Who is the beneficiary of the analysis and evaluation of the collected information?
- Why are the evaluation of the quality of the information and the final assessment of the outcome of paramount importance?
- How is the information evaluated and assessed?

3.1 The motivation for an independent national evaluation of information relative to security issues

Collection, analysis and assessment of information is performed by international or multinational organizations such as, e,g,, the International Atomic Energy Agency, the North Atlantic Treaty Organisation, the European Commission and Council of the European Union and leading States such as the United States of America. There is a strong need for a country like France and some others to conduct an independent national evaluation of information regarding security issues, particularly nuclear ones. The need is generally twofold:

- A domestic dimension for issues, such as terrorist threats, that could directly affect the national security within the territory of the State, or for issues which could affect the security of the country as external direct threats to national interests.

- A multinational dimension when policies of some States that could endanger global or regional security (East Asia, South Asia, Middle East, Eastern Europe) may be questioned. Then the national policy based on national and international information should support and reinforce the multinational and international level: EU Council, IAEA, UNSCR, NSG, G8, etc...

When an event involves fissile or radioactive materials, nuclear related activities, hazardous chemical agents, such as toxic chemicals or atmospheric pollutants, or biological agents such as virus or bacteria, it may raise collective security concerns that have both national and international implications which are closely linked. To illustrate the point we will use an example involving nuclear security. Let us consider the case of a fictitious State which is suspected of non-compliance with its obligations under international agreements and which is suspected of having developed a military programme to acquire nuclear weapons capabilities along with delivery capabilities. When non-compliance is established and the existence of a nuclear military programme is very likely, even without clear evidences, the collective security becomes questionable. At that point it the situation needs to be assessed at different levels:

- At the international level by the IAEA.
- At the multinational level as for example in the European Union; the action there is driven by the Council of European Union and the High Representative for the European Security and Defence Policy.
- At the national level in order to assess the threat to a country's own interests and to those of the international community; the international dimension is necessary in order to determine how to help the organisations in charge find ways to resolve the crisis, improve security and maintain peace.

3.2 The particularity of France's status regarding nuclear issues

France's status regarding nuclear issues is somewhat particular both from a political point of view and a technical one. This particular status affects the manner in which France gets involved in the solution of issues relative to nuclear security. Consequently, the process of information collection and analysis implemented by France is likely to differ from similar processes implemented by most other States. Every State has its own specific methodology for collecting, processing and assessing the information it can obtain; however, the determining factors for developing specific methodologies are the political status and political environment of each State and the technical expertise upon which a State could rely. In a specific State, the process is strongly dependent on the type and the organisation of the government and, in the final analysis, on the priority the government assigns to the issue of proliferation of weapon of mass destruction and international security.

A political particularity

As one of the five Nuclear Weapon State under the terms of article IX, paragraph 3 of the Nuclear Non-Proliferation Treaty and a permanent member of the United Nations Security Council, France bears particular responsibility for the preservation and strengthening of international peace and security. Indicative of how this responsibility is being exercised are the actions of France against the proliferation of weapons of mass destruction. The principles upon which the national policy of France is based regarding nuclear security issues, such as nuclear disarmament, the fight against the proliferation of weapons of mass destruction and their means of delivery, and terrorism are articulated in a booklet "Fighting Proliferation Promoting Arms Control and Disarmament: France Contribution" distributed the 2005 NPT Review Conference [24].

A technical specificity

France has a long history of research and developments and a record of industrial achievements; it runs large scale advanced civilian nuclear facilities which cover the whole nuclear fuel cycle; in the process it has acquired recognized expertise in every step of the nuclear fuel cycle. From the development and maintenance of its nuclear deterrent, France has also acquired an expertise in design, production of fissile material, manufacture and testing of nuclear weapons as well as on pertaining to safety and security.

France's nuclear technical assessment relies for the competences of its nuclear research and development laboratories at the Atomic Energy Commission (Commissariat à l'Energie Atomique: CEA) [25]. In 1958, the prime Minister of France designated the Commission as the national technical advisor to the government for all questions of foreign nuclear policy in the area of civilian applications (fuel cycle, material production), military applications (nuclear weapons fabrication and testing) and legal aspects. The government also utilizes institutes such as the "Institut de Radioprotection et Sûreté Nucléaire", (IRSN) [26], administrative agencies such as the Customs Department, and Research and Development laboratories of the Ministry of Defence. It relies also on the unique expertise of nuclear fuel cycle operators like AREVA and COGEMA and on a network of high technology companies. This large pool of expertise allows France to analyse in depth all the steps and all the aspects of a proliferating nuclear programme (from mine to weapon including delivery capabilities) and to provide adequate support to international organisations like the IAEA or the CTBTO. The analysis, relying on expertise in the Ministry of Defence, may encompass other weapons of mass destructions and their possible means of delivery.

In that context, the mechanism used in France for assessing information regarding nuclear proliferation may be somewhat unique and not necessarily applicable to other States. Nevertheless, some general features can be extracted which could have wider applicability. The assessment of the international aspect of nuclear proliferation is made through the implementation of a methodology based on expertise, experience and technological tools. The assessment aims at the various stages of the proliferation process and emphasizes detection of the intentions of proliferation-capable States as early as possible. The methodology comprises development of scenarios of proliferation, highlighting of clandestine programmes and follow up of suspected military programme (cf. Iraq, North Korea, Iran, and Libya) or already established ones. Depending on the situation, monitoring and survey technologies, some very sophisticated e.g., satellite imagery, ultra-traces detection, bio chips, etc., are implemented in various domains such as open sources analysis, remote detection and sensing, bio-sensors, etc. Also, the proliferating capabilities from nuclear fuel cycle based on dual-use technologies (as gaseous ultra centrifugation for uranium enrichment) are analyzed.

3.3 Data collection and analysis process

France draws its conclusions from the analysis and assessment of all the information available to it, i.e., open sources, its own national technical means, supplied by allied countries [27], and international [28], multinational [29], or non-governmental organisations. It this context, of the type of the national technical means [30] the State has developed over an extended period of time and on which it can to collect information independently plays a very important role. In addition, information and analysis could be provided by foreign sources; the quantity and value of that information depends on the nature and closeness of relationships with allies, other States and multinational organisations.

Type of collected information

A wide range of sources of data types are taken into account for the assessment of a situation as shown in Figure 1. The process which aims to transform all the collected data in knowledge, available and reliable for making decisions has to consider three criteria: the source, the origin and the nature of the data.

1. 1. The nature of data could be:

- Data from open sources which encompass news medias, scientific media national and international open sensing networks, commercial satellite imagery, etc;
- Data from various sensors dedicated to specific monitoring tasks, such as the sensors of the International Monitoring System for the CTBT;
- Data from remote monitoring as satellite imaging sensors of various kinds, panchromatic, multi spectral, infra-red, radar, hyper spectral or open aerial imagery;

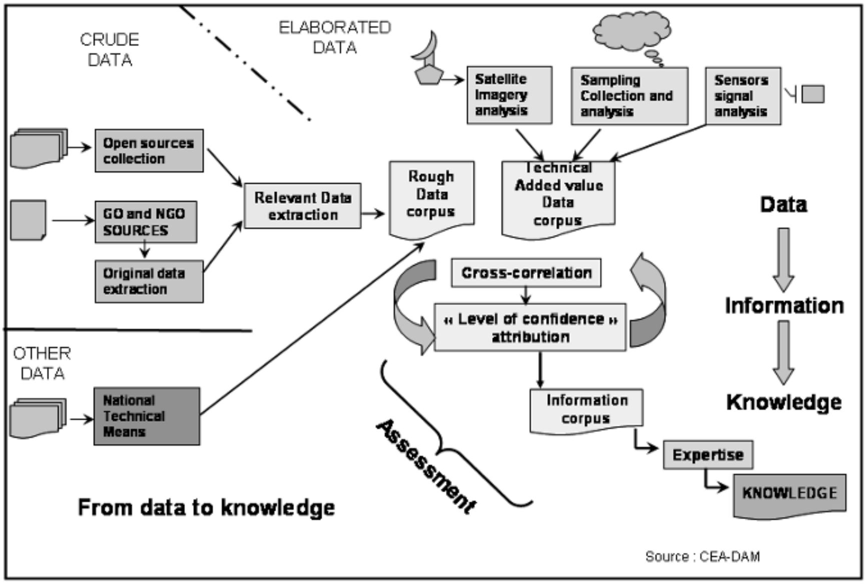


Fig. 1. Types and natures of information

- Data from environmental sampling.

2. The **origin of data**:

- National or international open sources as for instance the data from the auxiliary seismic stations of the International Monitoring System of the CTBT or commercial satellite imagery;
- National technical means, such as military satellite imagery, e.g., HELIOS, or other means of national intelligence;
- Bilateral exchanges between States;
- International or multinational organisations, e.g., IAEA, UNMOVIC / INVO, G8, NSG and Export Control, EU, NATO, etc.

3. The **nature of the data** could be:

- Raw, such as data coming from open sources which report information but don't do any analysis;
- Processed, such as data obtain by specific means that have been adapted to the objectives for which the data are collected. For example:
  - Environmental sampling
  - Detection from specific sensors
  - Imagery analysis
- Confidential requiring special handling.

3.4 Analysis and assessment methodology

Validation & Assessment principles

The validation of the collected data and the information from them could be separated into two main categories which are not necessary mutually exclusive:

- the **credibility** of the data
- the overall technical **coherence** of data

Credibility: One challenge facing the validation and assessment process is to be able to evaluate the quality of the data which depends on the credibility of the source and the confidence one has in it. That is particularly the case with data from some open sources such as the media and the Internet. In that sense, the sources of intelligence information and data are not that much different from the open sources, because most of the time such sources cannot be checked to help with the validation. A similar problem stems from using experts to evaluate the data. Since it would be difficult to question the judgement of experts, there is a danger that they could confuse the soundness of their own knowledge with the confidence one should have in the collected data. The only way to avoid this pitfall is to find ways to correlate data from different sources and expert judgements. A special attention has to be paid to this last point. One can easily demonstrate that seemingly multiple pieces of information in different formats could originate in a single source.

Coherence: Technical validation is often much easier. The goal is to correlate data coming from different sources to assess their overall coherence and eventually detect any missing data that could validate the main data corpus or to reappraise its credibility. Validation of non-technical information presents the most difficulties. In such cases, the methodology should include definition of a "confidence threshold" or a weight to be used as a template each times this type of information as to be screened. This weighting may change with time or when more credible information becomes available either to confirm or to invalidate the subject information. The confidence threshold approaches unity and has minimal impact for information considered inherently true or highly possible.

At the early stages of the process, what is collected through the different channels are raw "*data*" rather than "*information*". Whatever the source, the data have to be processed and validated before they can be used as basis for further analysis. This phase is not a simple one, particularly for open source data, becaue of the uncertainties associated with their source. The next step after validation consists of the transformation of the raw data into rough information. The second and the third steps consist of expert analysis and use of model(s) of the nuclear fuel cycle "***from mine to weapon***"; they consider all proliferation pathways: diversion, external assistance, undeclared facilities scenarios as in the "physical model developed and run by the IAEA in the frameworks of safeguards verification. See [3] and Figure 2.

In a physical model, all the basic steps of a nuclear fuel cycle and weaponization process are identified and described in detail including possible alternative technologies for each step and combinations of them, and possible proliferation pathways and their technical characteristics. Technical guidelines and handbooks are drafted to ease the analysis. These include:

- Various enrichment techniques, gaseous diffusion, ultracentrifugation, isotope laser separation, chemical separation, electromagnetic separation, vortex and nozzle tube, cyclotron plasma separation, etc;
- Different types of reactors, uranium metal and heavy water or graphite moderators, light water, research reactors, etc;
- Various reprocessing/plutonium separation techniques as Purex, Pyrochemical separation, etc;
- Weaponization processes, including fissile material processing, high explosive, triggering, fissile material attractiveness,...design and calculation, etc;

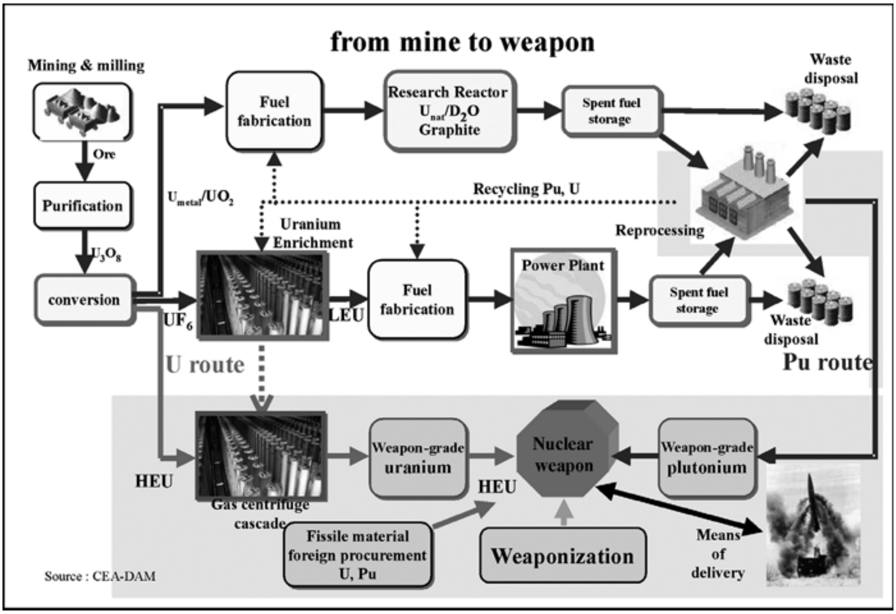


Fig. 2. From mine to weapon

Validation & Assessment framework

In order to be able to design and implement appropriate sensors for detecting indicators of possible activities, it is necessary to perform in depth technical analysis at each of the above-mentioned steps and to identify signatures associated with each of these activities. See Figure 3. Some examples of activities and signatures are:

- Satellite imagery: specific indicators and signatures.
- Environmental sampling: particle isotopic composition, impurities, dating, morphology.
- Procurement: undercover import network, front company, procurement of certain type of material and equipment (as maraging steel, certain magnets, balancing machines, flow forming machines, etc.

Understanding and monitoring proliferation involves three steps:

- Proliferation development phases (Figure 4a);
- Proliferation monitoring methodology (Figure 4b);
- Proliferation monitoring technologies (Figure 4c);

These along with the physical model and the list of indicators and signatures form the background for the information collection, analysis and assessment process.

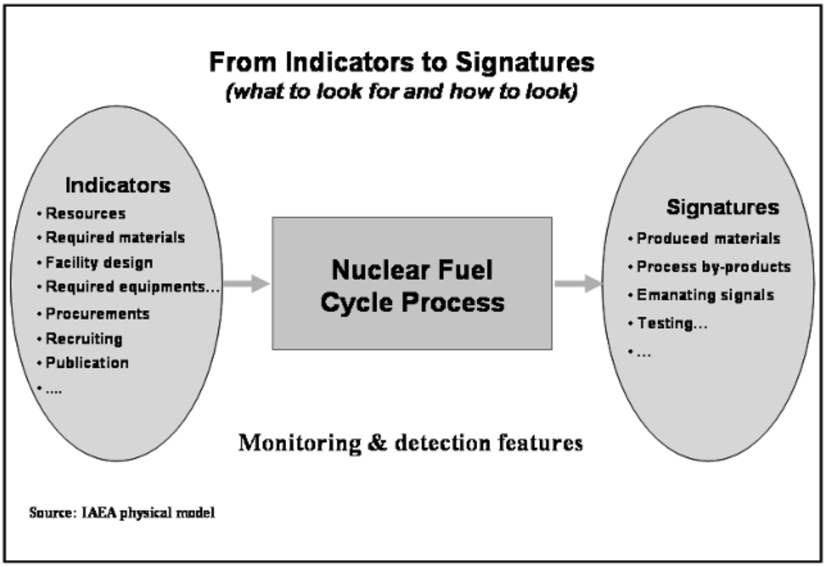


Fig. 3. Indicators (of activity) and signatures (of process)

Drafting guidelines and handbooks for proceeding along these steps requires the use of technical experts on nuclear fuel, weaponization and related technologies. It is important to realize that for a proliferator, the objective is not to develop an economic, safe and reliable nuclear fuel cycle; criteria

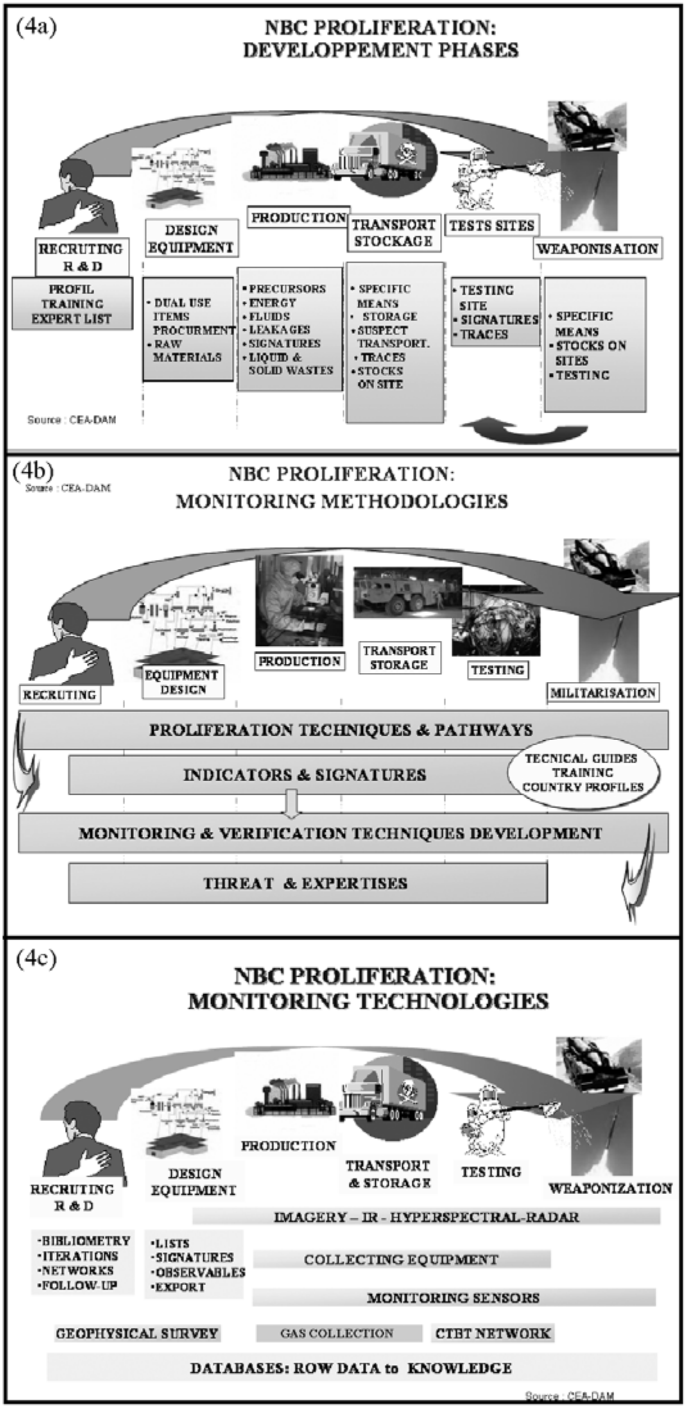


Fig. 4. 4a: Proliferation development phases, 4b: Monitoring methodologies, 4c: Monitoring technologies

for developing a nuclear weapon programme and for choosing the technologies does not follow the same logic. The aim of a proliferator is to produce fissile materials suitable for weapons as soon as possible with cost being a secondary consideration to ease of access and to secrecy of development. These objectives may require the use of technologies which could have been long abandoned in countries with advanced nuclear fuel cycle techniques; consequently, only retired engineers would have in depth knowledge of obsolete technologies. France and other countries with a similarly long record of nuclear development have the opportunity to rely on those experts and their knowledge to provide support to the national authorities and to organisations like the IAEA.

3.5 Importance of analysis and assessment

The main purpose of the analysis and assessment is to provide objective information with the lowest possible level of distortion. As a general principle, organizations prefer to make decisions on the basis of their own analysis of objective information and to minimize the influence of decisions made by external entities. This principle applies particularly to States that desire to make their own independent judgments on international issues. The authorities, under certain circumstances, need to have the ability to make optimal decisions, mostly fuzzy one, that are in consonance with objectives of the policies of the State. If the information provided to decision-makers is not robust enough, it may contribute to decisions that not only may not be in agreement with existing State policies, but they might even be contrary to such policies. In other words, information or knowledge submitted to the State authorities, are to be used in the framework of a policy. It is preferable for the decision-maker to arrive at a decision first by relying on the analysis of independently assessed objective information. Decisions arrived at through this process can be subsequently modified on the basis of external inputs.

Open sources data analysis

It is relatively simple to collect open source data; it can be done using automatic tools. But if the right query is not defined, the amount of data will turn to be very large posing difficulties for the analysts to extract the information they are looking for. That means that there should be continuous screening of the data, either automated or manual, on the basis of knowledge provided by experts. Although working with free open sources or open sources requiring payment has advantages, it also has disadvantages. The biggest problem is not to know what kind of processing the data have undergone and what criteria have been used before being disseminated by the open source. In other words, their validity is unknown. For example:

- **News from the classic media:** The data may be distorted, either intentionally by the editor, or unintentionally by a non-expert author in an effort to make the reading more interesting for the typical reader. This case illustrates two opportunities to disturb the real data.

- **News from scientific media:** The data from scientific media might be better than those from the standard ones, because they have to preserve their scientific credibility.
- **Data from Non Governmental Organizations (NGO):** Information from NGO, just like information from Governmental organisations is always tinted by political considerations. Sometimes, it's easy to extract the real information; at other times it is much more difficult. Assigning a level of confidence in a given data set would take into account the credibility of the NGO based on past history. The declaration of NCRI about the nuclear programme of Iran is a good example.
- **Data from technical sources:** When working on commercial satellite imagery for example, the situation is pretty different and the data are more reliable, except if they are provided already partially or totally processed by external structures and. In this case, specific teams are needed to drive a first level of expertise to extract the real information from a managed corpus. The validation is nearly only technical by specific treatment of the rough data.

Expertise

Expertise in all scientific and technical fields is the most important resource needed for conducting a reliable and credible screening of collected data and validating information. To make proper decisions governmental authorities need to base their actions on information prepared and validated by experts. Available expertise should cover both information technology areas, e.g., image processing, internet survey, language technologies, as well as the specific topics to which the information at hand refers, e.g., nuclear fuel cycle activities, weaponization, etc. Experts should involved in all steps of the process to select data to prepare the corpus of the information, question the credibility of the information, perform cross-correlation and data fusion, and validate the data. As more and more data are selected and screened they contribute to the accumulation of expertise.

Expertise is not only useful for dealing with current issues, but also for building the knowledge corpus to be used in future analyses. As shown in Figure 1, databases are a very important feature of the analysis and validation process. Databases are used for storing and retrieving information about past events, analysing new events and checking them against past knowledge. Databases as expert knowledge depositories contribute to the quality of the outcome. They are also needed to build and operate models of the proliferation process for use as templates for analysing and assessing nuclear activities deemed suspicious according to collected information (Fig. 2).

Cross-correlation and data fusion

Cross correlation of data and information, and data fusion are critical steps in the analysis and assessment process. As discussed, collected data on a specific event could originate in different sources and could cover a wide range of different activities. Cross correlation and data fusion can help identify gaps and inconsistencies in the information. For example, satellite pictures can be used to validate or invalidate information from scientific media relative to a facility; or import export information could contradict open source information. Cross correlation and data fusion can also help in developing a broad understanding of the event in question and preparing executive summaries for the decision makers. For each country of interest, the outcomes of the data fusion process could be used, in conjunction with a Geographical Information System, to identify on a map, facilities of interest along with all available information about each site. The information could also be integrated with that derived from a proliferation model and the nuclear fuel cycle.

3.6 Evaluation and Assessment process: national organisation

National organisation

When the specific acts that constitute non-compliance and proliferation are important enough to have a serious impact on international security and need to be raised in international fora such as the Board of Governors of the IAEA, the United Nations Security Council, etc, the French Government needs to develop its own position on the case and to determine ways to support the action of these organisations in consultation and coordination with its partners in the European Union and other important partners, such as the United States, Russian Federation, etc, through the exchange of proper and validated information and analysis. As mentioned earlier, the French authorities need to have the ability to arrive at their own conclusions independently in order for France to maintain the ability to draw its own conclusions independently and credibly (Fig. 5).

The position building process involves several ministries, Foreign Affaires, Defence, sometimes, the ministry of Economy, Finance and Industry (nuclear fuel cycle, fissile materials and export control) and the ministry of Interior (illicit trafficking, terrorism); they are coordinated at the Prime Minister level by the General Secretary for National Defence Ministries (SGDN) with some involvement of the Cabinet of the Presidency in the decision process. Having had a long involvement in non-proliferation issues, the ministries have created ad hoc structures to deal with proliferation of weapons of mass destruction, disarmament, nuclear weapons issues, global and regional security, transfers of sensitive technologies and nuclear terrorism; they have their own legal, political and technical expertise to address the issues.

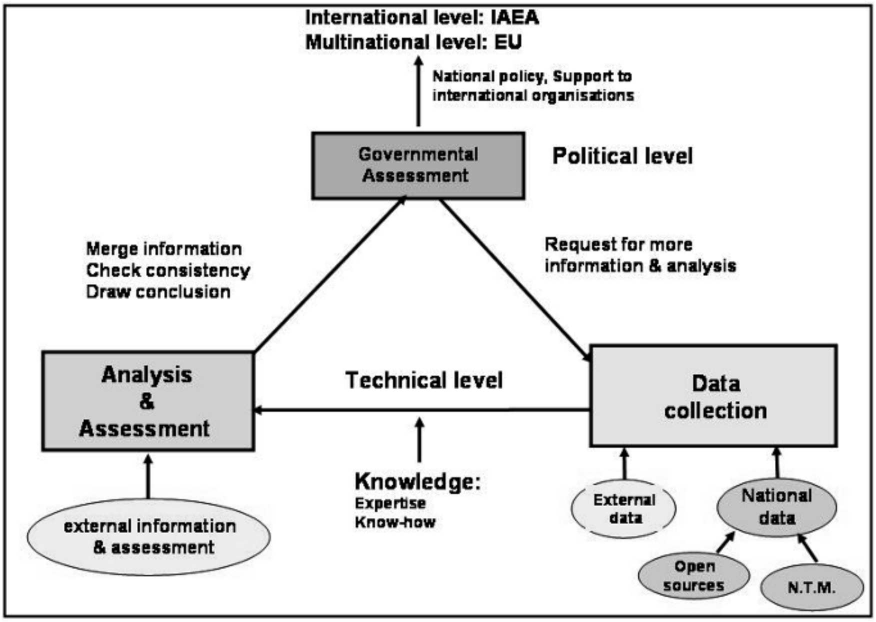


Fig. 5. National assessment

The comprehensive assessment starts with the technical evaluation. For nuclear issues, it draws on expertise of the French Atomic Energy Commission (CEA), the Institut de Radioprotection et Sûreté Nucléaire (IRSN) and nuclear industry operators such as AREVA and COGEMA and some others. Several Departments of the CEA contribute to the technical support of the ministries. In particular the Military Division Application (DAM) of the CEA provides expertise to the ministry of Defence for all technical aspects of proliferation and security issues and the International Relations Division of the CEA supports the ministry of Foreign Affaires. Tight links have been established between nuclear research and development laboratories, intelligence services which provide analysis based on national technical means and ministries which make policy. As the Director of International Relations Divisions of the CEA is also France's governor to the IAEA, this organisation constitutes an efficient channel to validate and transmit information to support the action of the IAEA for the implementation of international safeguards.

Who benefits from the analysis and evaluation of collected information?

At the national level, the policy making bodies of governmental authorities benefit from the information and analysis and determine the corpus of information that could be transmitted abroad. In particular, information, analyses, expertise, knowledge and technical support are provided to the IAEA for the implementation of safeguards and nuclear security either through the Board of Governors or through the French Safeguards Support Programme to the IAEA Divisions seeking such support. In return, the Support Program tries to satisfy those needs such as development of particular inspection tools, training on specific technologies, analysis, etc, with the aim to improve the implementation of safeguards and help the IAEA discharge its responsibilities.

The validation of the information transmitted to international bodies is of paramount importance as regards credibility of national authorities which may found their policy on this information and efficiency of international organisation which will base its action on this information, often in a difficult context.

The confidentiality issue

The question of confidentiality of the data and information collected, processed and evaluated is particularly important and difficult to deal with, when the outcome of the process has to be forwarded abroad, shared and discussed with another State or a group of States, multinational bodies or an international organization. The level of confidentiality of transmitted information has to be adapted to take into account the policies of the State concerning protection and classification of sensitive information. Some of the factors that are taken into account are: "need to know" policy, restricted dissemination and access, separate network, limitation inherent to any international organisation, the nature of the relation, and the needs of the recipient State or organisation.

At the other end, the IAEA and similar organizations, in return for having access to highly specialized tools and information should establish and implement a confidentiality policy with more stringent rules to protect the sensitive information it receives; otherwise, the source of information and the non-proliferation regime would be endangered. Though the management and protection of highly confidential information in the IAEA have been dramatically improved in the last years, some progresses still remain to be done.

The confidentiality level of the final product of the process within the State (Fig. 6) depends on:

- The nature of the processed data: open sources, national technical means / intelligence, foreign sources;
- The type of processing applied to the data. In particular, screening the data through protected software or analysing the data through particular expertise raise significantly the level of confidentiality.

Even if the original data are all obtained from genuine open sources as for example data from newspaper articles, agency dispatches, images from commercial satellites, the processed data may still be sensitive: for example:

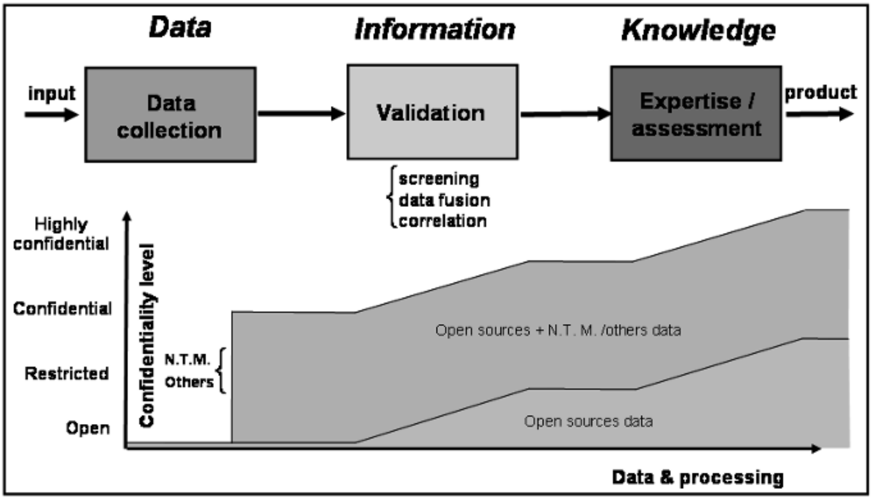


Fig. 6. Confidentiality level as a function of data's sources and processing

- Commercial satellite image focusing on a specific area or facilities could alert those who use the facilities or the area for undeclared activities;
- The ways these data are processed and analysed, for example, through a "physical model" that includes specific features and expertise on nuclear fuel cycle or weaponization;
- Specific types of image processing software for the commercial satellite images could make the final product confidential and its distribution restricted.

A fortiori, when information from national technical means or from intelligence is used during the analysis to validate open sources information, the outcome of the process is classified.

3.7 Some examples

The preceding discussion could be illustrated by an example drawn from the activities of the IAEA in Iraq. In 2003 and before, there were suspicions and investigations about alleged attempts by Iraq to acquire several shipments of about 100,000 high strength aluminium tubes to be used in gas centrifuge manufacture with the aim of producing highly enriched uranium, a basic fissile material necessary for the fabrication of nuclear weapons. However, extensive evidence collected during the IAEA inspections in Iraq, supported the conclusion that Iraq did not plan to use the tubes in gas centrifuges, but to use them as conventional combustion chambers for rockets. After intensive analysis based on data supplied by the Iraq Nuclear Verification Office and other sources, nuclear experts concluded that the tubes were never intended for the manufacture of gas centrifuges and were not suited for that purpose [31][32]. This outcome helped the Agency to defend its own conclusion in the framework of the overall assessment of Iraq's clandestine nuclear programme [33].

The assessment of the Democratic and Popular Republic of Korea (DPRK)'s plutonium production capabilities which is important for the evaluation of DPRK nuclear weapon capabilities or, if in the future this country accepts to abide to the international law and allows IAEA inspectors to resume their work, for the verification of DPRK's declaration is another example of how information from national nuclear expertise could help the Agency to carry out its responsibilities.

4 Conclusion

In the past, States performed information collection, analysis and assessment to support their own policies independently of any external connections. In the present international environment, information and analysis are no longer used for domestic needs only; they are also used to contribute to international and regional peace and security through exchanges with and in support of organisations in charge of verification of compliance of international agreements, such as the IAEA safeguards and the Non-Proliferation Treaty. Beginning in the fifties, instruments were created to respond to the global risks associated with the proliferation of weapons of mass destruction and their means of delivery and, more recently, with the emergence of hyper terrorism which may use such weapons. At the same time, several countries engaged in clandestine nuclear programmes and a multinational covert network was established for illicit trade of sensitive technologies. Following the discovery of these activities, international verification has become more intrusive and demanding. International organisations, like the IAEA, rely more on extended and assured support from member States to perform their task efficiently. The support is particularly needed in receiving of information to which it has no easy access and in performing analysis of the data that the organisation itself cannot do. Hence the roles of member States and international organisations regarding information collection and analysis are tightly bound and interdependent. Member States rely on their own national technical means and intelligence and their own capabilities to collect and analyse information. International organisations rely on the data collected by the verification system and on their own capabilities to collect and analyse open source information. Exchanges of information and knowledge between member States and international organisations, through appropriate channels such as the Board of Governors of the IAEA, and support through the Member States Support Programmes contribute to the clarification of concerns about suspicious programmes or issues and eventually to the international peace and security. So in the information collection, analysis and assessment process, the question of the validity of information is paramount both for the credibility of the policy-making bodies of the governmental authorities and for the international organisation which will base its action on the communicated information. The question of confidentiality is a very important question which needs to be carefully addressed when forwarding processed information, analysis and expertise abroad. Even when the source of information is open, the processing and analyses applied to an open source corpus of data may make them sensitive. Consequently, the recipient international organisation should have appropriate mechanisms in place to handle sensitive information appropriately, within the inherent limitations of international organisation in that domain.

References

1. Cooley, J. (1998): International Atomic Energy Agency (IAEA), Director, Department of Safeguards, Division Concept and Planning : "The Programme to strengthen the Effectiveness and Improve the Efficiency of Safeguards", *International Seminar on the 1998 preparatory Committee for the 2000 NPT Review Conference, ANNECY, France, 27 02 - 01 03 1998.*
2. United Nations (2005): International Convention for the Suppression of Acts of Nuclear Terrorism.
3. United Nations Security Council (2004): Resolution 1540, Adopted by the Security Council at its 4956th meeting, on 28 April 2004, document S/RES/1540 (2004), "*Affirming that proliferation of nuclear, chemical and biological weapons, as well as their means of delivery, constitutes a threat to international peace and security*"
4. Iran Watch (February 2005): "IAEA reports and other documents - Director General's Report: Implementation of the NPT Safeguards Agreement in the Islamic Republic of Iran (GOV/2003/40, 10 June 2003)". http://www.iranwatch.org/international/index-iaea.html.
5. Kyriakopoulos, N., "*The Information Infrastructure of a Treaty Monitoring System*", this volume.
6. Schriefer, D., " *Information Collection and Analysis: The International Level*", this volume.
7. Louis-Victor Bril, L-V., and J. G. M. Gonalves, "*Open Source Information Collection, Processing and Applications*", this volume.
8. Pierre Goldschmidt (2000): "IAEA Safeguards: Evolution or Revolution?", Keynote by IAEA Deputy Director General for Safeguards at the 41st INMM annual Conference, July 2000, New Orleans (Louisiana), USA.
9. Remarks: At the time the IAEA was created in 1956, States were very reluctant to accept safeguards on their civilian fissile materials. Only very light verification dispositions were accepted by States. Progressively, the narrow scope of verification as contained in safeguards agreement IAEA/INFCIRC/26 (1961), were slightly strengthened during the sixties as IAEA/INFIRC/66/rev.2 agreements (1968). This agreement remains the one still ruling the nuclear verification of the IAEA in the three non- parties to the NPT, Israel, India and Pakistan.
10. Pierre Goldschmidt, P., op.cit. "*The principle of international verification of States' commitments to abide by the terms of agreements and not to engage*

in violations thereof is a post-Second World War novelty. The initial call for international verification can be traced to increasing awareness of the benefits of peaceful nuclear energy use and the dangers inherent in its misuse, as witnessed by Hiroshima and Nagasaki. As more and more States started to develop nuclear capability, the fear was that, unless strictly monitored, international nuclear trade could lead to horizontal proliferation of nuclear weapons"

11. National Technical Means (NTM) comprise all the monitoring and surveillance of a country of its own.
12. International Atomic Energy Agency (IAEA), United Nations Organisation based in Vienna, in charge of Non Proliferation Treaty Safeguards verification.
13. Organisation for the Prohibition of Chemical Weapons (OPCW), United Nations Organisation based in The Hague, in charge of the implementation of the Chemical Weapon Convention (1992) which aims at the elimination of Chemical Weapons.
14. Comprehensive Test Ban Treaty Organisation (CTBTO) is the organisation based in Vienna which will responsible for the implementation of the Comprehensive Test Ban Treaty (1996) when it will enter into force.
15. United Nation Monitoring Verification and Inspection Commission (UNMOVIC), former United Nations Special Commission (UNSCOM) is the organisation based in New York, United Nations, which is responsible for the implementation of the United Nations Security Council Resolutions (UNSCR) for disarmament of Iraq and the elimination of Iraq's weapons of mass destruction excepted nuclear.
16. Iraq Nuclear Verification Office (INVO), former IAEA Action Team is the organisation based at the IAEA, Vienna which depend of the IAEA Director General and is responsible for the nuclear disarmament of Iraq under UNSCR.
17. Treaty between the United States of America and the Russian Federation on Strategic Offensive Reductions (SQRT/Treaty of Moscow) has been signed on May 24th, 2002 and entered into forced on June 1st 2003 (http://cns.edu/pubs/inven/pdfs/sqrt.pdf).
18. The Proliferation Security Initiative (PSI) is a global effort that aims to stop shipments of weapons of mass destruction, their delivery systems, and related materials worldwide. Announced by President Bush on May 31, 2003, it stems from the National Strategy to Combat Weapons of Mass Destruction issued in December. UN Security Council Resolution 1540, adopted unanimously by the Security Council, called on all States to take cooperative action to prevent trafficking in WMD. The PSI is a positive way to take such cooperative action (source: U.S. Department of States, The Proliferation Security Initiative, Bureau of Non Proliferation, Washington, DC, May 26, 2005, http://www.state.gov/t/np/rls/other/46858.htm).
19. As examples of bilateral instruments including verification disposition: Partial Test Ban Treaty and Threshold Test Ban Treaty, START I and II, ABACC organisation. Of multilateral instrument: the Open Sky Treaty, the Treaty on Conventional Forces in Europe and of international instruments as the Non-Proliferation Treaty. and the IAEA safeguards, the Chemical Weapons Convention and the Organisation for the Prohibition of Chemical Weapons, the Comprehensive Test Ban Treaty and the Provisional Technical Secretariat of the CTBT Preparatory Commission., Export Control Groups, NSG, Zangger, Australia Group, Missile Technology Control Regime and the Biological Weapons Convention as the SQRT/ Treaty of Moscow does not provide for verification.

20. International Atomic Energy Agency, (1997): *Model Protocol Additional to the Agreement(s) Between States and the International Atomic Energy Agency for the Application of Safeguards*. IAEA/INFCIRC/540 (corrected).
21. Renis T. (2004): International Atomic Energy Agency, Department of Safeguards: "*Drawing Safeguards Conclusions for a State as a Whole*", Paper presented at the 45th INMM Annual Meeting, Orlando (Florida), July 2004.
22. Iran Watch (2005): IAEA Reports and other documents document GOV/2005/67, 2 September 2005, para. 50 "*Given Iran's past concealment efforts over many years, such transparency measures should extend beyond the formal requirements of the Safeguards Agreement and Additional Protocol and include access to individuals, documentation related to procurement, dual use equipment, certain military owned workshops and research and development locations. Without such transparency measures, the Agency's ability to reconstruct, in particular, the chronology of enrichment research and development, which is essential for the Agency to verify the correctness and completeness of the statements made by Iran, will be restricted*" (www.iranwatch.org/international/IAEA/iaea-iranreport-09022005.pdf).
23. El Baradei M. (2004): Statements of IAEA DG, 21 June 2004, Carnegie International Non proliferation Conference: "Even a verification system making use of the authority under the additional protocol may not reliably detect low levels of clandestine activities such that conducted in Iran and Libya for many years, unless at the very least supported and supplemented by the sharing of actionable information from an effective system of export control as well as intelligence information where applicable available" (www.iaea.org/NewsCenter/statements/2004/ebsp2004n004.html).
24. Non-Proliferation Treaty 2005 Review Conference, (2005),: booklet distributed by France "*Figthing Proliferation Promoting Arms Control and Disarmament: France Contribution*".
25. Commissariat à l'Energie Atomique (CEA).
26. Institut de Radioprotection et Sûreté Nucléaire (IRSN)
27. So is the particular relationships and information exchange practices between NATO countries or NSG members.
28. For example information from IAEA board of Governors or from the future CTBTO International Monitoring System, International Data Centre information dissemination protocol.
29. As for NATO or the EU in the framework of European Security and Defence Policy.
30. The CTBT which provides for the use and the role of the National Technical Means in the verification process. (article IV, paragraphs 5 and 37). The IAEA safeguards verification system provides also for the use of "third party" information (see, 3).
31. Albright, D. (2003): "*Iraq's aluminium tubes: Separating Fact from Fiction*", December 5, 2003, on ISIS websites, www.isis-online.org.
32. Gellman, B. and W. Pincus (2003): Washington Post Sunday August 10, 2003, page A01, "*Depiction of Threat Outgrow Supporting evidence*".
33. International Atomic Energy Agency (2003): "*Fifteenth Consolidated Report of the Director General of the International Atomic Energy Agency under paragraph 16 of Security Council Resolution 1051 (1996)*" at www.iaea.org/OurWork/SV/Invo/reports/s_2003_422.pdf.

Emerging Verification Technologies

Verification technologies are either specifically designed for that purpose, or consist of instruments developed for other purposes and adopted for use in verification regimes. As technology evolves, ways need to be developed for using the new advances to improve verification. In addition to the research and development efforts, it is equally important to pay attention to the production phase in order to ensure adequate and reliable supply of these technologies.

Advanced Sensor Technologies

Jürgen Altmann

1 Introduction

For decades, the mainstay of verification of compliance with arms-control and disarmament treaties was formed by the so-called national technical means of verification (NTM) - mainly satellites, but also remote-sensing and air-sampling systems on aircraft and ships as well as at fixed sites, operating from outside the monitored territory and under sole control of the monitoring party. They are fully integrated in intelligence gathering, targeting and attack planning, with only a small portion of their capacity devoted to actual verification of agreements[1]. When Gorbachev introduced glasnost, co-operative verification - taking place within the monitored country, under mutually agreed rules - began in earnest[2]. Co-operative technical means of verification (CTM) appeared in the form of equipment for on-site inspections. They started in the form of binoculars, photo cameras and dictaphones for manoeuvre observation under the 1986 Stockholm CDE Accord and were greatly expanded with the 1987 Treaty on Intermediate-Nuclear Forces that stipulated not only various forms of temporary inspections, but even continuous presence at one missile production plant each in the USA and the then USSR. Weight scales, radiation detection devices, vehicle detectors, even large x-raying devices for whole missile containers were added to the list of equipment [1]. The Strategic Arms Reduction Treaty (START 1) [2] of 1991 included an impressive set of CTM for inspections (Table 1).

The 1990s were a golden age for arms control/disarmament and co-operative verification. Bilaterally, after START 1, USA and USSR/Russia

[1] However, NTM got accepted status with protection against interference in the first nuclear arms-control treaties, and rules were introduced to make their functioning easier, e.g., concerning non-encryption of telemetry during ballistic-missile tests.

[2] Of course, IAEA safeguards have been used for co-operative verification of the NPT since a long time, but the nuclear-weapon states take part only voluntarily and only with (parts of) their civilian nuclear facilities. Nuclear weapons and related facilities are excluded.

agreed on deeper reductions with START 2 (1993)[3]. The Treaty on Conventional Armed Forces in Europe (CFE) of 1990 between the members of NATO and (former) WTO is routinely being verified by on-site inspections [3]; the equipment includes night-vision devices, video cameras, tape measures and laptop computers. In 1992 the Open Skies Treaty was signed, allowing aerial overflights (including the non-European parts of the USSR/Russia and the territories of USA and Canada) taking photographs and video films at 30 cm, infrared images at 50 cm, and synthetic-aperture-radar images at 3 m ground resolution [4][4]. Specific equipment for sensing, sample-taking and analysis was introduced with the Chemical Weapons Convention of 1993 [5]. An extensive world-wide monitoring network with continuous large-scale signal processing is being built up for verification of the Comprehensive Test Ban Treaty of 1996 [5,6].

However, important areas of arms limitation are not being covered appropriately, either in substance or concerning verification, and the situation has deteriorated since about 2000. The ABM Treaty was abrogated 2002 by the USA. A prohibition on space weapons, though consistently demanded over decades by the international community, is not being negotiated. A fissile-material cut-off treaty, also urgent and wanted by a great majority of countries, has been put on hold. Concerning gaps in verification, the US-Russian Strategic Offensive Reductions Treaty (SORT) of 2002 has been criticised for not including any verification measures, leaving open what will happen after 2009, to which year START I will remain in force [7]. Much more burning is the gap concerning verification in the Biological and Toxin Weapons Convention of 1972; the negotiations on a compliance protocol were stopped in 2001, although increasing advances in biotechnology make reliable verification of compliance ever more pressing [8]. Even though there are a few examples of preventive arms control, limitations of dangerous upcoming new military technology is not on the international agenda, let alone discussion on their verification.

The end of the Cold War has not removed the arguments for arms control. Even though the fundamental ideological divide is no longer there, fundamentally the security dilemma is still at work. States try to provide their security by armed forces that prepare for war. Strong defence is usually linked to effectiveness in offence, too, so that military preparations create mutual threats. Agreed limitation and reduction of arms and forces do help, but need to be combined with adequate verification of compliance - otherwise the fear of circumvention by others would create strong motives for (covertly) breaking the rules oneself. Another, particularly timely, argument relates to terrorism. Weapons and other military systems could fall into the hands of terrorists,

[3] However, START II did not enter into force, due to delays and differences about the ABM Treaty.

[4] The treaty entered into force only 2002, but agreed test overflights were done from the beginning [4], App. D).

the easier, the smaller the systems are and the more generally available the knowledge and means for their production are. This holds for new chemical and biological warfare agents and for several new weapons that microsystems- and nanotechnology will make possible[5]. Without agreed limitations, systems and technologies would diffuse from leading states to many others, some of which would pose few restrictions on exports. Future severe terrorist threats could thus be prevented by early, adequately verified, limits that apply to the relevant countries.

Table 1. On-site inspection equipment and other co-operative verification schemes contained in the Strategic Arms Reduction Treaty (START 1, 1991). Note that the Treaty also includes inspections of reentry vehicles on ballistic missiles

Inspections	
linear measurement devices	measuring wheel
camera equipment	water-sampling kits
flashlight, magnetic compass, pocket calculator,	portable computers
tape seals, dosimeter, satellite receivers,	printers
radiation detection equipment,	accessories
curvometer,	digital multimeter
pair of dividers,	portable copier
weighing devices,	portable fax
theodolites,	video camera
levels	recorder
survey chains,	hand tools
rods,	fence vibration meter
stakes,	magnetograph recorder
light meters	oscilloscope
Portals, Exits	
TV cameras	traffic lights
infrared breakbeam system	electromechanical gate position sensors
magnetometric sensor	semaphore gates
induction loop	auxiliary equipment
weight sensors	gate seals
Doppler road sensors	data authentication devices
Perimeter	
TV surveillance system and lighting	fence sensor
video motion-detection equipment	cables and other auxiliary equipment
Operations Center	
building	computer equipment, office equipment
control console	communication equipment
Flight-Test Telemetry	
exchange of recorded tapes	exchange of playback devices
exchange of transmission format, encoding (incl. physical conversion factors)	limits on encryption

This chapter is devoted to several emerging verification and monitoring technologies that could be used in future disarmament and peace processes. The next section explains ground sensors, including results of own experiments and theoretical analyses. Section three discusses options offered by microsystems- and nanotechnology. The fourth Section presents challenge ar-

[5] E.g. large and small combat robots, including bio-technical hybrids, see Altmann [9,10].

eas of disarmament and peace with recommended topics for verification research. Section five gives a conclusion.

2 Unattended Ground Sensors

A ground sensor is a sensor which is (semi-)permanently deployed near the ground in the open. It senses some (physical, chemical, biological) quantity, usually converting it into an electrical signal; the latter is processed, possibly recorded and transmitted - often over a network - to a monitoring centre. Here we deal with unattended sensors that work without a person attending to them[6]. Sensors can work in a passive mode, taking in excitation that has emanated from the objects to be detected and travelled to the sensor. This may concern a chemical substance; physics-based quantities are sometimes direct contact, more often an (acoustic, seismic, electromagnetic) wave. Under conditions where the emitted power is too low, e.g. at night in the case of an optical sensor for electromagnetic waves in the visible range, an emitter can be added to illuminate the scene/object, so that a stronger reflection reaches the sensor. Such active detection is also used with radar.

For co-operative verification or monitoring, sensors are relevant which can detect objects or motion on land, on or under the sea, or in the air[7]. Table 2 shows such sensor types based on physics quantities, together with important properties. Some need direct contact, others have medium or (potentially very) long range. Depending on type, quality, protection against weather etc., the price varies widely. Objects of detection are vehicles, including ships and aircraft, persons, gunfire or explosions. A few countries have equipped their armed forces with sensor systems that use several types of Table 2[8].

In order to monitor designated lines day and night, under all weather conditions, passive sensors will often be most practical. In particular for heavy vehicles, acoustic and seismic sensors will give a detection range from 50 to several 100 m, so that in a sensor chain, a spacing of 50 to 100 m will suffice. Acoustic signals can also give an indication of vehicle type, so that the system can focus e.g. on heavy military vehicles.

In peace operations, unattended ground sensors could be used for various monitoring tasks, such as at a cease-fire line or at control/demilitarised zones[9]. In disarmament, they could monitor the perimeter of a facility or

[6] Other sensors can be hand-held or carried by aircraft or satellite. Different categories sense radioactive, chemical or biological substances. Aircraft- and satellite-borne sensors are remote ones by definition.

[7] The automatic seismic, infrasound and radioisotope sensors of the International Monitoring System of the CTBT Organization come under the definition of unattended ground sensors, too. For their properties, see [5,6].

[8] However, military specifications with the ensuing higher cost will not be needed in many verification tasks.

[9] van der Graaf [11].

even the boundary of a reduction zone. At exit-entry points or the roads crossing the boundary, close-range sensors with vehicle-type detection capabilities (e.g. optical cameras with illumination) would be used. The rest of the perimeter/boundary would be off limits for the vehicles of interest. Here, medium-range sensors would make sure that illegal crossings would be noticed immediately. Such an event would be relayed to a monitoring centre, and personnel would move fast to the alarm location to try to stop an infraction, or at least to document it unequivocally.

A special task for acoustic or seismic sensors would be the monitoring of deployment areas ("corrals") for launch vehicles of mobile intercontinental ballistic missiles (ICBMs). In a potential future scheme of co-operative early warning of missile launches (see below), vehicle sensors along the perimeters could make sure that the ICBM launchers do not leave their respective deployment areas[10].

Since 1988, the Bochum Verification Project has done research on the potential of unattended ground sensors for co-operative verification of limits on land and air vehicles. For detection independent of daytime and weather over medium range, we have focused on passive, acoustic and seismic (and magnetic) sensors. Since such signals of military vehicles were not known in the published literature, we have carried out a series of own experiments [12][11]. The following paragraphs give exemplary results of our research on acoustic and seismic signals of heavy military vehicles [12 and refs.] and of military aircraft [14,15,16].

Concerning *land vehicles*, our experiments have shown that the maximum acoustic amplitudes decrease about proportionally to r^{-1} with distance r, as theoretically expected. Seismic amplitudes, on the other hand, generally show a steeper decrease, averaging about $r^{-1.6}$, however with marked local variations (Figure 1 a gives an impression). Using reasonable thresholds and background-noise amplitudes, acoustic as well as seismic detection ranges are about 50 m for medium trucks, 100 m for heavy road tractors and clearly above 100 m for tracked vehicles. With a spacing of 50 or 100 m in a sensor line (depending on the target vehicles), a pass across the line would be sensed by at least two sensors.

Figure 1 a demonstrates two interesting results for main battle tanks: At least at medium distances the seismic amplitudes from different types passing with about the same speed are similar, independent of the ground on which they drive (hard or terrain road) and of the presence of rubber pads on the track elements (M 48 and Leopard 1 with, T 55 without). Figure 1 b shows how the seismic peak amplitude increases with speed, and that generally the heavier vehicles produce higher excitation.

[10] Sensors should not be distributed within the deployment areas to keep the exact location of the launchers secret - this is required for stability against a first strike.

[11] See also [13]. Full experimental details are provided in our Verification - Research Reports. See http://www.ep3.ruhr-uni-bochum.de/bvp, Publications.

Table 2. Comprehensive selection of possible sensor types for objects or motion. Road control points include portals of enclosed areas (after Blumrich [11])

Sensor type	Active/ Passive	Range	Costs in US$	Available with existing systems	Recommended for	Possible applications
Mechanical, acoustical sensors						
Contact switch	P	0	a few 100	no	only few cases	detection of vehicles, counting of axles, velocity
Piezo-electric pressure sensor/cable	P	0	300-3,000 resp. 70,000/km	yes	Enclosures, road control points	weighing, counting of axles, velocity, wheel base, monitoring fences
Geophone	P	10 m-several km	100-7,000	yes	almost all cases	detection of persons, vehicles, aircraft (also recognition), and gunfire
Microphone	P	100 m-several 10 km	30-3,000	yes	almost all cases	detection of vehicles and aircraft (also recognition), and gunfire
Hydrophone	P/A	100 m-several 1,000 km	3,000-7,000	no	rivers, some coastal areas	detection of boats, ships, amphibian vehicles, underwater detonations
Ultrasonic sensor	A	several 10 m	100-1,000	no	only few cases	detection of vehicles, vehicle profile
Electrical, magnetic, optical sensors						
Magnetometer	P	several 10 m (SQUID: several 100 m)	100-3,000	yes (SQUID: no)	road control points	detection of vehicles, armed personnel
Induction loop	A	1 m	7,000-20,000	no	road control points	detection of vehicles, velocity and length
Conventional photo camera	P/A*	several m-several km	100-3,000	no	not recommended	person, vehicle, and aircraft identification
Digital photo camera	P/A*	several m-several km	several 1,000	no	only few cases	person, vehicle, and aircraft identification
TV camera	P/A*	several m-several km	700-7,000	yes	almost all cases	person, vehicle, and aircraft identification and tracking
Infrared camera	P/A*	several km	10,000-1 million	no	only few cases	person, vehicle, and aircraft identification and tracking
Infrared sensor	P/A	10 m-100 m	100-3,000	yes	almost all cases	detection of persons and vehicles
Break-beam device	A	several m-several 100 m	30-300	yes	road control points	detection of vehicles, velocity and profile
Fiber-optic cable	A	0	7,000-14,000 / km	no	enclosures	detection of persons, vehicles, and destruction of enclosures
Radar	A	several m-several 100 km	7,000-sev. millions	only singly	cease-fire lines	detection of vehicles, artillery, aircraft, ships, tracking and possibly identification
Lidar	A	several m-several km	700-700,000	no	not recommended	detection of vehicles, artillery, and aircraft, tracking and identification

*active with additional illumination

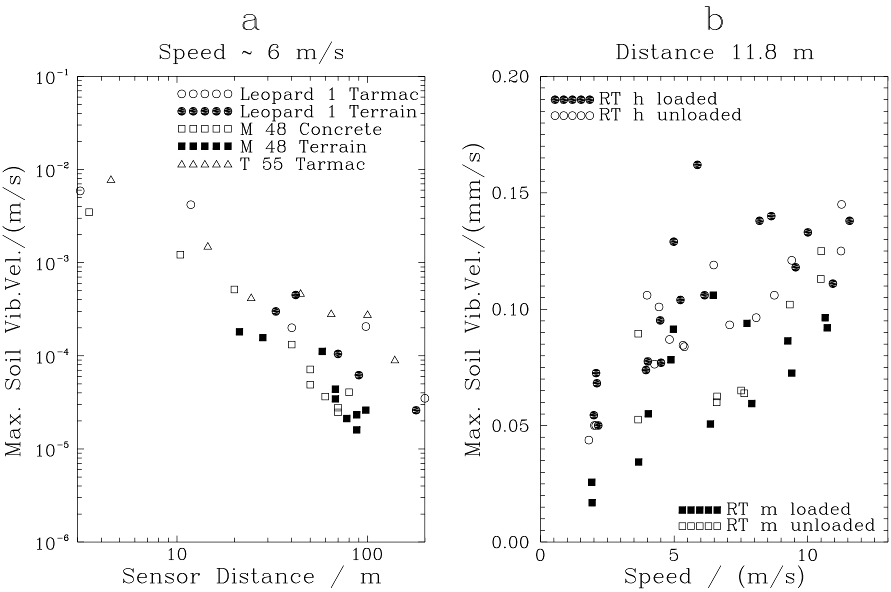


Fig. 1. Similarity and variability of seismic amplitude under different conditions (From Altmann [12]). a) Peak values of vertical soil vibration velocity versus distance for main battle tanks of different types, driving on different soils and road types, during passes with about 20 km/h. b) Peak values of vertical soil vibration velocity versus speed at 11.8 m distance from the lane centre, during passes of a heavy (MB 2648, RT h) and a medium (YTV 2300, RT m) road tractor, loaded and unloaded

While acoustic signals propagate, they keep their signal form, so that propagation delays between different sensors can be estimated e.g. by cross correlation. This allows to determine the direction to a source with its variation over time. Seismic signals, on the other hand, suffer from marked form change even for closely spaced sensors. This can be explained by dispersion of Rayleigh surface waves together with soil variation. Thus, the direction to a vehicle cannot be determined easily by beam forming; this is different from usual geophysical measurements where waves from earthquakes or explosions propagate uniformly across a sensor array.

In spectra of acoustic as well as seismic signals, there are harmonic series of lines connected to the engine, and additionally to the track for tracked vehicles (Figure 2). The higher stationarity of acoustic spectra makes them better suited for vehicle-type recognition. We have used the relative powers of the engine-related line series and found that out of 4 tracked and 4 wheeled vehicle types, the former could be recognised correctly above 90%, the latter above 60% of the time [13]. We have observed variation of the relative powers of the engine harmonics with engine rotation rate and, for some vehicles, with the observation angle. For vehicles with two exhausts, the latter can be explained by superposition of the signals from the left and right exhaust where the propagation-time delay varies with direction.

With respect to *military jet aircraft* moving on or near an air base, we have found that the acoustic and seismic amplitudes during take-offs are 1-2 orders of magnitude above those of landings. A chain of sensors along the runway(s) can detect these and other activities (such as overflights) and differentiate between them - using the maximum amplitudes as well as the time delays between their occurrence at the different positions (Figure 3). By triangulation using two three-dimensional microphone arrangements off the runway one can find the trajectory of a moving aircraft with remarkable accuracy (10-20 m for distances of 200 m, Figure 4). Due to the broad-band noise from jet engines, type recognition is not too promising.

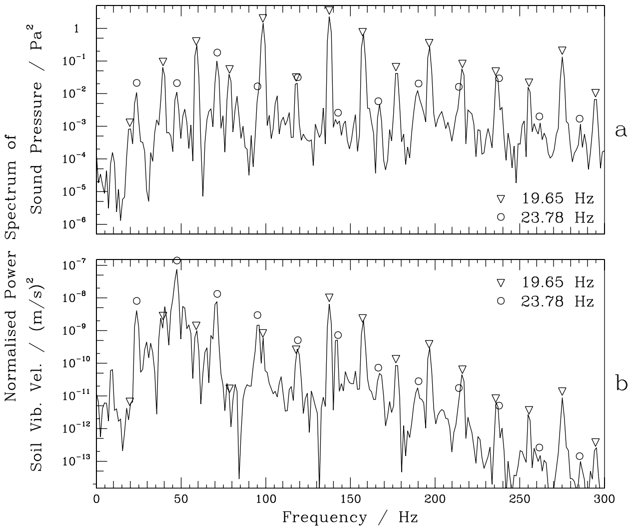


Fig. 2. Acoustic (a) and vertical seismic (b) power spectrum at 11.8 m distance when a Leopard-1 main battle tank just passed the zero point. Symbols (engine: triangles, track: circles) mark all integer multiples of a fundamental. (From Altmann [12])

Acoustic and seismic sensors can also be used to detect *launches of intercontinental ballistic missiles* [17]. This is important since mainly for economic reasons the Russian early-warning system has deteriorated significantly; not all satellites are being replaced, and there are gaps in the radar coverage. During several hours per day Russia cannot convince itself that no nuclear attack is underway. Co-operative early warning by sensors near the missile silos would provide an additional channel for double-checks in case of errors in the early-warning system.

Missile launches are extremely loud events. About 0.5% of the kinetic power of the exhaust gases is converted to acoustic power - typically, 5-15

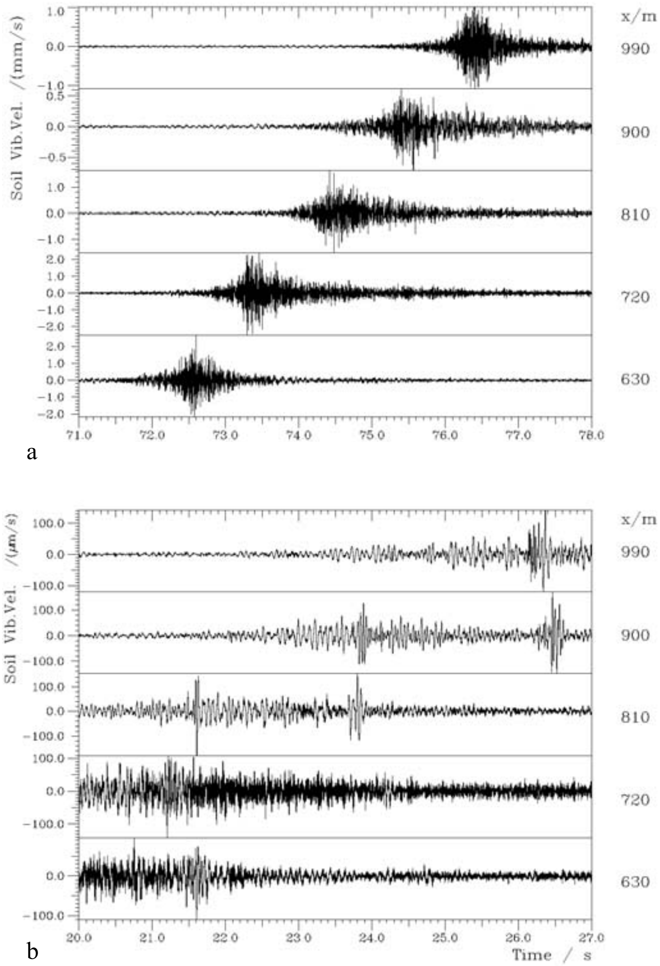


Fig. 3. Seismic signals at the runway margin during a take-off (a) and a landing (b) of a Tornado fighter/bomber (after Blumrich, [11]). Geophone co-ordinates along the runway are given on the right. With the mutual distance of 90 m, the average velocity in (a) is 95 m/s. From the maxima of the engine-caused high frequency vibrations in (b) one derives a speed of around 50 m/s. The short pulses in (b) are caused by expansion joints. Note the much lower amplitudes compared to (a)

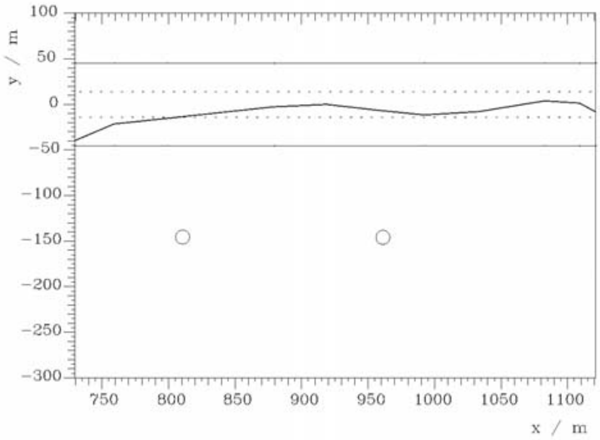


Fig. 4. x/y trajectory of a landing Tornado fighter/bomber, determined by triangulation from two 3-D microphone arrangements at the positions indicated. Dashed line: part of the runway usable for aircraft, time interval: 12 seconds. The trajectory agrees well with the actual track of the aircraft at the runway centre line. (From Blumrich, [14])

MW. This propagates outward as broad-band noise mostly between a few Hz and a few 100 Hz, the main effect being geometric attenuation in proportion to inverse source distance. Microphones can easily take up this noise, but would be exposed to the weather, requiring maintenance. However, the sound pressure also acts on the ground. The acoustically induced ground motion can be sensed by seismic sensors (geophones, i.e. velocity sensors, or accelerometers) that can be buried; spoofing would be much more difficult. The acoustic-seismic transfer factor depends on the soil, but is usually between 10^{-6} and 10^{-4} m/(s Pa). Considering background noise (below or around 1 μm/s) and noise from other natural sources (thunder) as well as artificial ones (mainly jet aircraft), one arrives at a recommended sensor distance from the silo of 100 m to 1 km. The maximum sound pressure will then be in the range 10-500 Pa (level 114-148 dB re. 20 μPa), the soil velocity in the range tens of μm/s to several mm/s. A launch can be differentiated from other sources of similar strength by spectral characteristics (broad-band noise, maximum at several 10 Hz) and the amplitude time course (smooth increase, then decrease during many seconds)[12]. Since typically, silos are located at around 10 km mutual distance, one sensor (or arrangement of 3 sensors) is needed for each silo. A secure link has to provide continuous real-time communication to the

[12] Thunder from close range would show short claps with steep increases and decreases of amplitude. Aircraft overflying at short distance would produce shorter signal durations; additional discrimination can be provided by evaluating the (time-varying) direction to the source using 3 sensors near each silo.

monitoring side. Costs would be around \$50,000 per silo - a very small figure considering the cost of the missile (tens of millions of \$).

3 Technologies offered by Microsystems- and Nanotechnology

Microsystems technology (MST)[13] deals with structures of 0.1 to several 100 μm size, and nanotechnology (NT) works at 0.1 to 100 nm, down to the level of atoms and molecules (1 nanometre = 10^{-9} m). MST and NT are areas of intense research and development (R&D), but NT is much broader and promises revolutionary changes. Military applications of MST and NT could create dangers to arms control, stability, and humans and society. Among the particularly problematic applications are new types of (small) weapons, autonomous combat systems, small robots including bio-technical hybrids, body manipulation, new chemical/biological warfare agents. These applications should be limited preventively while not hampering the positive civilian uses [9,17].

Singly or combined, MST and NT provide many new possibilities for monitoring and verification. In particular NT will provide much more powerful computers with strongly improved artificial intelligence. These could be used to search data bases, the public media, the Internet in order to find patterns of activity that might indicate illegal behaviour. Equipment as well as persons could be tracked - e.g., scientists or engineers with special knowledge. The downside is that this brings a strong danger to privacy that could be very difficult to contain.

Generally, NT will allow electronics, optronics, communications equipment etc. that are much smaller and have a much lower power demand compared to present systems. This will give portable systems far more capabilities; systems can be integrated in, e.g., glasses or garments. The scope for on-site inspection equipment can widen markedly - however, at the cost of increased mistrust concerning additional, non-sanctioned functions. Swarms of small satellites, launched cheaply by small rockets, could form a large-baseline radar, providing global monitoring with very good ground resolution at relatively little cost. However, the potential for anti-satellite attack will have to be restrained.

MST and NT will make sensors more sensitive, smaller and less power-consuming. In many cases, different sensors as well as processing, recording and communicating electronics will be integrated, and series production will allow low cost. Thus, sensors could be used cheaply in many places - fixed, in hand-held or worn equipment. They would be linked into a (ubiquitous) network. Among the physical quantities sensed can be acceleration, pressure,

[13] Sometimes MST is also called micro-electro-mechanical systems (MEMS), but it comprises also optical, magnetic, chemical etc. principles.

temperature, contact, magnetic field strength, various forms of radiation. Optical sensors can provide images in the infrared, visible and ultraviolet regions. Chemical sensors can signal pH and concentrations of other ions. Labs on a chip will provide total chemical analysis, including small versions of traditional analysis equipment such as gas chromatography and optical spectroscopy. Chemical substances/agents or biological organisms can be detected by key-lock recognition, using a specific base pattern on one DNA strand or a particular antibody. Binding can be signalled by a change in electrical conductivity or fluorescence. Functionalised dendrimer molecules or carbon nanotubes can also play a role. Parallel multiple detection is possible by arrays of sensitive reactants. Much R&D potentially relevant for verification is being carried out in the context of homeland security - for detection of dangerous chemicals or pathogens.

NT provides the new technique of cantilevers (of sub-μm size) as in scanning-probe microscopes. With appropriate coating, binding of specific molecules will increase the mass of the lever which in turn can be sensed by a change in the mechanical resonance frequency. In another scheme, selective binding closes a pore in a membrane which reduces the ion current through the pore. If the selective coating is applied to magnetic nanoparticles, they can be used to remove the agent of interest from a solution.

Similar sensor systems could be used for future verification. One sort would improve the methods of the existing verification system of the Chemical Weapons Convention. More important would be the creation of equipment for detection of old or new biological weapons, or of preparations for them, to be used in the compliance and verification protocol of the Biological and Toxin Weapons Convention that does not yet exist, but that gets ever more urgent[14]. Small, cheap and numerous chemical and biological sensors could be used at fixed sites, on board mobile items (transport boxes, containers), in any piece of equipment. They could also be used during challenge inspections to test samples of body fluids for indications of exposure to certain agents - in vitro and principally also in vivo. Also here the danger to privacy and human dignity has to be acknowledged and protective measures are needed.

MST and NT will allow small tags that sense quantities that are important for the transport history of an item (e.g. acceleration, temperature, humidity), record them in memory and can be interrogated e.g. with radio frequency. This principle could also be used in seals and locks.

Finally, there is the possibility of small robots with sensors. Their size could be decimetres, later centimetres or even millimetres. If cheap enough, they could be scattered in high numbers. They might autonomously roam a region, searching for illegal or suspicious activities or substances. However, small robots are highly ambivalent; there is a strong potential of misuse for

[14] Negotiations on a compliance and verification protocol were stopped in 2001 mainly because of US resistance, [18]: Section 8.6.

espionage and even for (criminal, terrorist, military) attack that more than outweighs the potential verification uses.

4 Challenge Areas and Topics for Verification Research

With scientific-technical advances arise requirements for new methods and means for the verification of agreements in the interest of peace and international security. On the one hand, the world needs improved methods for existing agreements, also to counteract their undermining by new developments that were not available at the time of signing. On the other hand, there is a necessity of new agreements - some requested by the international community since a long time, e.g., a space-weapons ban, some to contain dangers from upcoming new technologies preventively[15].

The following list gives an incomplete overview of the areas where verification and monitoring research is needed. Some of it is already underway. Verification has to meet various requirements; in the first place, it has to provide sufficient information on compliance to potential opponents while simultaneously accepting legitimate (or perceived) needs for secrecy. There is a complex interaction between the substance of an agreement and its verification methods. In devising rules and limits for technologies or systems, not only have restrictions on military applications to be balanced with positive civilian uses; also verification introduces costs and other burdens. Thus, economic, political and other factors enter the considerations. These factors form their own topics, mainly for social-science research. They are not static, and in particular their change may be interesting. In order to not restrict verification options prematurely, however, scientific-technical research should be carried out independently of economic and political considerations to some degree.

Verification research is needed in many areas, among them:

- nuclear safeguards: safeguards for nuclear final depositories, for accelerator-driven systems, for fusion reactors; inclusion of tritium as special nuclear material;
- nuclear weapons: disarmament of tactical nuclear weapons; nuclear-weapon free zone in Europe; limits on nuclear submarines; fissile-material cut-off treaty;
- chemical/biological warfare agents: detection, in particular of new agents;
- UN peace operations;
- land mines: improved detection, reduced false-alarm rate;
- container security;
- limits on small arms and light weapons;
- limits on ballistic missiles: launch detection;

[15] For a detailed discussion of preventive arms control see Altmann [17], Ch. 5.

- ban/limits on space weapons: observation from ground, from space, pre-launch inspection;
- ban/limits on small/large, unarmed/armed, military/civilian robots;
- limits on cyber warfare;
- software for finding indications of non-compliance in publicly available media;
- beyond peace and international security: agreements on the environment, climate and resources[16].

Of course, advances in generic areas such as sensing, non-destructive analysis, information processing, communications will be beneficial. Specific technology areas may be neglected in other contexts, but could be particularly fruitful for verification. One example is a gravity gradiometer, a relatively non-intrusive means of detecting the presence of high-density material. It has been discussed for verifying the number of nuclear warheads on top of a missile without lifting the shroud, and could conceivably also be applied in safeguards.

On the systems level, verification research should deal with:

- communications, data storage, automatic processing;
- the relationship between encryption and transparency;
- the relationship between efficiency and cost;
- the relationship between false-alarm rate and probability of detection.

Social-science and interdisciplinary research should be devoted to:

- a UN register of military research and development;
- the economics and organisational aspects of verification;
- the acceptance of transparency in different sectors (military, industry) and different countries/cultures, and ways for improvement;
- the relationship between armament levels and required intrusiveness of verification;
- ways toward strengthening international, co-operative verification.

5 Conclusion

Many technologies are already available that could improve verification. Others are on the horizon, in particular using advances in microsystems- and nanotechnology. Intensified and widened research would help, even though not all projects will lead to practicable verification means or methods.

Even though the availability of means and methods for adequate verification is a necessary prerequisite for agreements that limit military capabilities in the interest of peace and international security, ultimately, the decision to enter such agreements is a political one. A task of major importance is thus to improve the conditions for such decisions.

[16] See e.g. MacFaul, [19].

References

1. Altmann, J. (1992): On-Site Verification Technologies - An Overview. In: Altmann, J., H. van der Graaf, P. Lewis and P. Markl (eds.) (1992), *Verification at Vienna - Monitoring Reductions of Conventional Armed Forces*, Gordon & Breach, New York etc.
2. START 1 (1991): Protocol on Inspections and Continuous Monitoring Activities, Annexes 8, 9; Protocol on Telemetric Information. In: *START - Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms.* U.S. Arms Control and Disarmament Agency, Washington DC
3. Zwilling, M. (2006): Treaty on Conventional Forces in Europe (CFE). This volume.
4. Dunay, P. M. Krasznai, H. Spitzer, R. Wiemker and W. Wynne, (2004): *Open Skies - A Cooperative Approach to Military Transparency and Confidence Building.* UN Institute for Disarmament Research/UNO, Geneva/New York
5. Carlson, J. (2006): Experience and challenges in WMD treaty verification: a comparative view . This volume.
6. Kalinowski, M. B. (2006) Comprehensive Nuclear-Test-Ban Treaty CTBT Verification. This volume.
7. Boese, W. and J.P. Scoblic (2002): The Jury Is Still Out. Arms Control Today, Vol. 32(5), pp. 4-6
8. Nixdorff, K. (2006): Biological Weapons Convention (BWC). This volume.
9. Altmann, J. (2001): *Military Uses of Microsystem Technologies - Dangers and Preventive Arms Control.* Agenda, Münster
10. Altmann, J. (2006): *Military Nanotechnology: Potential Applications and Preventive Arms Control.* Routledge, London/New York
11. Blumrich, R. (1998): Technical Potential, Status and Costs of Ground Sensor Systems. In: Altmann, J., H. Fischer and H. van der Graaf (eds.) (1998): *Sensors for Peace - Applications, Systems and Legal Requirements for Monitoring in Peace Operations.* UN Institute for Disarmament Research/UNO, Geneva/New York
12. Altmann, J. (2004): Acoustic and Seismic Signals of Heavy Military Vehicles for Co-operative Verification, *Journal of Sound and Vibration*, Vol. 273(4-5), pp. 713-740
13. Altmann, J., S. Linev and A. Weiß(2002): Acoustic-Seismic Detection and Classification of Military Vehicles - Developing Tools for Disarmament and Peacekeeping. *Applied Acoustics*, Vol. 63(10), pp. 1085-1107
14. Blumrich, R., (1998a): Sound Propagation and Seismic Signals of Aircraft Used for Airport Monitoring - Investigations for Peace-Keeping and Verification. Verification - Research Reports, no. 10. ISL, Hagen
15. Blumrich, R. and J. Altmann (1999): Aircraft Sound Propagation Near to the Ground: Measurements and Calculations. *ACUSTICA - acta acustica*, Vol. 85(4), pp. 495-504
16. Blumrich, R. and J. Altmann (2000): Medium-range localisation of aircraft via triangulation. *Applied Acoustics*, Vol. 61(1), pp. 65-82
17. Altmann, J. (2005): Acoustic-Seismic Detection of Ballistic-Missile Launches for Cooperative Early Warning of Nuclear Attack. *Science and Global Security*, Vol. 13(3), pp. 129-168

18. Nixdorff K., M. Hotz, D. Schilling and M. Dando (2003): *Biotechnology and the Biological Weapon Convention*. agenda, Münster
19. MacFaul, L. (2006): Developing the climate change regime: the role of verification. This volume.

Monitoring Reactors with Cubic Meter Scale Antineutrino Detectors

Adam Bernstein and Nathaniel Bowden

1 Introduction

Fission reactors emit huge numbers of antineutrinos. These highly penetrating particles may be useful for the measurement of two quantities of interest for reactor safeguards: the reactor's power and plutonium inventory throughout its cycle. Despite their small interaction probability with matter, the high flux of antineutrinos from reactors means that cubic meter scale detectors at tens of meters standoff can record hundreds or thousands of antineutrino events per day with a signal to noise ratio of ten to one or better.

Antineutrino detectors add quasi-real-time material accountancy to the set of reactor monitoring tools available to the IAEA and other safeguards agencies. They can provide an independent estimate of plutonium inventory, good to at least a few tens of kilograms, from well outside the core. Event rates and statistical considerations probably limit the range of applicability to reactors with thermal powers above $\sim$ 50-100 Megawatts. The hundreds of reactors worldwide that meet this criterion represent a substantial fraction of the world's reactor inventory.

Possible benefits from this approach include the ability to compare direct measurements of composition with declarations and other IAEA material accountancy metrics; a possible decrease in the time to detect unauthorized diversion of fissile material; less intrusiveness for operators, reduced inspection frequency for the safeguards agency, and possible cost savings from the standpoint of both the reactor operator and the safeguards agency.

Recognizing the potential of this technique, our Lawrence Livermore National Laboratory/Sandia National Laboratories collaboration has deployed a prototype safeguards detector at a reactor in Southern California, in order to test both the method and the practicality of its implementation in the field. This article describes how estimates of fissile inventory and reactor power can be extracted from measurements of the antineutrino flux and energy spectrum, presents preliminary results from our prototype reactor, and discusses further steps needed for practical implementation of this technique, including improvements in the detector design, as well as the cost and practicality of widespread deployment.

2 Reactor Monitoring with Antineutrinos

As a typical power reactor core proceeds through its irradiation cycle, the mass of each fissile isotope varies in time. Neutrons fission uranium and plutonium throughout the cycle, while the competing process of neutron capture on U-238 produces plutonium. As a consequence of this variation in mass, the relative fission rates of the isotopes also vary significantly throughout the reactor cycle, even when constant power is maintained. This change in fissile content induces a systematic shift in the antineutrino flux over the course of the cycle, known as the "burnup effect". Burnup, measured in GigaWatt days per ton of heavy metal, is a common measure of the amount of neutron exposure and hence level of uranium consumption and net plutonium production in the core. The burnup effect has long been recognized and corrected for in past reactor antineutrino experiments [1], and is key to the utility of antineutrino detectors as reactor monitoring tools.

The size of the effect varies depending on the core type, fuel management strategy, and fuel enrichment. By comparing the change in antineutrino rate over a single cycle of a standard Pressurized Water Reactor (PWR), to the change in plutonium content, one can get an approximate idea of the degree of correlation. Using a simulation of a 3.8 GigaWatt thermal (GWt) PWR, the net increase in plutonium content after one year of operation in an equilibrium cycle is about 200 kg, and this increase will cause a change in the antineutrino rate of about 6% in this same time period. With a cubic meter scale detector, the antineutrino rate can be measured with a statistical accuracy of 1% in a matter of weeks or even days.

An estimate of the reactor plutonium inventory can be extracted from either of two quantities measured by an antineutrino detector: the total antineutrino rate integrated over a broad energy window, as just described in the example above, or the energy spectrum of the detected antineutrinos. To explain the connection between these measured quantities and the desired inventory measurement, we must first describe the antineutrino production and detection processes.

2.1 Production of Antineutrinos in Reactor Cores

Antineutrino emission in nuclear reactors arises from the b-decay of neutron-rich fragments produced in heavy element fissions. The average fission is followed by the production of about six antineutrinos that emerge from the core isotropically and without attenuation. In the energy range from about 2 to 8 MeV, the average number of antineutrinos per fission is significantly different for the two major fissile elements U-235 and Pu-239. Hence, as the core evolves and the relative mass fractions and fission rates due to U-235 and Pu-239 change, the antineutrino flux from the core will also change. For example, Figure 1 shows the evolution of the relative number of fissions over a one year cycle in a typical LEU reactor, along with the predicted change in the antineutrino rate in the LLNL/SNL detector caused by the variations in U-235 and Pu-239 content (assuming 100% detection efficiency). Only the sum of the antineutrino fluxes from each isotope is measured in a real detector. Detection efficiencies from 10%-80% have been achieved with earlier detectors.

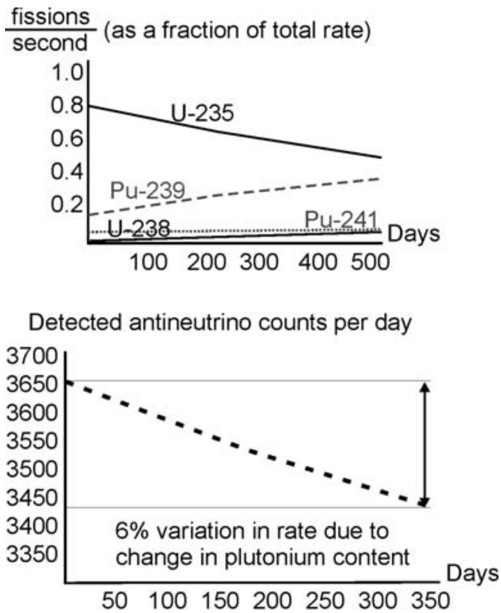


Fig. 1. The leftmost plot shows the relative variation in fission rates from each isotope over a cycle. The rightmost plot shows the resulting daily antineutrino count rate plotted versus time, with a perfect 0.64 metric ton detector at 25 m standoff. This simulation is for a 3.8 GWt reactor in an equilibrium cycle. The change in antineutrino flux is about 6% over the course of a cycle, here taken to be one year

Because of the direct relation between plutonium content and the total antineutrino count rate, the former quantity of safeguards interest can be derived from the latter quantity measured by antineutrino detectors.

Measurement Scenarios

The correlation between antineutrino count rate and fissile inventory provides the simplest method for extracting an estimate of plutonium content.

To *absolutely* determine the plutonium inventory given a measurement of the antineutrino count rate, additional inputs are required: the fuel geometry, the initial fuel enrichment, the absolute reactor power, the detection efficiency, and the predicted energy spectrum of the antineutrinos must all be known. Past experiments have demonstrated approximately 3% systematic uncertainty in the antineutrino flux from all of these sources, dominated by the near 2% uncertainty in the emitted spectrum of antineutrinos from the core[1]. However, for safeguards purposes, a measurement of the antineutrino count rate *relative* to reactor startup may suffice, in which case most of these time independent systematic shifts would be eliminated, leaving primarily statistical error, and the time dependent burnup effect itself which we seek to extract.

As long as flux alone is used to estimate plutonium inventory, even such relative measurements require independent knowledge of the reactor power, which is a free parameter that could be used to tune the antineutrino rate and mask the burnup effect. A second method for estimating fissile inventory is potentially more robust, since it does not depend on normalization by the absolute power of the reactor. In this approach, changes in the shape of the energy spectrum of the emitted antineutrinos over the cycle are correlated with changes in the plutonium content. At first glance, this approach might appear limited by the above-mentioned 2% uncertainty in antineutrino energy spectrum. This limitation could be overcome however, by using an initial single cycle calibration period that would empirically correlate plutonium inventory with the antineutrino count rate for the particular reactor in question. In addition, it is worth noting that a new generation of electron spectrometry measurements is now being proposed by the Double-Chooz collaboration in France[2], which would further reduce the absolute uncertainty in the antineutrino spectra of the individual isotopes.

2.2 Detection of Reactor Antineutrinos

A common method for detecting antineutrinos is the inverse beta decay interaction

$$\overline{\nu}_e + p \rightarrow e^+ + n. \tag{1}$$

Here the antineutrino (ν) interacts with free protons (p) present in the detection material. The neutron (n) and positron (e_+) are detected in close time coincidence, providing a dual signature that is robust with respect to the backgrounds that generally occur at the few MeV energies characteristic of these antineutrinos. In addition to the antineutrino flux, the reaction (1) also allows measurement of the antineutrino energy as:

$$E_{\overline{\nu}} = E_e - M_p + M_n + m_e + O(\frac{m_e}{M_p}) \tag{2}$$

where $E_{\overline{\nu}}$ is the antineutrino energy, E_e is the positron kinetic energy, M_p, M_n and m_e are the proton, neutron and electron masses respectively, and $O(\frac{1}{2})$

are terms of order $\frac{m_e}{M_p}$ that mainly account for the nuclear recoil. The reaction in (1) has an energy-dependent cross-section and a threshold of ~ 1.81 MeV.

Figure 2 shows the energy spectrum of fission antineutrinos, folded with the energy-dependent detection cross section of (1) for the two most important fissile elements Pu-239 and U-235. The difference between the spectra are apparent, amounting to 50% or more from bin to bin. As indicated above, the spectral differences between these elements cause the total antineutrino rate measured in the 1.8-8 MeV range to change significantly as a function of time, even at constant power. Though not shown here, contributions from other isotopes such as U-238 and Pu-241 can be accurately accounted for and do not change the results.

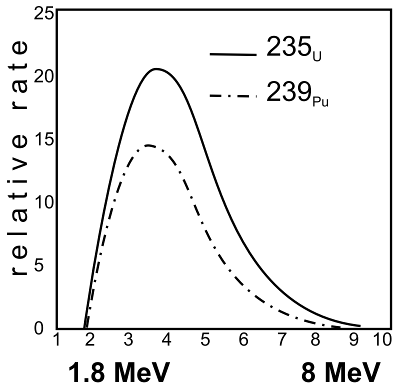


Fig. 2. The theoretical antineutrino spectra from uranium and plutonium, after convolution with the inverse beta decay cross section. The pure spectra differ by 50% or greater across the energy range of interest. Only the sum spectrum is measured in an actual detector

Organic liquid scintillator is often used as a detector for antineutrinos. It has a high density of quasi-free proton targets to enable the reaction (1), and it can be doped with different neutrophage elements to enhance sensitivity to the neutron in the final state of the antineutrino interaction.

The detection of MeV-energy antineutrinos via the reaction (1) using organic liquid scintillator has been standard in nuclear physics since the early experiments leading to the discovery of the antineutrino. In the past 45 years many detectors have been built to reduce backgrounds in very large fiducial masses and to improve the precision of the measurements. Modern liquid scintillator detectors, such as Chooz[1] and Palo Verde[3], have fiducial masses of several tons and have run for a few years with total detector-related systematic errors on the absolute antineutrino count rate below 3%. These detectors have very good time stability, compatibility with plastic hardware and modest health hazards. For the relatively small detectors needed for nuclear safeguards it may be possible to use a completely non-hazardous scintillator, or to use blocks of solid plastic scintillator.

In the process (1) the ionization signal from the e^+ and its annihilation gammas is followed by neutron capture, providing a delayed coincidence that substantially reduces backgrounds. This capture can occur on hydrogen, but a common strategy is to use a neutrophage dopant such as gadolinium, which brings the dual benefits of reducing the capture time from about 170 to 30 microseconds relative to capture on hydrogen, and increasing to 8 MeV the energy released in the gamma cascade following capture, compared to 2.2 MeV for hydrogen.

3 The LLNL/SNL Prototype Antineutrino Detector

A prototype detector for reactor monitoring was installed at the San Onofre Nuclear Generating Station (SONGS) in mid 2003 and began taking in data in late 2003. The current full scale 0.64 ton detector has been operational since August 2004. The detector is located in the tendon gallery[1] of Unit 2, resulting in a core-detector separation of about 25 m. This gallery is an ideal location for the detector, since it is close to the core while remaining outside of the containment structure, essentially no access to it is required for day-to-day reactor operations, and it is about 20 m underground, providing approximately five-fold attenuation of the most important backgrounds, which arise from penetrating cosmic muons.

Figure 3 provides a cutaway view of the detector, which consists of three subsystems; a central detector containing the liquid scintillator target read out by photomultiplier tubes, a passive water or polyethylene shield on all sides, and a muon veto system placed outside the water shield on five sides of the detector.

The central detector consists of four identical stainless steel cells, each with inner dimensions 17" by 17" by 40". These are filled with a liquid scintillator doped with gadolinium at the 0.1% level, with the weight concentration verified by assay. The total mass of liquid is 0.64 tons. Scintillation light generated by the interaction of particles in the cells is converted to electrical signals by 9" Photomultiplier tubes (PMTs) (two per cell, not shown in the figure).

Gamma and neutron rates in the central detector are reduced by passive water or polyethylene shielding, which surrounds the detector on six sides. This is especially important to reduce the flux of high energy neutrons impinging on the cells from outside the detector, as these can produce signals that mimic antineutrinos.

[1] The tendon gallery is an annular concrete hall that lies directly beneath the reactor containment structure. The gallery is used to periodically adjust the tension in reinforcing steel cables which extend throughout the concrete of the containment structure.

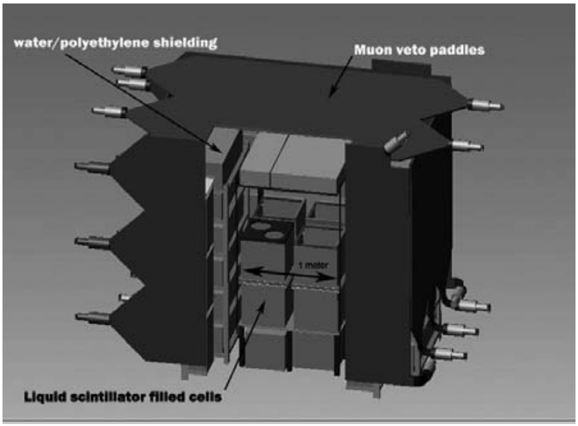


Fig. 3. A cutaway view of the LLNL/SNL antineutrino detector deployed at the San Onofre Nuclear Generating Station

An approximately one inch thick plastic scintillator envelope identifies and rejects nearby cosmic rays and their associated interaction products. As shown in Fig. 3, the envelope is comprised of scintillator paddles of different sizes placed on five sides of the detector, readout by 5" PMTs.

3.1 Results

The purpose of the prototype detector was threefold: to install and operate a detector at a commercial reactor in order to confront the practical questions arising from real-world deployment; to demonstrate the antineutrino monitoring capability, and to extract an estimate of the precision of reconstruction of the plutonium inventory based on an antineutrino measurement. The first two goals have been met, and the long term stable operation of the detector required for meeting the last is currently underway.

Antineutrino Count Rate and Detection Efficiencies

Here we summarize our initial data: a fuller description of the data analysis is found in reference [4] and in a forthcoming publication. The antineutrinos are selected by demanding that a pair of high energy depositions occur in the detector within no more than 100 msec of each other, and, to avoid muon-induced backgrounds, greater than 100 msec from the most recent muon veto signal. The software energy thresholds are 3 MeV and 4 MeV for the prompt (positron-like) and delayed (neutron-like) signals.

Figure 4 shows the count rate across an outage at the reactor. With an efficiency of 15%, derived from analytic calculation and simulation, the rate is consistent with the predicted rate based on simulations of the reactor antineutrino flux.

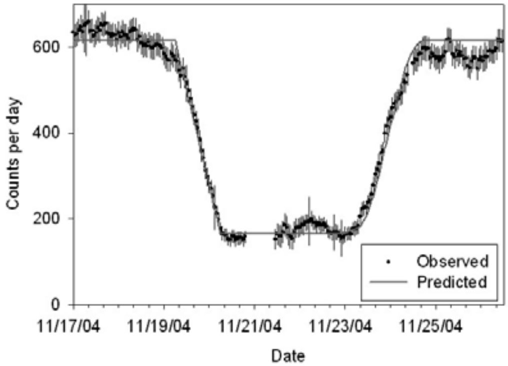


Fig. 4. The antineutrino count rate versus time through a reactor outage. The shutdown period reveals the persistent backgrounds, arising from muon induced events that can mimic antineutrinos, and a 2% contribution of real antineutrinos from the distant reactor. The signal to background ratio is about 3:1

The time and energy signatures of the selected antineutrino events are clearly compatible with their expected distributions. Figure 5 shows one important example, the interevent time between the two successive events that define an antineutrino candidate. The falling exponential with a mean interevent time of 28 microseconds behaves just as expected for the time correlated antineutrino events. The reactor-off data demonstrate that this antineutrino signal is about 3 times as large as the persistent correlated backgrounds that come from cosmic rays. This exponential lies above a much lower background which occurs at just the rate expected from the random gamma/neutron-induced coincidences that can also trigger the detector.

Operational Considerations

The detector has run stably and continuously for months at a time. The antineutrino rate is automatically calculated each hour on a local dedicated data-processing computer. Small (∼50 kilobyte) data summary ASCII files are uploaded continuously to a secure website, containing the daily antineutrino count rate and state of health data for all the electronic systems in the detector, including phototubes, high voltage bias supplies, logic processing crates and the data acquisition computer. Flags are set in the event of a deviation above a preset value of any diagnostic from its mean value. An automatic calibration routine relies on an omnipresent gamma line in the background data (the 2.6 MeV Th208 line) to set the energy scale, which is periodically checked with an Americium-Beryllium (AmBe) source.

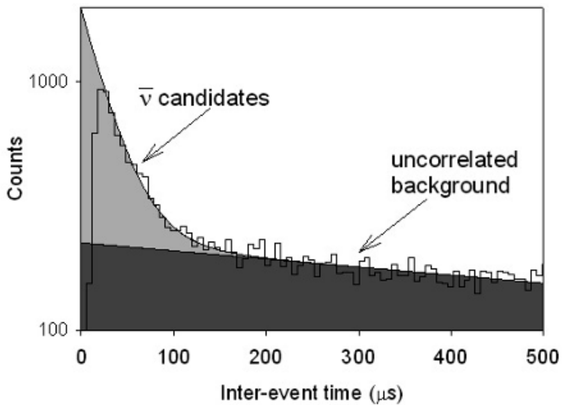


Fig. 5. The interevent time distribution for the antineutrino candidate events. As predicted, the interevent time distribution is well fit by an exponential with a mean time equal to the neutron thermalization and capture time, on top of a slower exponential background with a rate constant corresponding to the trigger rate of the detector

4 Conclusions and Discussion

We have demonstrated at one reactor that a detector can be installed in a convenient location outside of containment, with 20 meters of concrete overburden to reduce cosmic-ray backgrounds, and away from most reactor related activities; that it is possible to count hundreds of antineutrinos per day with a small detector of relatively simple design as required for a safeguards application; that the daily reactor power can be tracked continuously; that the detector can operate without interfering with reactor operations, that data can be analyzed automatically and remotely; and that the detector can run for months at a time without failure again as required for robust deployment.

Continued data taking with the full detector is required to verify sensitivity to the burnup effect, and to estimate the precision that can be reached on the power and plutonium inventory measurements. However the clear presence of the effect in past experiments, and the available statistical precision of a 1% measurement every 25 days in the present experiment are both strong indicators that this confirmation will take place with about 6-10 months of data taking. There is no doubt that the burnup effect can be measured. For safeguards applications, the central questions relate to the precision of the inventory measurement derived from the rate or spectrum, and the practicality of deployment.

Concerning precision, with a 1% statistical rate measurement made every few weeks - easily achievable with a modestly sized detector such as the current prototype - and with the major systematic shifts removed via subtraction of an initial rate measurement at startup, a granularity of tens of kilograms of plutonium should be achievable. This remains to be demonstrated with additional data from the current prototype. More accurate models of antineutrino flux from each isotope would reduce the spectral uncertainties alluded to earlier and increase the precision on the plutonium inventory estimate. However, this theoretical requirement can be circumvented to a degree by calibrating an installed detector against known fissile inventories for a given reactor type. It is plausible that this calibration can be extended to identical reactors of the same design, thereby increasing the generality of the application.

Several avenues of further research suggest themselves. A study of reactor designs worldwide is needed to determine whether the favorable deployment environment found in the current example is generally achievable. While our first detector presents a realistic and encouraging starting point, further optimization should be pursued among the conflicting demands of design simplicity, low cost, and ease of use versus measurement precision. The next generation of near reactor antineutrino experiments will benefit the application envisioned here and should be strongly encouraged, just as the last generation of experiments has motivated and enabled the deployment of our current prototype safeguards antineutrino detector. Finally, the IAEA should assess the feasibility of deployment within the existing reactor safeguards regime, using the results of our experimental effort[4] and the increasing number of theoretical studies now available in the literature [5, 6, 7].

References

1. M. Apollonio et al. (1999): Limits on neutrino oscillations from the Chooz experiment, Phys. Lett. B, Vol 466, pp 415-430.
2. S. Berridge et al. (2004): Proposal for U.S. participation in Double-Chooz: a new theta13 experiment at the Chooz reactor, hep-ex/0410081
3. Boehm et al. (2001): Final Results from the Palo Verde neutrino oscillation experiment, Phys Rev D, Vol. 64, 112001
4. N.S. Bowden, et. al (2004): First Results from a Nuclear Reactor Monitoring Antineutrino Detector, INMM conference proceedings, INMM 45th Annual meeting, July 2004.
5. A. Bernstein, Y. Wang, G. Gratta, T. West (2002): Nuclear Reactor Safeguards And Monitoring With Antineutrino Detectors, J. Appl. Phys., Vol. 91, Issue 7, pp. 4672-4676
6. P. Huber, T. Schwetz (2004): Precision Spectroscopy with Antineutrinos, Phys. Rev. D 70, 053011
7. M. M. Nieto, A. C. Hayes, C. M. Teeter, W. B. Wilson, and W. D. Stanbro (2005): Detection of Antineutrinos for Non-Proliferation, Nucl. Sci. Engin. 149, pp. 270-276.

Digital Verification Techniques in the Nuclear Safeguards System: Status and Perspectives

Bernd Richter

1 Introduction

For more than 25 years the nuclear safeguards system had been based on states' declarations and International Atomic Energy Agencies (IAEA) verification[1]. The world community, in response to the violation of the Treaty on the Non-proliferation of Nuclear Weapons (NPT), strengthened the safeguards system, i.e., NPT compliance verification system, by establishing the Additional Protocol (AP)[2]. Under the AP, the IAEA's mission is to detect undeclared nuclear facilities, materials and activities, and to verify the correctness and completeness of states' declarations. While continuing to use material accountancy to detect diversion of nuclear material, the IAEA, henceforth, has to execute extended access rights within the nuclear facilities as well as on the states' territories. Furthermore, the IAEA has to handle more comprehensive information to be provided by the states as well as information acquired by the IAEA from open sources about states' nuclear activities. To this end, the IAEA has acquired new competence in satellite imagery analysis and open source information analysis and is re-engineering its safeguards information system. In Eastern Europe and Asia new states have come under safeguards, and nuclear programmes in Asia and elsewhere are being expanded. Finally, in the course of nuclear disarmament in nuclear weapons states the IAEA will have to safeguard excess fissile materials transferred from former military use.

In order to cope with these challenges, the IAEA, in cooperation with member states, develops approaches to increase its efficiency and effectiveness in using its resources. The IAEA will focus more on qualitative safeguards

[1] INFCIRC/153 (corrected) = The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-proliferation of Nuclear Weapons, Vienna, Austria, reprinted in June 1972.

[2] INFCIRC/540 (corrected) = Model Protocol Additional to the Agreement(s) between State(s) and the IAEA for the Application of Safeguards, Vienna, September 1997, reprinted in December 1998.

measures concerning the nuclear fuel cycle in a state as a whole and on key activities like enrichment and reprocessing. Inspection effort related to routine activities at declared nuclear sites that are less sensitive will be reduced enabling the IAEA to re-allocate its staff. In 1992, the European Safeguards Research & Development Association (ESARDA) Working Group on Containment & Surveillance had proposed the concept of substituting on-site inspection effort by unattended and remote monitoring techniques with data evaluation at IAEA headquarters, as this may not only improve the cost effectiveness of routine safeguards but also reduce the interference with plant operations [1]. In addition, nuclear radiation exposure of IAEA inspectors and technicians as well as of plant operators' staff will be reduced. Also, the European Commission, especially in designing new safeguards approaches in a regional union of 25 member states, has started to consider this concept [2]. Another aspect of unattended and remote monitoring is improving the data collection and analysis by acquiring safeguards data in a timely manner at random or programmable time intervals. Given the ever increasing amount of safeguards data it is also important to develop appropriate data review methods.

The whole concept requires the use of state-of-the-art technologies. In autumn 2004, after in-depth discussions, the two ESARDA Working Groups on Containment & Surveillance and on Techniques and Standards for Non Destructive Analysis (NDA) issued guidelines for developing unattended and remote monitoring and measurement systems [3]. In this context, the ESARDA Working Group on Containment & Surveillance has also started to revisit the issue of how to determine the performance and assurance of containment & surveillance equipment, an issue which the working group already addressed in the late 1980's [4].

The present paper draws upon the ESARDA work concerning unattended and remote monitoring and highlights trends in the area of image surveillance, radiation monitoring, and electronic sealing. The example techniques presented in the paper will meet the requirement of system integration into sensor networks which will become more and more important in nuclear safeguards. Finally, it should not be overseen that, in the future, some activities up till now carried out by the safeguards inspectors may be carried out by the nuclear facility operators provided the performance and assurance of the safeguards equipment will find the operators' acceptance.

2 General Remarks

The large variety of nuclear facilities to be safeguarded requires a great flexibility on the part of the IAEA in designing facility-specific safeguards instrumentation. The use of digital techniques (hardware, firmware, software) and modular hardware and software solutions for automated on-site instrumentation enables to design equipment systems integrating different sensor techniques such as cameras, radiation monitors, and seals. It has to be taken into account though, that electronic components have short times to obsoleteness requiring short-term replacement. A typical example for rapidly changing technologies are data carriers. As a matter of fact, technical progress leads to new concepts and requires periodical replacement of safeguards equipment.

For cost reasons (procurement, training, repair and servicing) it is desirable to use commercial-off-the-shelf (COTS) components to the greatest extent possible. Nevertheless, it is necessary and expensive to adapt COTS components to nuclear safeguards applications. From the IAEA's point of view the critical component of a safeguards system is the sensor head with digital data generator module. Here, loss-free data acquisition and local storage as well as a high data security including authentication are required. Normally, this is realised with customised solutions for hardware and firmware, which, by nature, are expensive, as the nuclear safeguards market is very small, and these requirements are not requested in other verification systems. Therefore, a number of IAEA member states supports the IAEA in developing customised equipment, in order to keep the IAEA's procurement costs free from the development costs.

In a remote monitoring scheme the IAEA must be able to evaluate the safeguards data at IAEA headquarters. For the reason of safeguards confidentiality only encrypted safeguards data will be transmitted. The implementation of remote monitoring systems requires cost-benefit analyses on a case-by-case basis. Costs depend on country-specific factors such as the number of facilities involved, availability and quality of a communication infrastructure, and communication tariff, and on other factors such as licensing of encryption algorithms and archiving requirements.

For software upgrading and trouble shooting, the IAEA may wish to have remote system access to its remote monitoring systems. This will only be granted under the provision that the plant operator's security concerns can be sufficiently met, as there is always a non-negligible security risk of unauthorised access. Furthermore, the plant operator may be concerned about the unaltered status of the data transmission scheme, if, for instance, delayed transmission of surveillance data has been implemented.

The amount of data to be handled must be kept as low as possible, i.e., only relevant data should be transmitted, archived and evaluated. Otherwise, transmission times may become unacceptably long, archiving capacities extremely large, and data management and evaluation very laborious, when considering a whole country. The remote transmission of optical surveillance data involves large data files. Applicable data reduction methods are mathematical compression to reduce the file size and front end scene change detection to transmit only relevant images. To further reduce the amount of transmitted data, it is possible to correlate different types of data, e.g., images are relevant only if radiation is detected.

The remote retrieval of state-of-health data allows to monitor the performance of the safeguards systems and to initiate timely repair and maintenance. Whereas highly reliable sensor head/data module units with uninterrupted power and loss-free data storage provide the assurance of continuity of knowledge, temporary outages of COTS components can be tolerated.

In some types of facilities inspection effort can be reduced by the facility operator performing safeguards relevant activities. For instance, transport and storage casks with spent fuel are sealed under camera surveillance using electronic seals with seal-video interfacing approved for safeguards use.

3 Digital Safeguards Instrumentation

In the future, unattended integrated remote monitoring and measurement systems will play a major role. They consist of sensor heads, associated electronics, digital data generators, a data collection system, and network interfacing equipment for remote data retrieval. The majority of such systems is computer-based.

Sensors and Data Generators

Sensors with their signal processing electronics as well as digital data generators are security relevant components, as they are the sources of the safeguards data. Any unauthorised physical access must be inhibited. Data authentication takes place in the data generator. Ideally, the components are mounted in a common tamper-indicating enclosure. Servicing, repair and replacement must be restricted to the IAEA's staff.

This concept is realised in two equipment categories used by the IAEA: Digital image surveillance and electronic sealing. The IAEA's standard digital camera unit has a low power original equipment manufacturer (OEM) charge-coupled device (CCD) camera and the digital data module DCM 14 [5] mounted in the sealable IAEA standard camera housing [6]. Also, the VACOSS [7] electronic seal has many features of the concept.

In contrast, for radiation sensors development efforts have to be directed towards authentication of NDA data and tamper protection. The development of the digital unattended multi channel analyser DIUM [8] is a first step in this direction (see below). It is worth mentioning that radiation detectors usually need to be physically separated from their data generators. In this case, the principle of tamper-indication must be separately maintained for (1) the sensor, (2) the signal line, and (3) the data generator module.

Data Collection System

Within a nuclear facility the data collection system receives data from the sensors used. It stores the data until retrieved on site by an inspector or remotely transmitted to IAEA headquarters.

For on-site retrieval the data must be available on an exchangeable storage medium. Contemporary standards are digital linear tape (DLT), magneto-optical (MO) disk, recordable compact disc (CD-R), and DVD. In addition to the exchangeable storage medium, data collection systems may have other internal storage devices.

If a data collection system is interfaced to a public communication network, the data can be directly transmitted over the network to IAEA's headquarters. In this case, the confidentiality of the data must be guaranteed at all times by means of an appropriate encryption scheme. If the data are retrieved on site, confidentiality is the responsibility of the IAEA staff all the way from the facility to the headquarters. The inspector may want to transport encrypted data only, in order to ensure confidentiality in case of loss of the data carrier.

The reliability of the data collection system can be ensured by a range of measures including one or more of the following: Uninterruptable power supply, sufficient local storage to store the data from the different sensors over a longer period of time, redundancy of the system's vital components, auto-monitoring of different state-of-health parameters, transmission of state-of-health alarms. Networked data collection systems must offer a sufficient level of security against unauthorised access.

Network Interfacing Equipment

This equipment is used to interface the data collection system to a public communication network, with the aim to transmit the collected data and, if agreed, to give the IAEA remote access to the system. The following aspects are important: Confidentiality of the transmitted data; prevention of unauthorised access to the safeguards system and safeguards data; IAEA's secure remote access to the data collection system.

Commercial-Off-The-Shelf (COTS) Components

Due to the concept of loss-free data acquisition and storage in sensor head/data generator modules, other components such as data buses, communication links, microcomputers, and data collection system are not security relevant and, therefore, may be COTS products. Failures and mains power outages do not result in a loss of data. As only authenticated data are processed in these components, tampering is not possible undetected. The components can be serviced, repaired and replaced by commercial contractors. This will further reduce the IAEA's interference with plant operation.

Approval for Routine Inspection Use

Prior to authorising equipment for routine inspection use the IAEA requires the systems to successfully pass different evaluations:

- Qualification testing including radiation testing[3],
- Third Party vulnerability analysis of the hardware and firmware as regards safety and security (including authentication and encryption) methods[4],
- acceptance testing including usability review, and
- field testing.

Featuring Digital Safeguards Instrumentation

Unattended and remote monitoring techniques for safeguards should have the following features:

- Data authentication at the sensor level,
- front end data reduction including data compression and data correlation,
- sufficient data storage capacity at the sensor level,
- data encryption,
- remote data transmission out of facilities to IAEA headquarters,
- compatibility between devices of different origins,
- integrated data review,
- option for plant operator's performance of safeguards activities.

A widely accepted compliance with these features may help to reduce procurement costs and training effort for inspectors and technicians, solve data security issues, and match development efforts spent under different member states programmes in support of the IAEA.

When handling and operating unattended integrated remote monitoring and measurement systems the IAEA should [9]:

- Perform strong configuration controls for data security,
- perform system access controls,
- use approved encryption algorithms,
- apply standardised vulnerability assessments,
- apply vulnerability assessment to entire system, not just to the security algorithm,
- use certified copies of commercial-off-the-shelf software,
- provide implementation guidelines for TCP/IP connectivity of Ethernet standard, and
- apply appropriate procedures for key management related to authentication and encryption.

---

[3] The IAEA applies the IAEA/Euratom "Common Qualification Test Criteria for New Safeguards Equipment", Version 2.0, January 2002. For environmental testing the IAEA co-operates with the Joint Research Centre at Ispra under the Euratom Support Programme to the IAEA. For radiation testing the IAEA co-operates with the Atominstitut in Vienna. The procedure for irradiation testing is being revised under the German Programme in Support of the IAEA.

[4] The DCM 14 digital camera module was evaluated by an Australian Expert Team in the frame of a joint Australian-German Support Programmes task to the IAEA.

4 Technical Approaches

In the following, three examples are given for existing or upcoming digital systems complying with the requirements of unattended operation, remote data transmission, and system integration. The given examples cover the major monitoring principles, i.e., image surveillance, radiation monitoring, and electronic sealing. The equipment is designed for integration into systems with new functionality, including the correlation of image data with radiation data and electronic sealing. For example, an image or sequence of images will only be registered, if a certain radiation level or radiation characteristics is present, or if an electronic seal is attached to or detached from a spent fuel cask.

Optical Surveillance

Optical surveillance systems are designed to run in unattended mode. Their advantage is that they do not interfere with plant operations when registering safeguards relevant image information on operator's activities. The safeguards inspector matches this information with the operator's declarations, without the need for his physical presence. The IAEA uses optical surveillance in the following safeguards applications, worldwide:

- Single-camera surveillance at locations that are easily accessible for inspectors,
- single-camera surveillance at locations that are difficult to access including underwater applications,
- multi-camera surveillance for all location types, and
- short-term and portable surveillance.

The IAEA's current systems are based on the DCM 14 digital camera module and the associated family of single- and multi-camera surveillance systems which were developed between 1993 and 2001 and authorised for inspection use between 1999 and 2002. The IAEA generally requires an equipment lifecycle of up to 10 years. In 2008, the design and most of the technology will be between 10 and 15 years old. Assuming a minimum period of 4-5 years to be necessary to design, develop, evaluate, test, and approve (for inspection use) custom-designed safeguards equipment, the IAEA, adhering to the concept of a digital camera module as the core component, has recently initiated the development of a "next generation surveillance system". This will be briefly addressed, too.

The DCM 14 (see Figure 1) provides the following functions and capabilities: Image acquisition, analogue-to-digital conversion, data compression, data authentication, data encryption, internal and external triggering, maintenance capabilities, power management, battery backup, and local data storage on PC-card. The module including camera can operate on battery power for 10 days at a 10-minutes picture taking interval (or 1 day at a 1-minute interval).

The most recent DCM 14-based system configuration is the Digital Multi-camera Optical Surveillance (DMOS) System [10]. The collected data can be reviewed locally at nuclear facilities and/or at IAEA field offices and headquarters. Furthermore, the system is designed for remote data transmission out of facilities with the transmitted data remotely to be reviewed when received at IAEA field offices and headquarters.

The DMOS system permits the connection of up to 32 cameras. Each camera and DCM 14 is mounted in a sealable IAEA standard camera housing. The control and recording unit is installed in a 19-inch cabinet. The camera units are connected via RS-485 cables to a custom-designed interface providing the camera data via RS-232 cable to the computer.

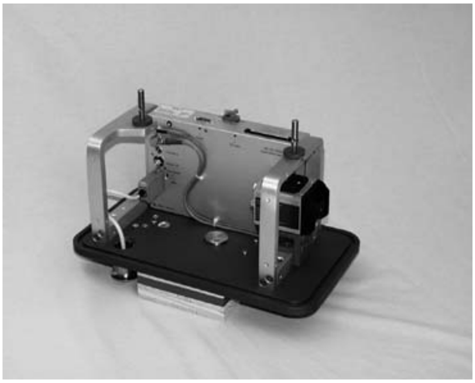


Fig. 1. Base plate of IAEA camera housing with DCM 14 module and CCD camera (courtesy: Dr. Neumann Consultants)

The DMOS system uses compact low power CCD cameras (OEM products) with auto iris lenses. For facilities with 50 Hz and 60 Hz mains power supply two video standards, CCIR and EIA, are available. The following COTS-components are implemented: (1) hardware: industrial PC with Thin Film Transistor (TFT) display and membrane keyboard, Small Computer System Interface array (SCSI), and digital linear tape drive; (2) operating system: Windows NT 4.0 Server. The DMOS system allows remote image transmission with the option of delayed image retrieval[5]. Status data are associated with each image file, such as the status of the housing switch of the camera and the temperature in the camera housing. These data should be retrievable at any time without delay, as they can help to monitor and enhance the performance of the unattended system by triggering servicing.

Field experience has resulted in new design requirements (see below) and the requirement of mitigating the general hardware and software (operating

[5] Delayed data retrieval means that each data file is released only after a preset time interval.

systems) obsolescence problem. To facilitate a future replacement programme, the IAEA wants the next generation digital camera module to be compatible with the existing DCM 14-based surveillance technology.

For the new technology the following features are deemed crucial:

- Camera unit: Mid- and high-level radiation resistance, colour imagery, enhanced tamper indication, picture taking at higher frequencies over extended intervals, Ethernet connection with Transmission Control Protocol (TCP)/Internet Protocol (IP), and hardware mostly based on Field Programmable Gate Arrays (FPGA),
- Storage media of the digital camera module: It is anticipated that due to obsolescence of the PC-cards the transition to another COTS-technology will be necessary. At a certain development stage the most appropriate solution has to be found,
- Battery backup: For the DCM 14 a Li-Ion battery proved to be the best choice. During the development of the next generation digital camera module this has to be re-evaluated,
- Colour display for portable single-channel system: ruggedness,
- Operating system for multi-channel system: not necessarily mainstream OS such as Microsoft.

Radiation Monitoring

Unattended radiation monitoring systems developed for the IAEA have so far not been standardised. The objective of the digital unattended multi-channel analyser (DIUM) project [8] is to use as many standardised components as possible. These components are the system enclosure rack with an uninterruptible power supply, external cabling to radiation detectors, and eventually detector assemblies and enclosures.

The DIUM (see Figure 2) will use high frequency sampling and patented digital signal processing. Furthermore, it will be designed for unattended operation in nuclear facilities with the data collected to be retrieved and reviewed locally, in IAEA field offices and/or at IAEA headquarters, or with the data transmitted remotely and reviewed when received there.

The functionality of the DIUM will be comparable with the DCM 14 camera module: local data storage, uninterruptable power supply, data compression, time stamping, authentication, encryption, remote data transmission, trigger capabilities. The data storage capacity will cover 5 days, if mains power or the data collection computer will not be available. In addition, it will provide high voltage to the detector and power to the preamplifier.

The DIUM will be capable of operating with different types of detector heads, e.g., sodium iodide, germanium, and cadmium-zinc-telluride, and it will be designed for installation and integration with other data acquisition modules, such as the DCM 14 digital image surveillance technology, and other

Fig. 2. Digital Unattended Multi-channel Analyser prototype(courtesy: target systemelectronic GmbH)

digital signal sources. To capture fast processes, e.g., in bulk handling facilities and storage facilities, the measurement time may be short. Therefore, the DIUM will have a high data acquisition rate.

Although universal multi-channel analysers are being widely used in attended and unattended modes, there is no product commercially available, which would perform this task satisfactorily. While capturing fast processes in real time, the instrument is very much comparable to a surveillance camera system taking a picture every second. The difference to optical systems lies in the character of the data. The DIUM is storing radiation spectra and counting rates rather than pictures. In contrast to a digital camera unit, the radiation sensor may be separated from its data acquisition module.

Measurement times are in the range of 100ms to a few minutes. The measurements are similar to those performed in radioactive decay studies after neutron activation with the unattended data acquisition constantly going on and, thus, producing an enormous amount of data. The DIUM system is able to handle very high input counting rates from the radiation detector. This feature will minimise the effect of being overloaded and thereby blinded for important data. A high throughput is desirable, in order to minimise the statistical error for the data analysis.

It is very important to have no dead time periods between two consecutively measured spectra. A continuous stream of spectra with no missing code is stored on a flash memory disk.

The DIUM has an extra large memory to store many short time spectra on the board level. A safeguards-specific feature is embedded authentication and encryption of spectrum data. Together with an accurate time stamping, the authentication record added to each individual spectrum ensures that the data are not tampered with. In addition to the spectrometric input for detectors, trigger inputs and outputs are required for synchronisation purposes and electronic seals. Among the various radiation detectors that may be connected, there are also plastic scintillators and GM-tubes for gamma counting.

The main task of an unattended multi-channel analyser is to acquire repeatedly spectra from the same location, i.e., to detect changes in the radiation field. The interesting information is the difference between consecutive measurements rather than the analysis of a single measurement itself. If not explicitly stopped, the unattended multi-channel analyser will continue to collect spectra and deliver them to a remote computer. Loss-free data acquisition is ensured by storing all data locally in the data module on a removable storage medium. When the local data storage device is full, the oldest data are overwritten. This procedure works rather like a ring buffer, until the storage medium is removed for evaluation and replaced in the data acquisition module.

Local data storage capacity has been designed for up to five days operation until a potential problem may be fixed. When taking a spectrum every second, nearly 500,000 spectra must be stored without loss. Even with the ever-growing capacities of memory cards data compression is mandatory.

Together with the spectrum data a state-of-health record is stored. It contains information like ambient temperatures, detector high voltage and bias current, and preamplifier power. Tampering with the detector and detector failures will cause a change in one or more of such parameters.

The temperature is recorded as one parameter of physical stress. Another stress factor in nuclear facilities is often an elevated level of neutron radiation. Ongoing electronic circuit miniaturisation causes an increased sensitivity to neutrons inducing malfunctions and system crashes. The problem is moderated by using selected memory chips which are not prone to such neutron-induced effects. A software technique using checksums and error correction with watchdog functions ensures safe operation in the standard instrument cabinet.

For reasons of data integrity and authenticity an authentication method similar to the one implemented in the DCM 14 camera module [5] will be used to authenticate individual spectra. The DIUM signal sampling, while taking a spectrum, also acquires true statistical noise in the form of random zeroes and ones as a natural base for all encryption algorithms and hash function. When using the natural noise generator for the encryption all publicly known attacks to falsify the authentication are doomed to fail. The authentication method will be subject to a Third Party Vulnerability Assessment. For remote data retrieval also encryption will be required and approved by the state.

Electronic Sealing

The IAEA started to use electronic sealing on a routine basis in the early 1990's. The sealing method is based on the measurement of light transmitted through a fibre optical cable that is connected to a secure box with electronic circuitry. While the concept has proven highly successful, the seal technology is not state of the art. The IAEA defined the following requirements for a future electronic safeguards seal:

- High detection probability of bypassing or short-circuiting of the sealing function,
- tamper-indicating housing which, however, can be opened non-destructively for maintenance, upgrade and/or repair,
- up to 3 years operation on battery, while battery replacement information should be highly reliable,
- high-capacity event-log with support for back-end authentication verification,
- secure communication protocol based on a standardised cryptosystem and state-of-the-art cryptography,
- support for network applications, i.e., network of seals as well as seals in a network of different device types including computers, digital cameras, radiation monitors,
- radiation tolerance through software means such as strict watchdog regime and majority vote variables.

A new candidate seal is the electronic optical sealing system EOSS [11] (see Figure 3) which, at the time of writing this article, was still in its final phase of Third Party vulnerability assessment before awaiting its authorisation for inspection use. The sealing function is realised by using a fibre-optic cable (FOC). The sealing security is based on the fact that fibre-optic cables are generally more difficult to tap or bypass and to repair than electrical wires.

Fig. 3. Electronic Optical Sealing System prototype(courtesy: Dr. Neumann Consultants)

The seal has a light source and a light sensor with the light being transmitted through an external FOC. The FOC is designed for multiple connection and disconnection. It can be manually "opened", i.e., disconnected, and "closed", i.e., connected, without using any tool. Every opening and closing is registered by the internal micro-controller with annotation of date and time. The open/closed status of the FOC is monitored by transmitting and receiving short light pulses at certain time intervals. If the FOC is closed, every light pulse is immediately detected by the receiver. If no signal is detected, then the FOC is considered to have been opened. Moreover, the seal checks for the tamper-indicating event of light being received with the optical transmitter being switched off.

EOSS uses a single-mode cable that has to be operated with laser light. In contrast, the multi-mode technology uses considerably larger core diameters as well as normal light, typically from light emitting diodes. The higher requirements regarding precision, make single-mode systems more difficult to tamper with.

The EOSS housing consists of two compartments. Whereas the inner part contains all security-sensitive components, the outer part houses the batteries as well as the electrical and fibre-optical connectors, in order to facilitate repair.

The battery pack consists of two lithium AA-cells for redundancy and dedicated electronics for monitoring the battery lifetime. The lithium technology provides a high energy capacity as well as a wide temperature range from -20 to +85°C. A single battery will power the seal for approximately two to three years.

At very low temperatures, certain memory cells tend to keep their information for a long time even without power supply. Theoretically, this would allow to retrieve the authentication keys by deep freezing the seal and short-cutting the battery. Therefore, the temperature is monitored and, at very low values, the keys are erased.

The EOSS registers different categories of events. The Seal Log contains openings and closings of the fibre-optic cable. The User Log contains activities like user log on/off and key-set generation. Moreover, the User Log registers potential or real tamper attacks (e.g., denied requests from the network). The third part of the log contains State-of-Health information (e.g., battery usage, min. and max. temperature).

Data authentication implemented in the seal uses the Triple Data Encryption Standard (TDES) [12].

The EOSS seal has a RS-485 interface. The hardware allows cable lengths of up to 1,000 m. Up to 32 seals can be connected to one twisted pair cable (party-line). The seal reader is a standard notebook or personal computer. A compact size RS-485/RS-232 converter is available to connect the party-line to the PC's serial port.

5 Summary

The IAEA is interested in reducing its routine inspection effort at declared nuclear sites that are less sensitive. The approach taken is the concept of substituting on-site inspection effort by unattended and remote monitoring techniques with data evaluation at IAEA headquarters. This may not only improve the cost effectiveness of routine safeguards but will reduce the plant operators' escorting requirements as well as nuclear radiation exposure of IAEA and plant operators' staff. Another advantage may be acquiring safeguards data in a timely manner.

The large variety of nuclear facilities to be safeguarded requires a great flexibility on the part of the IAEA in designing facility-specific safeguards instrumentation. The use of digital techniques (hardware, firmware, software) and modular hardware and software solutions for automated on-site instrumentation enables to design equipment systems integrating different sensor techniques such as cameras, radiation monitors, and seals. The two ESARDA Working Groups on Containment & Surveillance and on Techniques and Standards for Non Destructive Analysis (NDA) issued guidelines for developing unattended and remote monitoring and measurement systems. These guidelines will be subject to review and revision, as requirements and technologies change with progress.

Unattended and remote monitoring systems techniques should have the following features:

- data authentication at the sensor level,
- front end data reduction including data compression and data correlation,
- sufficient data storage capacity at the sensor level,
- data encryption,
- remote data transmission out of facilities to IAEA headquarters,
- compatibility between devices of different origins,
- integrated data review,
- option for plant operator's performance of safeguards activities.

A widely accepted compliance with these features may help to reduce procurement costs and training effort for inspectors and technicians, solve data security issues, and match different member states' development efforts.

Three examples are given for existing or upcoming digital systems complying with the requirements of unattended operation, remote data transmission, and system integration: DCM 14-based camera systems and next generation surveillance systems NGSS, digital unattended multi-channel analyser DIUM, and electronic optical sealing system EOSS. The examples cover the IAEA's major monitoring principles, i.e., image surveillance, radiation monitoring, and electronic sealing. NGSS is only at the beginning of its development, DIUM is just about entering into its testing and evaluation phase, and EOSS has passed most of its testing and evaluation, but is still not authorised for inspection use. The presented equipment is designed for integration into systems with new functionality, including the correlation of image data with radiation data and electronic sealing.

Finally, it should be mentioned that, in the future, it will be desirable to have available an appropriate generic review capability for integrated safeguards systems. Development efforts may start, once there will be sufficient achievement of harmonising and standardising the different categories of monitoring systems.

References

1. ESARDA Working Group on C/S (1992): Report of the Workshop on C/S Safeguards Techniques Applicable to the Intermediate and Long-Term Storage of Irradiated Fuel, 14th Annual ESARDA Meeting, ESARDA 25, p. 75-89.
2. P. Meylemans, P. Chare (2002): Perspectives in C/S developments and the impact on Euratom safeguards, Proc. 24th ESARDA Annual Meeting.
3. ESARDA (2004): Guidelines for Developing Unattended and Remote Monitoring and Measurement Systems, October 2004, submitted for publication in the ESARDA Bulletin.
4. F.J. Walford (1989): The Need to Formalise the Performance of C/S Systems, Proc. 30th INMM Annual Meeting.
5. K.J. Gärtner et al. (1996): The Design and Testing of a Digital Video Data Authentication and Encryption Device, Proc. 37th INMM Annual Meeting.
6. G. Neumann et al., (1997): The Use of Smart Sensors and its Implications on Safeguards Procedures, Proc. 38th INMM Annual Meeting.
7. B. Richter et al. (1988): "The Design and Quality Assurance of the VACOSS Series Production Model", JNMM, Vol. XVII, pp. 666-670.
8. J. Stein et al. (2002): Design Concept of the Digital Unattended Multi-Channel Analyzer, Proc. 43rd INMM Annual Meeting.
9. Workshop on Integration of Safeguards Equipment Systems, Minutes, Niagara Falls, 7-9 April 1999, Release 1, IAEA, Vienna, April 1999.
10. K.J. Gärtner et al. (2000): The Digital Multi-camera Optical Surveillance System DMOS - Functions and Applications, Proc. 41st INMM Annual Meeting.
11. B. Richter et al. (2002): Design Concept of the Electronic Optical Sealing System EOSS, Proc. 43rd INMM Annual Meeting.
12. S. Lange et al. (2002): "Authentication and Encryption Implemented in the Electronic Optical Sealing System EOSS", Proc. 24th ESARDA Annual Meeting.

Emerging Verification Technologies

Wolfgang Rosenstock

1 Introduction and Fundamentals

For full confidence in a treaty the motto should be "Trust - but verify". Therefore, objective mechanisms for evaluating and measuring treaty compliance are generally mandatory. In the following paragraphs, non-intrusive verification procedures by measuring nuclear radiation in situ will be discussed. Nuclear measurement techniques are applied, inter alia, in verification of the following treaties: CTBT (Comprehensive Test Ban Treaty, not yet in force), CWC (Chemical Weapons Convention) and NPT (Nuclear Non Proliferation Treaty). In this paper emphasis is laid on detection and identification of concealed nuclear material.

Meanwhile, a lot of information on nuclear techniques is available worldwide. For virtually everyone there is full access to the principles of modern physics and technology. So, in a modern society characterized by global trade and extensive electronic information exchange, the control of access to nuclear weapons technology has grown increasingly difficult. The physical and technical barriers to mastering the essential steps of uranium enrichment have eroded over the years, and a lot of information on how to design weapons is already available. Virtually every nation has access to the 1940s-era technology used to develop the first nuclear weapons.

Looking at technical routes to nuclear weapons capability it turns out that the principal shortfall for "like to haves" is to obtain a sufficient amount of fissionable material. Since the major existing technologies for uranium (U) and plutonium (Pu) processing are well controlled, a country or even a transnational organization may be looking at new or alternative methods for production of small quantities (a few kilograms), sufficient for one to several nuclear weapons. As technology continues to advance, new methods of enrichment and reprocessing will be investigated and developed. Such processes may include enrichment by means of Laser Isotope Separation (LIS) or methods of nanotechnology (e.g., using nano-membranes). The ability of a nation with a certain economic and technological rank to use alternative enrichment techniques is also facilitated by the fact that export requirements for the appropriate equipment are not as restrictive as they are for commercial components of large-scale nuclear fuel production. In addition, due to worldwide scientific exchange, technology advances and improvements occur internationally.

For U-enrichment using gaseous diffusion, one of the earliest successful enrichment techniques, a separation factor of 1.002 is reached per diffusion stage, which means that hundreds to thousands of diffusion stages are needed to produce highly enriched uranium (HEU). Although for gas centrifuges the separation factor is greater, the according uranium enrichment plant is still quite a large complex. The alternative processes accomplish in one step enrichment to levels of three to ten percent, so less than ten stages would be needed to produce HEU. So, for a production capacity of only a few kilograms of HEU per annum a small facility can easily be operated in a garage or any other small inconspicuous building. Since for a proliferator the value of HEU will be extremely high, this process does not need to be economical in the sense of large-scale industry.

2 Search and Monitoring Unit

Having this in mind, it is obvious that radiation measurements are crucial and decisive to prove compliance with non-proliferation, especially in case suspicions arise at a specific location. For that purpose we have set up a special measurement car and a mobile measuring unit with high resolution gamma-detectors and sensitive neutron detectors. The aim is to detect and locate nuclear or radioactive material at the greatest possible distance. Then, the next step is to identify detected special nuclear material (SNM) by non-destructive and non-contact analysis, as far as possible. Importance is set to the demand that our systems limit access to sensitive information, so they can be applied by a NNWS (Non Nuclear Weapon State) without major restrictions.

For search and detection we operate a car-mounted system, which can be quickly moved to an area of interest to check for the presence of concealed nuclear or radioactive material. For that purpose a conventional car is equipped with a radiation measurement system. It consists of sensitive neutron detectors and a scintillation gamma-detector with natural background rejection (NBR). The position of the car is recorded by GPS synchronized with he data. For the neutron measurements six neutron slab counters are combined in a row on each side of the car. Figure 1 shows the arrangement on the loading platform of the car. The pulses of the six neutron modules on each side are summed passively, and each side is analyzed separately. Between the racks for the neutron detectors we have fastened the PC and the power management system (including a back-up battery), the electronics, and the gamma detector. The results are displayed live on a monitor mounted in the front of the car, or, in case of a covert search, the data can be stored in a non-volatile memory in the electronics.

Special nuclear material is detected by means of their neutrons. A quantity of 0.5 kg reactor plutonium (respectively 3 kg of weapon grade plutonium) can be detected clearly from the traveling vehicle at a speed of up to 40 km/h at a distance of at least 10 m, even behind stonework [1]. Greater quantities are detected even if the suspect building is 50 meters or more away from the road. The approximate position of the nuclear material is determined by the measurement, since the neutron detector row facing the concealed material shows a higher counting rate than the opposite row. From the intensity ratio left/right detector rows the distance to the nuclear material can be estimated. Furthermore, measurements have been performed in road traffic. A nuclear or radioactive load can be detected when passing a moving vehicle or when driving in front of or behind that vehicle [2]. Again, the minimum detectable quantity is in the order of 0.5 kg reactor plutonium, dependent on shielding and the arrangement of the material on the inspected vehicle.

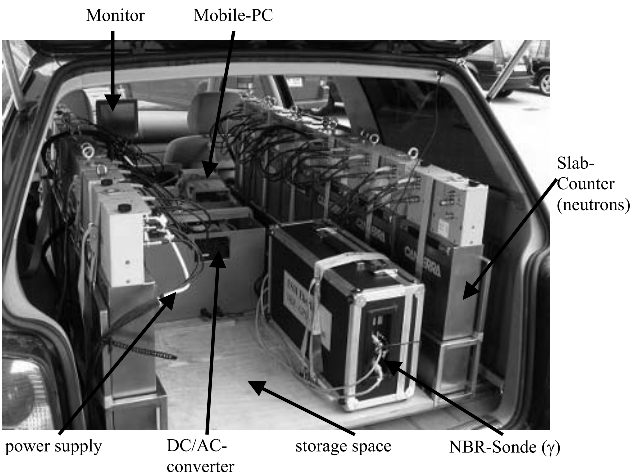


Fig. 1. Radiation inspection and measurement car, detectors and electronics fitted in a small station wagon on the loading area

Longer measuring intervals can be taken, if parking close to the suspect object is possible for several minutes. In addition, it may be possible to measure neutron coincidences. If coincidences are recorded, this is a clear evidence for fissionable material. Dependent on the measuring time a multiplicity analysis is possible for determining the type and enrichment of the material.

To perform a detailed analysis on site we have at our disposal a transportable monitoring unit (container) equipped with a system for the detection, identification and characterization of nuclear material by non-destructive and non-contact methods [3]. This container is equipped with systems for passive and active measurements. Due to the limited range of nuclear radiation the detectors have to be placed in the vicinity of the tested object. Acquired data are transferred to the container via radio transmission. For in-field operation with no mains power available, the power supply is realized by a diesel generator (with a power of 25 kVA) mounted on a trailer. In the air-conditioned container there are work places for two people who perform the measurements and do a prompt pre-evaluation of the data. A global communication system allows the transferring of measuring data and assessment to a far away center of operations where necessary decisions are to be made. The container can be easily transported on ground by truck or, more rapidly, by helicopter, particularly to off-road locations. In this case, also the power generator is transported by the helicopter. For global deployment and for long distances the transport is done by fixed-wing plane, and, in the country of destination, again via helicopter or truck.

3 Passive Methods

Neutrons are a good indicator for the presence of fissionable material, and their shielding is complex and voluminous. They result from spontaneous fission, but a sufficient number for clear and reliable detection is only produced by the isotopes Pu-240 and Am-242^m with thousands or more neutrons per gram and second. With spontaneous fission, two or more neutrons are emitted simultaneously. Moderated He-3 counters are used for neutron detection, predominantly so-called neutron slab-counters. Their modular design enables measurements in complex, difficult geometry. Daisy-chained neutron slab-counters are arranged surrounding a suspect object. Consequently, counting, coincidence and, eventually, multiplicity measurements are possible with high efficiency. Data are processed in a shift register. The relation of singles to coincidence counts characterizes the type of nuclear material.

The nuclear physical properties of relevant materials show that neutron emission from uranium isotopes due to spontaneous fission is very low, especially from U-235 with only $0.6 \cdot 10^{-3}$ neutrons per gram and second. The same is true for neptunium. Therefore, these materials are not detected by their neutrons from spontaneous fission.

Clear information on enrichment and isotopic composition is obtained by high-resolution gamma spectrometry. Taking into account shielding and self-absorption as well as distance and efficiency of the detector the total activity of a sample can be calculated. A subsequent multi group analysis (MGA) of the spectrum provides the isotopic composition. In the following iterative steps the total mass is evaluated. Masses as low as several 100 mg and isotopic activities starting from some GBq can be identified with these procedures within short measuring time intervals (e.g., a few minutes depending on geometry).

Even if the nuclear material is shielded by a few centimeters of lead or tungsten to impede detection and, all the more, identification, information on the type and content of material may be gained in combination with high-resolution gamma measurements and theoretical calculations [4]. The strategy here is similar to a trial-and-error method. Various possible shielding geometries are simulated in a short time. For each geometry the efficiency of the detector-shielding system is calculated. All efficiency calculations can then be used with the existing measurement to extract the likely shield geometry by comparing the calculated activity values of the material determined by high-energy lines and low energy lines.

However, the significant gamma-energies and intensities of some nuclear fission materials are very low, e.g., 186 keV for U-235 and 95.9 keV for Np-237. These low energies are easily shielded by 4 mm of heavy metal as is shown in Figure 2 for the isotope U-235.

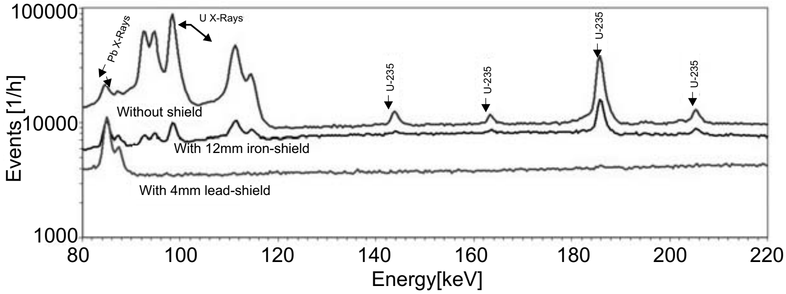


Fig. 2. Influence of a thin metallic shield (e.g., iron, lead) on identification of enriched uranium by passive gamma measurements (distance detector - nuclear source 25 cm)

The counting rate is plotted as a function of the gamma energy. With 4 mm lead shielding of the enriched uranium there is no longer any structure in the energy spectrum, and only the background is measured.

4 Active Methods

This all shows that there exist cases where passive neutron and gamma measurements cannot reveal the existence of nuclear material. If, however, a suspicion continues to exist, assurance can only be obtained by applying active methods. For that purpose, we employ active neutron interrogation of the object in question. These nondestructive measurements are performed using a sealed tube neutron generator with an intensity of up to $1 * 10^8$ n/cm^2. The object is irradiated with a pulsed neutron beam, and, in the pulse pauses, the time structure of delayed neutrons is recorded by multi-channel-scaling counting [5]. The detection of fission-induced delayed neutrons gives clear evidence of the existence of special nuclear material. Additionally, the absolute yields of the delayed neutrons as well as their yields as a function of the time after the neutron pulse vary significantly from fissionable isotope to isotope and, thus, constitute a clear signature of the isotopic composition.

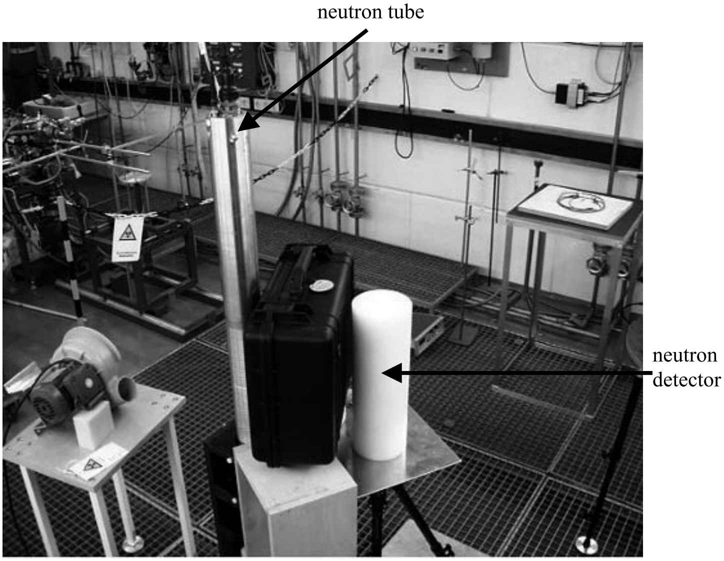


Fig. 3. Active neutron interrogation of a suspect briefcase for special nuclear material. Clear evidence is possible within one minute at a distance of up to several meters

Figure 3 shows a typical experimental arrangement for inspection of a briefcase. The briefcase is irradiated with pulsed neutrons from the left, and delayed neutrons are recorded with a moderated neutron detector on the right. By this method, the existence of fissionable material is confirmed within a few minutes, whereas determination of the isotopes takes a longer measuring period, e.g., about half an hour depending on the quantity. By moving the neutron detector along the briefcase it is possible to localize the fissionable material. In order to merely screen objects for the existence of nuclear material, the distance between object and neutron detector may be between 5 and 10 meters. In this case, no detailed information on the isotopes and quantity will be gained.

However, with active methods you will gain a lot more information, since this procedure allows quick and non-intrusive locating and inspecting of a suspect object as well as identifying concealed material by its unique, material-specific signatures. So, pulsed fast neutron analysis can be applied for detection and identification of explosives. In particular, with regard to improvised explosives, conventional techniques fail in most cases, whereas active neutron interrogation yields clear indication. The neutrons interact with the elements of the inspected object and induce gamma radiation. These gamma-ray energies are unique to the chemical elements in the inspected object. All explosives have characteristic ratios of the elements N/O, C/H, N/H. So, by measuring these ratios the type of explosive is determined. A quantity of 100 g is detected within a few minutes. Furthermore, this method is used in chemical warfare identification, drug detection and identification and may be helpful to discover different bio-agents.

The methods and procedures described so far are well-tested and can be directly used for verification. In the following sections possible new developments and refinements of detectors as well as of systems are discussed, which may become significant in the future for in-situ verification measurements.

5 New Techniques and Perspectives

New materials for detectors are under development improving efficiency while also reducing volume and power consumption. Concerning neutron detection these are scintillating glass fibers incorporating Li-6 (lithium-6) and cerium. Li-6 has a relatively high neutron cross-section. By the neutron reaction with Li-6 charged particles are produced which interact with the cerium generating a flash of light, which is registered. This material can be fitted to any required shape and, thus, be placed along major roads or at entry points, in order to detect illicit shipment of nuclear material. With reference to gamma detection new scintillators based on lanthanum chloride and lanthanum bromide are under development. They show a significantly better energy resolution than sodium iodide (NaI), a higher light emission and have a high density leading to high volume specific efficiency. With these scintillator materials small and lightweight gamma detectors may be developed to identify the isotopic composition of nuclear material, improving the capabilities of hand-held detectors so far in use.

In the field of detectors a new improvement is the high purity germanium (HPGe) telescope detector for simultaneous high-resolution measurement in the whole energy region from 35 keV to 3 MeV. This high-resolution gamma detector unit consists of two different HPGe crystals, mounted one after the other in one detector end cap with separate signal processing circuits. The first crystal is a planar germanium detector optimized to identify the low energy lines from uranium and plutonium gamma rays (100 keV). The second crystal is a coaxial detector with high efficiency for higher energy gamma rays. The great advantage is that qualitative and quantitative measurements can be performed with one device simultaneously within a short time. The first crystal will give information on enrichment and isotopic composition, whereas the rear crystal supplies the data for calculating the activity.

Another innovative device is a small pocket detector with independent automatic data transmission to a center of operations. A mobile phone is equipped with a gamma-detector (CsI (Tl)), with the option of measuring counting rates and energy spectra, and a neutron detector (LiI (Eu)), which measures the counting rate only. Besides a search mode and dose rate, measurement processing of the data enables automatic nuclide identification. The typical detection limits are at a distance of 20 cm from the material: 0.3 g for Pu and 10 g for U. In the search-mode a vibration alarm will indicate enhanced radiation levels, an automatic notification of a central office via SMS is possible, too. With GPS, localization is possible and the built-in camera transmits a picture of the inspected object. If a lot of these mobile phones with detectors are deployed, they may network together autonomously, and thus enable a representation of the situation in a center of operations. Furthermore, in the future, this pocket detector may be extended by further pluggable detectors for the detection of biological and chemical (B, C) agents.

Under some circumstances, the detection of nuclear material inside an object is required without opening the object. In these cases gamma-ray imaging systems are used. In the following, a gamma scanner is described. It consists of the measuring head itself and a remote control unit including the power supply. Each part has a weight between 10 and 20 kg, so that the whole system can be easily moved.

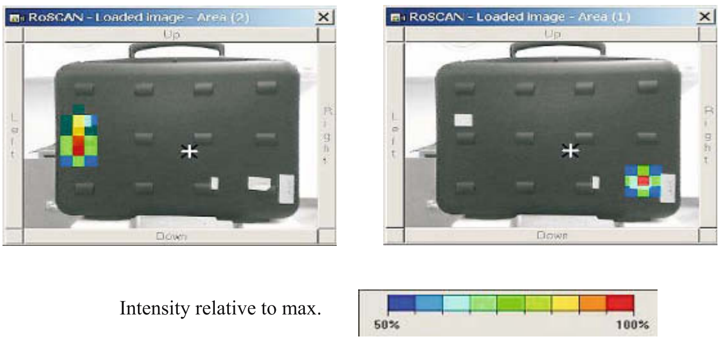


Fig. 4. Active neutron interrogation of a suspect briefcase for special nuclear material. Clear evidence is possible within one minute at a distance of up to several meters

The scanner has two interchangeable detectors, a CsI crystal with relatively high efficiency and a CdZnTe room-temperature semiconductor with high-energy resolution [6]. The object of interest is scanned sequentially and, for each measuring point, a gamma spectrum is recorded. A digital image in the visible spectrum is superimposed on the measured color-coded gamma intensities. Consequently, the position of the nuclear material is easily determined in the display. An example of the inspection is shown in Figure 4. Here, two radioactive sources were placed in a briefcase. The energy spectra were analyzed for each point proving that the briefcase contained two different nuclides. In the left picture, the colors represent the peak area of the 1,173 keV line of Co-60 (activity 2 MBq). The distance to the briefcase was 100 cm, the measuring time 100 s. The color bar shown in the lower right corner of the figure is proportional to the gamma intensities. In the right picture, an evaluation for the 662 keV line of Cs-137 is shown (activity 0.3 MBq). The gamma scanner was tested up to distances of 45 m to the object containing a radiation source. However, then the activity must amount to some 100 MBq.

To enable investigation of objects containing dense materials or those that are shielded by heavy metal, neutron imaging systems have to be applied. In contrast to gamma-ray imaging this is an active method, called neutron (transmission) radiography. A suspect object is irradiated with neutrons and, on the opposite side of the object, a digital picture is taken with an image plate. Whereas neutron radiography is widely used at research reactor laboratories, mainly with thermal neutrons, there is practically no experience with mobile systems. Today, small neutron generators and tubes are available to perform such measurements outside a laboratory. The main disadvantage of mobile systems is the low neutron flux compared to a reactor; therefore, refined techniques have to be developed. Whereas an X-ray picture of an object containing dense materials cannot depict the inner structure in the object, this is possible with neutrons. Neutrons penetrate the thick metal wall of a container or surroundings of high density very well and, consequently, inner structures are clearly visible.

Another category of monitoring systems are Unmanned Aerial Vehicles (UAVs) equipped with nuclear radiation detectors and autopilot GPS. They may be used to disclose illicit handling of nuclear material. The autopilot GPS allows the UAV to be operated as an autonomous remote monitoring platform offering a high radiation sensitivity in connection with a good locating capability. As already described above, a facility producing a few kilograms of SNM only may be very small and, consequently, could be easily concealed. In this case, the detection of the nuclear activities may be accomplished by noble gas monitoring, as an extension of environmental monitoring. Besides direct measurements, including radio transmission of the data during flight, the UAV can be used to collect air samples and return them for laboratory analysis. At a reprocessing plant about 10^{13} Bq of the noble gas krypton (Kr) is released per 1 kg of Pu, and an operating nuclear power plant emits some 10^{11} Bq xenon (Xe) per day. Noble gases are volatile and very difficult to retain. They are not bound to particles and, therefore, there is no washout with rain. As a matter of fact, there is a high background of Kr-85 in the atmosphere due to its relatively long half life of t = 10.76 a. However, in the vicinity of the processing facilities there is a relatively high airborne radiation intensity. Even at higher altitudes there is a significant increase in activity levels, so that the possibility of detection can be expected.

6 Conclusions

In conclusion, the following can be summarized with regard to monitoring treaty compliance by applying nuclear verification principles that are based on non-destructive and non-contact measurement methods. Clear evidence for the presence of SNM can only be obtained by the detection of a nuclear radiation signature. The verification goal is a definite identification with only minimum findings on design details, where commercially sensitive know how is involved. Therefore, the applied measurement methods should not be intrusive but highly effective. With the procedures discussed above plutonium can be easily detected by measuring neutrons emitted from Pu-240, which is always present. In contrast, U-235 surrounded by slight shielding can only be detected by active methods. If a specific suspicion exists, then the non-detection of nuclear radiation does not indicate the absence of nuclear material. In this case, more sensitive testing methods are required. Depending on how the material is packed a reliable determination of the quantity of SNM is not always possible.

In addition, it is important to keep in mind that, for a possible violator, the production of SNM does not need to not be economic. Therefore, one should not only consider commercially well-established techniques but also alternative processes that are less efficient and more costly.

In order to obtain credible and independent assurance about non-declared activities and, thus, to deter and detect possible violators, it is essential to perform extensive nuclear measurements on a random basis. In addition, such systems and methods may be used to combat transnational nuclear terrorism and asymmetric warfare.

References

1. Rosenstock, W.; Köble, T.; Hilger, P., and Engelen, J. (2002): Searching Plutonium from a Travelling Vehicle by Neutron Measurements; C&S Paper Series 12/P, Proceedings Measures to Prevent, Intercept and Respond to Illicit Uses of Nuclear Material and Radioactive Sources; International Atomic Energy Agency - IAEA -, Vienna, IAEA-CSP-12/P86, pp. 563 - 564, ISBN 92-0-116302-9
2. Köble, T., Rosenstock, W., Risse, M., and Peter, J. (2003): Detection of Nuclear Material During Fast Road Transport. Proceedings 44th Annual Meeting of the Institute of Nuclear Materials Management (July 2003, Phoenix, AZ, USA). CD-ROM. Eau Claire, WI, USA : Documation LLC, 6p.
3. Rosenstock, W; Köble T., and Risse, M. (2003): Measurement Techniques to Combat Nuclear Terrorism. 25th ESARDA Annual Symposium on Safeguards and Nuclear Material Management, Proceedings CD-ROM; Stockholm (Sweden), May.
4. Rosenstock, W.; Köble, T.; Durek, D. (1998): Characterization of unknown objects containing radioactive materials ; International Atomic Energy Agency -IAEA-, Vienna, Safety of radiation sources and security radioactive materials,

Vienna: IAEA, S. 291-294, (IAEA TEC DOC, 1045), Conference: International Conference of Safety of Radiation Sources and Security of Radioactive Materials <1998, Dijon, ISSN 1011-4289>

5. Rosenstock, W. ; Köble, T., and Hilger, P. (1999): Measurement of the Time Structure of Delayed Neutrons After Induced Fission in Nuclear Material; Proceedings EUR 18963: 21st ESARDA Annual Symposium on Safeguards and Nuclear Material Management, pp. 321-325, European Commission.
6. Köble, T.; Rosenstock, W.; Risse, M., and Engelen-Peter, J. (2004): Locating Nuclear Material by Gamma Scanning. Proceedings 45th Annual Meeting of the Institute of Nuclear Materials Management, CD-ROM, Orlando, FL, USA (July).

A Sustainable Approach for Developing Treaty Enforcement Instrumentation

Marius Stein and Bernd Richter

1 Introduction

In fulfilling their mission treaty enforcement agencies rely on technical instrumentation to gain assurance that signatory parties comply with their treaty obligations. Such instrumentation must be suitable for highly specific applications and must comply with challenging specifications and user requirements. While technical solutions are generally available, both the development and production of such instrumentation are impacted by a variety of economic and political problems. These include factors such as small production runs, irregular orders, obsolescence of critical system components, and issues arising from the funding commitments of treaty organizations and supporting agencies. For example, the International Atomic Energy Agency (IAEA), when procuring instrumentation for Safeguards application, is confronted by a complex network of private suppliers, research and development institutions, Member States Support Programs (MSSPs), and its own internal divisions.

The IAEA relies on a tight and strictly regulated inspection regime in its mission to verify the compliance by Non-proliferation Treaty (NPT) Member States with their Safeguards agreements, IAEA inspectors employ instrumentation that provides information from which it can be concluded if nuclear materials have been diverted from civil applications in the absence of inspectors. Since the earliest applications of Safeguards in 1961[1] , emerging technologies have been applied to strengthen the IAEA's Safeguards systems by increasing synergies between inspection efforts and automated control. Digital surveillance and other Safeguards instrumentation are an integral part of the IAEA treaty enforcement strategy at the beginning of the 21st century.

Reliance on Safeguards equipment carries inherent significant downsides which, if not managed properly, threaten to offset the benefits found in the

[1] The first installation safeguarded by the IAEA was the Japanese JRR-3 research reactor, with a Safeguards system approved by the IAEA Board of Governors in 1959 and implemented in 1961.

increased assurance that Member States comply with their non-proliferation agreements. On the one hand, the IAEA finds itself locked in a development race, since as new Safeguards technologies become available so do enhanced means to defeat them. This issue is mitigated by the fact that Safeguards instrumentation is still considered an additional proliferation detection tool which merely supports the personal visits of IAEA inspectors to nuclear facilities. There are, however, other, more mundane issues that have a more significant impact on the usage of instrumentation related to the unique position of the IAEA as an international treaty enforcement agency. These problems are encountered during the procurement, development, funding, installation, and maintenance of Safeguards equipment.

The following paper will use the IAEA as an example with which to outline the complicated problems and needs related to the use of treaty enforcement instrumentation. It will describe the Agency's various partners and identify their contributions to successful instrumentation development as well as problems encountered in partnering with the IAEA. Next, it will give insight on how all partners must pool and coordinate their efforts in order to provide the Agency with a sustainable management approach and to support Safeguards instrumentation over the complete lifecycle. The Next Generation Surveillance System (NGSS) will serve as an example how essential steps to such a partnership have been recently realized. Concluding remarks will set the example of the IAEA into context with other treaty enforcement agencies.

2 The Unique Problems Related to IAEA Safeguards Instruments

The IAEA investigates all suitable markets to minimize the procurements costs of Safeguards instrumentation. The least costly alternatives are usually available in the consumer electronics market, where items are offered inexpensively and competitively in volumes in the millions. Compared to this, markets for industrial electronic components, measurement technologies, or surveillance and monitoring systems are relatively small with customized production volumes in the low thousands. Industrial electronic component markets are more expensive but are more likely to offer solutions suitable for Safeguards. Parts stemming from all of these markets include, for example, CCD cameras, digital storage media, and personal computers. In the design of a Safeguards system, commercially off-the-shelf (COTS) components usually have to be complemented by custom designed parts to meet the specific needs inherent in the application of Safeguards instrumentation such as include tamper indication, data authentication and encryption, and high reliability. The same complementary process applies to software products; usually, executable programs have to be adapted for Safeguards specific applications or written as customized programs.

The IAEA has neither the personnel nor the resources to accomplish this custom development work in-house. Thus, the Agency has to contract these projects to commercial entities and research and development institutions. Funding is provided by Support Programs that assist the IAEA with extra-budgetary funding for development and procurement of Safeguards instrumentation. Due to the Safeguards-specific user requirements, the development of both hardware and software is time consuming and expensive. Manufacturing of such systems must also be accomplished by external commercial entities, as orders are small in volume, are placed irregularly, and require very high quality control. The total number of systems needed varies from dozens to a few hundred every year or even in total. For some developments, only a few systems are required, making it impossible to realize significant Economies of Scale.

Safeguards-specific instruments have a low potential of attracting customers outside their niche market[2]. This puts the IAEA into a monopsonistic position, as the only buyer of Safeguards systems. On the other hand, the low volumes needed support only one manufacturer per system, adding a monopolistic provider to the already complicated Safeguards supply environment. Whereas the IAEA issues Basic Supply Agreements (BSAs) that state the number of systems they intend to purchase over a certain period of time at a fixed price, BSAs do not constitute a commitment to really purchase systems. This makes it impossible for manufacturers to anticipate and prepare for incoming orders without bearing the financial risk of stockpiling parts without receiving an order.

Further complication stems from the looming threat of crucial equipment parts becoming obsolete in the fast moving electronics market. Once a newly developed design has been authorized by the IAEA for inspection use, market-enforced technical changes require a lengthy and cumbersome process, drain Agency resources, and re-occur on a regular basis[3].

Even though the situation faced by the IAEA seems so complicated and cost-prohibitive as to prohibit employing instrumentation at all, the problems can be mitigated and even solved if properly managed. Before appropriate solutions can be offered, however, it is necessary to examine more closely the individual parties involved in the development, manufacturing, and support of Safeguards equipment.

[2] Some customers include the European Commission (EC), the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), and a few others, all with volumes lower than the IAEA.

[3] For example, Central Computer of the Digital Multi-channel Optical Surveillance System (DMOS) used by the IAEA is known to becoming obsolete about every six months.

3 Safeguards Instrumentation Parties

3.1 IAEA

As the central customer for Safeguards instrumentation, the Agency is responsible for procuring the development of appropriate technologies. Unfortunately, this must be accomplished with a strained budget. Because not enough personnel are available in-house to develop and build equipment, detailed user requirements must be communicated to potential partners to allow them to develop solutions in accordance with concrete IAEA needs. The identification of user requirements tends to be a complicated process as it involves multiple sections (e.g. technical support, operations, and concept and planning). Developments in the nuclear sector such as new reactor types[4] or new non-proliferation policies[5] sometimes call for new Safeguards approaches which have no reference to past projects, require innovative initiatives, and are impossible to test because the facilities they are to safeguard do not yet exist.

Without the input of commercial partners or research institutions specializing in the relevant area of the new approach it would be virtually impossible for the IAEA to develop suitable user requirements on its own. However, this bears with it inherent problems, in that a partner may attempt to influence the requirements development to favor an approach that is not necessarily the solution favored by the IAEA', but is appealing to the partner because it is easier to accomplish, cheaper, or inaccessible to possible competition.

One way to cope with these problems is for the IAEA to pool as much expertise as possible in-house to proof and criticize all second party input. An alternative method is to draw upon all available outside resources and expertise to draw an objective picture of what is needed. As an international agency supported both by its Member States in general and MSSPs in particular, the Agency has been very successful in employing both methods, attracting international experts to share knowledge (often at minimal expense) and to work for the IAEA on staff.

Another problem with the potential to significantly hamper Agency efforts to obtain Safeguards instrumentation lies in the procurement regulations of the United Nations. New development projects exceeding a certain expected cost volume have to be issued as open tenders, inviting all interested parties into an open bid process. In broad consumer markets this process has the advantage of attracting comparable offers at competitive prices. This is not necessarily the case in the Safeguards area. The personal experience that specific companies and research institutions have in Safeguards as a whole and with IAEA user requirements development is essential to providing a project schedule and delivery plan at a fair price. In addition, devotion to

[4] Such as the Pebble Bed Modular Reactor (PBMR) development or the reactor types investigated by the Generation IV forum.

[5] Especially the Additional Protocol INFCIRC /540 (corrected) and Integrated Safeguards.

the non-proliferation of nuclear weapons on the part of IAEA partners is an important aspect which should not be overlooked.

However, under current UN procurement rules, it is possible for a new company with a general interest in the Safeguards market to bid low on and win a tender, misjudging the boundary conditions of Safeguards. Later, after the effort needed has become obvious and has been recalculated there is a risk that the cheaper alternative becomes more expensive in the long term, as a newly awarded partner must slowly acquire the experience which an established partner would have calculated into its initial offer. In the worst case scenario, a new partner withdraws from Safeguards after failing in its efforts while in the meantime the established partner has dissolved or moved on to other markets because there was no room left in Safeguards for more than one company. The Agency would have expended time and resources only to be left without any partner available or willing to assist in the development of Safeguards instrumentation.

3.2 Member States Support Programs

Several MSSPs[6] provide extra-budgetary assistance to the IAEA through funding of development projects, equipment purchases, staff experts, and international exchange of expertise. Other than the regular contributions all Member States pass to the Agency every year, these extra-budgetary resources are subject to the specific funding regulations of each individual MSSP. The United States Support Program for IAEA Safeguards (USSP), for example, can only provide funds to the IAEA if they are used for purchases of equipment or services in the US. This regulation is a means for the US government to support both the international Safeguards community and its domestic suppliers. The German Support Program (GERSP[7]) was established for similar reasons: strengthening IAEA and EURATOM Safeguards, preserving German expertise in the Safeguards area, communicating changes in the German nuclear program to the IAEA, and supporting the German industry.

It must be stressed that MSSP assistance is essential to relieving the IAEA's strained regular budget and in providing instrumentation and expertise for comprehensive treaty enforcement capabilities. Due to the nature of the MSSPs, however, there are a few issues impacting the IAEA's ability to make optimal use of the offered assistance. Since part of the MSSP mission is to support the economy of its country of origin, many programs are

[6] States and organizations representing groups of states having formal support programs: Argentina, Australia, Belgium, Canada, Czech Republic, EC, Finland, France, Germany, Hungary, Japan, Republic of Korea, Netherlands, Russian Federation, South Africa, Sweden, UK, and US.

[7] The complete title of GERSP: Joint Programme on the Technical Development and Further Improvement of IAEA Safeguards between the Government of the Federal Republic of Germany and the International Atomic Energy Agency.

interested in not only having local companies and research institutions develop new Safeguards instrumentation but also in manufacturing the systems for the IAEA after development has been completed. The developer usually has an advantage of experience and thus a good chance of being selected as manufacturer (assuming he has the capabilities to do so). MSSPs therefore promote local developers for Safeguards instrumentation to secure not only funding for development, but also BSAs during later production.

At times multiple MSSPs have initiated the development of the same Safeguards instrumentation in parallel[8]. Since Member States must be treated equally and no effort to support the Agency with instrumentation should go unrewarded, the IAEA Safeguards Department had no choice but to evaluate and test all candidates. Generally, there is only enough demand for a single instrument in each respective category, drawing IAEA resources into a lengthy selection process. Further exacerbating the problem, the efforts of MSSPs that did not get selected are wasted because applicability of Safeguards instrumentation is limited in other markets.

Another issue encountered in the past lies with the intellectual property rights (IPRs) generated in projects funded by MSSPs. For example, the German government, as part of its mission to preserve Safeguards expertise, requires that all IPRs generated through funding of the GERSP are vested with the German government, while the development results are provided to the IAEA free of charge for worldwide Safeguards applications. Although Germany guarantees that there will always be a partner for the IAEA to procure Safeguards instruments governed by the GERSP and that the prices will remain "fair", in its mission to support the national economy, the GERSP also has an interest that licensees are German companies. With regard to supply assurance, during the developer selection process the GERSP requests a commitment on the part of the developer that they will also be the future equipment supplier However, this prevents the IAEA from using available global resources and competition to acquire instrumentation at a competitive price.

This issue is mitigated by the nature of the Safeguards market. While competitive procurement, as mentioned above, is not necessarily helpful for instrumentation development, it might make sense for the production of equipment. However, at that point, most of the funding has already been spent, and the differences in production prices tend not to differ a great deal. In addition, as will be explained below, the number of companies willing and, more importantly, capable of supporting Safeguards instrumentation over the complete lifecycle is limited. Thus, protecting the developer by governing the IPR and by issuing licenses only to qualified manufacturers, the GERSP preserves Safeguards expertise, supports domestic economies, and still enables

[8] For example, three MSSPs initiated the development of a seal to replace the fiber optic VACOSS seal: the GERSP (EOSS), the French Support Program (IRIS), and the USSP (VACOSS 5E).

the IAEA to procure instrumentation at reasonable prices. Also, it should be noted that if the IAEA were to select a manufacturer other than the developer, it would be necessary to repeat equipment authorization; a process that can take up to a year or even longer.

3.3 Commercial Entities and Research and Development Institutions

The IAEA and the MSSPs have a large number of both commercial and governmental cooperation partners which face differing obstacles and offer different solutions when dealing with the Safeguards market.

Large Companies

Large commercial entities have significant advantages in both the development and manufacturing of electronic instrumentation. In-house capabilities in research and development, tight quality control and documentation requirements, internal auditing, as well as financial security are just a few of the strengths that make large companies attractive partners for the IAEA. The downside, however, is that such companies are generally focused on markets that are magnitudes larger than the Safeguards market in production volumes. In-house processes are focused on automated large scale production, learning effects, and Economies of Scale. Experience has shown that, while large companies might be interested in supporting the research and development of Safeguards instruments, they are not interested in the small Safeguards market with its high production cost due to high quality standards and low order volumes which do not allow for automated production.

There is a converse danger that large companies overestimate the potential for Safeguards equipment for other markets, decide to enter into a bidding process, and then withdraw at some point when the actual market potential becomes apparent. Such involvement can cause significant delays in the initiation and conduct of research and development projects and can drain both IAEA and MSSP resources. Some examples are given:

A large German company serving the consumer electronics and security markets was asked to propose the development of an authentication method of digital surveillance images. Initial negotiations took months and did not result in a proposal. The company had problems with the highly specific user requirements, and the potential markets were considered too small. Also, communication with the IAEA and the Commission of European Communities (CEC) was slow and prone to misunderstanding. The company eventually lost interest, causing significant delays in commencing the project.

Another German company successfully developed the active VACOSS Sealing System but could not provide the required level of quality during the streamlined manufacture of the seals even though there was a high-standard quality control system in place. After two production runs of 100 seals each, the IAEA removed this company from its suppliers list. Evidently, this company was not interested in supplying the Safeguards market. This resulted in the GERSP requesting an a priori commitment to both develop and manufacture the development product.

A large Japanese company developed a few prototypes of an automated Cobra Sealing System reader that did not work reliably enough for Safeguards applications. The anticipated market was considered too small and the additional development effort needed too large, and the company withdrew their commitment to manufacture the readers. Even worse, once interest in the project had dissipated, the company was either unable or unwilling to provide the to-build documentation of the reader to the IAEA, making it impossible for the Agency to look for another manufacturer.

Mid-sized Companies

Generally, mid-sized companies are better partners for the development and manufacture of Safeguards specific instruments. The total anticipated market volume is more appealing to such partners and negotiations and user requirements finalization can take place on a much more intimate level. Certain mid-sized companies have evolved to be reliable partners to the IAEA over the past decades, building the backbone of the supply of Safeguards instrumentation.

Unfortunately, there are problems in partnering with mid-sized companies as well: they have the capability but also the necessity to focus on a certain field of expertise to remain competitive in a specialized area. This can result in a company misinterpreting the potential and specific needs for Safeguards instrumentation. For example, a German company specializing in the development and manufacture of perimeter security equipment discontinued a project for the authentication of analog video signals after it became obvious that the Safeguards market was not as similar to the security market as it first appeared. The company realized that there was little applicability for the technology to be developed in their core capacities and lost interest.

Mid-sized companies that support Safeguards thus must be committed to Safeguards and must consider it their core capability. Two of the authors represent one such company. Initially, this company received a license from the GERSP for the manufacture of the VACOSS seal after the German developer terminated production. Cooperation with the GERSP and the IAEA was extended by acquiring further licenses for the production of the DCM 14 based Safeguards surveillance system, working closely with a small German company. In cooperation with the USSP, the IAEA, and the CEC the company also initiated and successfully completed its own Safeguards specific developments (such as the General Advanced Review Software (GARS) for the review of Safeguards surveillance data). In addition, the company successfully worked with research and development institutions in the provision of Safeguards instrumentation, mitigating some problems related to such IAEA partners.

Small Companies

At first glance, the cooperation of small companies with the IAEA seems to be the ideal combination from a project management point of view. Small partners have the ability to fully concentrate on the IAEA as a customer and conduct the highly specified customized developments with their full attention and resources. Inherent in the structure of such small partners is the capacity to build a developer-customer relationship on a very personal level.

On the negative side, small companies are very dependent on their specialized niche market. Personal experience gained during previous projects is highly specific and not necessarily applicable to other markets; thus, should the niche market change, or should competition try to enter it, it is likely that a small company will be forced to either withdraw from Safeguards and seek other markets, or dissolve, since usually the market only supports one supplier for each respective Safeguards system. This applies not only to development projects but also to instrumentation production. Small companies usually have little or no other customers and are thus heavily dependent on a constant stream of orders to continue operating. Traditionally, the IAEA has ordered equipment irregularly through BSAs, making it difficult for a small partner to survive just on the basis of Safeguards.

There are a few successful small companies that support the Safeguards market, one of which is the above mentioned developer of the DCM 14 technique. However, over the past 15 years of supplying development services as well as instrumentation to the IAEA, this company has experienced exactly the problems described. To avoid bankruptcy due to lack of orders, the company partnered with a mid-sized US company, with the financial strength to spread IAEA orders over a period of time, thus providing DNE with a constant line of income. This small company also enjoys the strong commitment of the GERSP to conserve its Safeguards-specific experience.

Research and Development Institutions

Like small companies, government funded research and Development (R&D) also appear at first glance to be ideal partners for the IAEA in the development of highly specialized and complex Safeguards instrumentation. R&D facilities expand knowledge and science to new levels on a regular basis. Resources and expertise are abundant at such facilities, and there are few other institutions that can so fully grasp both the IAEA mission and the related technical requirements. Nevertheless, the IAEA's cooperation with research laboratories has been overshadowed by difficulties.

First of all, while the understanding of technical requirements is the most important issue related to the development of new Safeguards instrumentation, it is only a part of the whole. Maintainability in the field, operability by IAEA inspectors, ruggedness against harsh environmental conditions, and cost-effectiveness in the parts used are other factors that need to be considered when designing Safeguards solutions. While the R&D facilities excel at understanding a technical problem and providing scientifically sound solutions, they often lack the expertise to manufacture, install, operate, and maintain equipment in the field. Technologies have to be passed on for commercialization by an R&D facility after reaching prototype level. This is the stage where problems become apparent.

Commercial partners often find it difficult to adapt prototype technology to a commercially acceptable product with a streamlined manufacturing process. This transition is further complicated by the strict requirements of Safeguards instrumentation. Operating with a lack of commercial pressure, R&D institutions tend to pursue the most scientifically sound solution, which is not necessarily the one easiest to build, maintain, or support. Also, once a technology has been developed to the prototype stage, the scientists involved are required to move on to other projects and are therefore unavailable to assist in commercialization to the fullest extent.

In this respect it is essential that both the R&D institution and the commercial entity work together as early as possible to get an understanding of what a scientifically sound and commercially feasible solution should look like. This hardly ever takes place, though, because the IAEA, also in accordance with procurement regulations, has to wait for the development to be completed before issuing the commercialization and production of the instrument as an open tender. This is further complicated in that the IAEA usually does not contract the R&D facilities directly but with the respective MSSP as intermediary. This sometimes makes it difficult for the IAEA to judge the progress of a project and what can be done to facilitate an easier production of the instrumentation after the development has been completed.

4 Player Management

While the previous paragraphs seem to draw a dark picture of all the problems accompanying the facilitation of Safeguards instrumentation development and production, most of the issues encountered can be solved with a single attitude: Commitment to Safeguards. If all parties understand the problems related to the unique realities of Non-proliferation Treaty enforcement, all individual strengths can be enhanced while weaknesses can be negated.

It seems contradictory to suggest the IAEA to be committed to Safeguards, because in more than technical terms the IAEA is Safeguards. But commitment in this regard means commitment to the Safeguards market. The IAEA needs to look upon itself as a complex customer with a wide range of (often conflicting) user requirements that might change over the lifetime of a system development. It is also a difficult customer because it shows little or no commitment to the supplier other than BSAs, which merely fix the price for a system but do not offer enough security for a company's proper risk management. Low order volumes and irregular order practice further aggravate this problem. The IAEA has been very good at communicating an expected order outlook to its partners, but this process is not institutionalized and relies on the supplier's expertise to anticipate the proper need for each fiscal year. An official Safeguards needs meeting, conducted on an annual basis and involving all affected parties could help suppliers build up confidence in expected order volumes and help them achieve Economies of Scale, help prepare for parts obsolescence, and provide a Safeguards strategy to provide identical Safeguards instrumentation for the complete lifecycle of equipment. This would also provide the IAEA with more supply assurance.

The mission of MSSPs is not only commitment to Safeguards but also to other objectives such as those stated above. However, these different commitments can be combined if a comprehensive effort is undertaken to strengthen Safeguards as a whole. Instead of pursuing multiple development efforts in the same area, each MSSP should evaluate the strengths of its domestic commercial partners to the IAEA and research institutions and decide how these strengths can be applied to support this comprehensive approach. Also, it is essential for MSSPs to identify domestic supporters to the IAEA and evaluate how to best keep their contribution capacities and experience with Safeguards available for future application. If possible, MSSPs should provide sufficient funding to prevent obsolescence problems if last-time buy opportunities can be identified, and threatened parts can be stocked for the remainder of the Safeguards instruments' lifecycle.

Commercial companies have to be fully committed to the IAEA as a customer. Unique and difficult user requirements and the Agency as a bureaucratic giant pose obstacles that will test the patience of each partner, but the goal, the provision of Safeguards equipment, should always be foremost. Similar to the MSSPs, different levels of expertise (e.g., development, production, and commercialization) should combine their efforts where appropriate to mitigate the impact of problems on a single partner and smooth the transition from development to the actual fielding of Safeguards system.

R&D institutions must acknowledge the challenges technologies encounter once they leave the laboratory. Early involvement of commercial partners during the design phase of technologies can lay the ground for easier fieldability of the finalized product. In this respect, R&D installations not only could but should be part of the cooperation efforts that private partners should undertake. Combining expertise in all areas of system development, supported by the MSSPs with close cooperation with the IAEA will make Safeguards systems available more quickly, in accordance with user requirements, sound funding plans, and a lifecycle management in place for the complete lifetime of the system.

The IAEA has been very active in pursuing cooperative approaches for the development of new Safeguards systems. For the development of the Next Generation Surveillance System (NGSS), the replacement for the DCM 14 based surveillance system, the Agency pooled international expertise from both public and private partners to identify the needs and requirements of

NGSS. A cooperation of two established suppliers of Safeguards was selected with both parties sharing responsibilities in their respective core capabilities. NGSS is funded by both the GERSP and the USSP, a comprehensive effort unprecedented in the history of the development of Safeguards instrumentation. A team of representatives of all involved parties, with communication channels open at all times, will govern the development of NGSS to make it a successful replacement for the next 15 to 20 years.

There is, however, room for further improvement. While the IAEA expressed its intention to begin a development project in early 2003, the definition of user requirements for NGSS was not initiated until October 2003 with a meeting of international experts. It took until April 2004 to initiate the bidding process. This open bidding process was lengthy, involved an extensive selection process, and was finally concluded in March 2005. Hopefully, the experiences and obstacles encountered in the initiation of NGSS can be applied towards future development projects to make it easier for the best available partners to join their efforts towards Safeguards development.

5 Concluding Remarks

The situation encountered by the IAEA is generally similar to that of other treaty enforcement agencies. Highly specific user requirements, the limited need for systems over the complete technology lifetime, tight budgets, policy changes, and rapid movements in the electronics market make it difficult to ensure the availability of identical instrumentation for the required time-span (up to two decades). However, the experience gained in the Safeguards area can help other agencies in implementing instrumentation to expand confidence that treaty signatories comply with treaty obligations. In particular, the open, continuous dialogue between all involved parties can serve as an example that different players with different missions can find sufficient common ground to support one common goal: the provision and support of treaty enforcement instrumentation.

The problem solving mechanisms and approaches which have proved successful in the Safeguards area are in theory applicable to other treaty enforcement fields. However, cooperation in the technical field, (e.g. through the sharing of technology between multiple agencies) is less assured of success. Such sharing activities would mitigate the economic problems met in the development and production of instrumentation in niche markets. Unfortunately, the highly specific needs of individual agencies prohibit the one-to-one transfer of instrumentation to another field. Despite these obstacles, certain synergies are possible, making an on-going dialogue between different treaty enforcement agencies a cost and effort saving necessity. Thus, communication efforts such as the Institute of Nuclear Materials Management (INMM) and the European Safeguards Research and Development Association (ESARDA) Working

Group Verification Technologies and Methodologies should be encouraged and further expanded in the future.

VIII

Perspectives and Conclusions

An analysis of treaty verification regimes from a political science point of view has been deliberately chosen to add another perspective to the scientific one developed in this book. Another major conclusion relates to the importance of research and development for the future evolution of verification technologies and methodologies.

Continuity and Change in International Verification Regimes

Erwin Häckel

1 Introduction

Treaties limiting the spread of weapons of mass destruction are basically conservative in their intent and content. Like all legal instruments they are designed by their framers to preserve and stabilize a given status quo; in this case, the distribution of the most fearful means of violence among states. International compacts such as the Nonproliferation Treaty (NPT), the Chemical Weapons Convention (CWC) and the Biological and Toxin Weapons Convention (BWC) display their conservative bias quite clearly. Prevention of nuclear, chemical or biological weapons proliferation takes precedence over other treaty objectives. Although each of the treaties contains clauses calling for positive changes in the fields of disarmament, peaceful uses of technology and support for developing countries, these are obviously secondary goals of wishful quality, hopefully to be fulfilled in an uncertain future; whereas the mandate of non-proliferation has taken its prohibitive effect immediately upon signature and ratification. Promises of change are made contingent on the preservation of stability.[1]

International verification regimes reflect this order of priorities. They are designed to assure confidence that the status quo is being maintained. Compliance with nonproliferation commitments is being monitored and controlled (more or less effectively) by an array of restrictions, safeguards and accountancy measures while complementary progress in disarmament, peaceful uses and development is left to the good will of privileged parties. The quinquennial treaty review conferences are regularly dominated by disputes between governments over the proper balance or alleged imbalance of treaty goals and verification provisions. States which benefit from the status quo (mostly the nuclear weapon states and their allies) hold the treaties to be balanced and equitable; states which resent the status quo (mostly developing countries) often denounce them as being skewed and discriminatory. The former call for rigid implementation and stringent verification; the latter complain about it. To the present day, however, the proponents of stability, i.e., nonproliferation, have prevailed over those of change, i.e., disarmament, technology transfer and development. Although several review conferences failed in their effort to reach a consensus among member states, membership itself has continuously expanded and formal adherence to the treaties remained intact (with one exception, North Korea, leaving the NPT in 2003). This proves that confidence in treaty compliance was sufficiently assured through verification to establish the treaties as a credible and durable framework of nonproliferation within the community of states.[2]

More lately, however, confidence in the effectiveness of verification regimes has declined to such a degree that some parties, notably the United States, chose alternative methods to assure compliance. The most obvious example is the Iraq War of 2003 which the U.S. and its allies initiated on the grounds that there was no other way to make sure that Iraq was free from illicit weapons of mass destruction. A starker vote of no confidence in international verification is hard to imagine.[3] After all, it was the United States who had insisted for many years on the elaboration of international verification and safeguards systems. How did this change of mind come about?

2 Shortcomings

A variety of reasons can be cited to explain the decline of trust in verification regimes. The single most important one was probably the discovery in 1991, following the Second Gulf War, of a secret programme in Iraq for the development and deployment of nuclear, chemical and biological weapons in defiance of international law and in spite of an international verification system in place. Not only was this the first instance of a member country (in fact, one of the earliest signatories) of both the NPT and of the 1927 Geneva Protocol being caught red-handed in violation of its treaty commitments. Worse than that, Iraq's vast and illicit nuclear weapons programme had been carried on for many years under the eyes of the International Atomic Energy Agency (IAEA), whose inspectors faithfully certified the peaceful nature of the country's declared nuclear activities, and was finally uncovered not through the Agency's regular safeguards but only by means of the extraordinary investigatory powers of the United Nations Special Commission (UNSCOM). In addition, evidence was found that Iraq's clandestine procurement efforts for weapon purposes had been greatly facilitated by lax export controls in a variety of industrial countries around the world. All this led to the perception that international verification was insufficient to deter and detect disloyal and illegal activities among treaty members.

Other events added to this perception. In 1992 and again ten years later North Korea, an NPT member since 1986, was found by IAEA inspectors to be cheating on its nuclear materials accountancy in order to conceal an advanced nuclear weapons programme and, when confronted with the evidence, hastened to renounce the NPT altogether. Although the IAEA's verification system worked properly in this case, its alarm whistle sounded late and could not prevent the forbidden weapons programme from going forward. The North Korean example raised the spectre of a sinister option that could appear attractive for every dishonest NPT member: use the shield of NPT membership deliberately as a cover for illegitimate weapons development at the risk of being detected sooner or later and then, upon detection, withdraw from the treaty to go away unpunished as a nuclear armed state. It is precisely this spectre which haunted the American and European governments when they learned in late 2003 that Iran, an NPT member since 1970, had for many years misled the IAEA about its efforts to obtain weapons-usable nuclear material and technology. Pertinent clues had come from Iranian defectors, not from IAEA inspectors. And again, concerns were raised in the following year when the IAEA detected traces of (possibly innocuous) experiments with fissile materials which had been carried out unreported during the 1970s and 1980s in South Korea, Egypt and Taiwan.[4] There appeared to be loopholes in the nuclear safeguards system which allowed breaches of treaty obligations, whether deliberate or negligent, to remain unnoticed for a very long time.

An alarming defect of the international verification regime burst into the open early in 2004 when it was revealed that the eminent Pakistani physicist Abdul Qadeer Khan, father of his country's atomic bomb, had run for many years an extensive international sales operation for sensitive nuclear technology, catering to members and non-members of the NPT as well as Islamic and Communist governments without distinction. An invisible tier of nuclear suppliers, independent from the established Nuclear Suppliers Group (NSG) of industrial countries with their elaborate export controls, had come to flourish in the dark. Globalization had finally reached the black market for weapons of mass destruction.

Discovery of the Khan network renewed anxieties about the uncontrolled flow of sensitive materials and technology across permeable national borders. Such anxieties had reached a first peak in the early 1990s when the breakup of the Soviet Union caused expectations of "loose nukes", fissile material, weapon designs and unemployed brains streaming abroad towards the highest bidder. A decade later, while the ominous Soviet legacy had not yet been brought fully under control, the centre of illicit marketing appeared to have shifted to the South. Khan's enterprise, with its hub in Pakistan, had outposts in Malaysia and Dubai and listed North Korea, Iran and Libya among its customers. Middlemen in various European countries and South Africa were suspected to be on its payroll.[5]

Several factors combined to increase concerns about the Khan racket. Originating in a de-facto nuclear weapon state outside the NPT, it had grown up unnoticed by international verification systems and, to be finally traced down, it required a lengthy effort of collaboration, observation, penetration and information exchange by various (mostly American) national intelligence services. It revealed collusion among states that had long been under suspicion as "rogue states". It pointed to the increased role of non-state actors and semi-governmental enterprises in sophisticated technology barters. It manifested the dangers of fragmented authority and administrative breakdowns in failed or failing states. And, following the shock of "9/11" in America and elsewhere, it directed public attention to the possibility that weapons of mass destruction might fall into the hands of terrorist groups who would be ready to use them not in a conventional sense of deterrence but instead with the intent to create as much horror, cause as much destruction and kill as many people as possible.

It is this coincidence and accumulation of disquieting events and fearful expectations which resulted during the course of the past decade in widespread dissatisfaction with existing verification regimes and in a variety of initiatives to remedy their shortcomings. Some of the remedies sought to upgrade international verification, but not all; and not all succeeded.

3 Remedies

The discovery by UNSCOM inspectors of secret nuclear, chemical and biological weapons programmes in Iraq in the wake of Iraq's military defeat in 1991 gave a strong impetus to efforts for the improvement of international verification regimes. In the nuclear field the concept of "special inspections", which had lain dormant for many years, was revived to enable the IAEA to examine more thoroughly certain inconsistencies and accounting irregularities in NPT member states. The IAEA was invited to join Russia and the United States in a "Trilateral Initiative" to put fissile material from nuclear disarmament under international safeguards.[6] But the most important innovation was the Additional Protocol, which was concluded after a lengthy negotiating process in the IAEA and opened for signature in 1997. It enlarged the mandate of the IAEA to safeguard not only officially declared nuclear activities in NPT member states, as was hitherto the case, but to actively seek out and bring into the open any undeclared or purposefully hidden facts of proliferation relevance.[7]

In the chemical field significant progress was made with the establishment of an unprecedented verification and inspection system under the Organization for the Prohibition of Chemical Weapons (OPCW) since 1997. In the biological field some progress was made but not consummated when preliminary agreement was reached by 2000 about a similar verification system for the Biological Weapons Convention of 1972 which, however, foundered upon second thoughts by the United States Government about its acceptability, practicability and reliability. Likewise, failure of ratification by the U.S. Senate has prevented the Comprehensive Nuclear Test Ban Treaty (CTBT) with is novel verification system, signed by the U.S. in 1996, to enter into force.

The Additional Protocol with its intrusive monitoring and inspection provisions blazed the trail for a broader concept of international verification. The traditional IAEA safeguards system, enshrined in Model Agreement INFCIRC/153, was based on the principles of state sovereignty, objectivity, confidentiality and non-discrimination. It has now been supplemented and partially superseded by methods of information gathering and practices of evaluation (such as qualitative data assembly, selective monitoring, investigative search activities, remote observation, use of unorthodox intelligence, informed judgment, unequal distribution and allocation of resources, etc.) which had been held previously to be inadmissible for an international organization. The quest for more effective verification has injected elements of politicization, inequality and importunity into the system. Transparency, not regularity, has come to be the benchmark of verification. In the special case of Iraq, transparency was enforced by the U.N. Security Council with resolutions 687 (1991) and 1441 (2002) to such an extent that the country was - in effect though not in form - stripped of its sovereignty.

The search for transparency through intrusive verification is predicated on the assumption that not all treaty partners can be trusted to act in good faith or in a responsible manner. If the possibility of evil intentions or disloyal behaviour is anticipated as a rule, treaty compliance cannot be assured in an altogether gentlemanly fashion alone. An attitude of scepticism and distrust may therefore be a healthy ingredient for the safeguards philosophy of an international watchdog agency. But it has costs of its own. It increases the international agency's dependence on inputs from member states (such as financial contributions, expert personnel, technical equipment, administrative cooperation and support, information flows from open sources as well as confidential evidence from national intelligence services), and it increases the burden of proof and reliable performance which member states expect to be furnished. At the same time, somewhat paradoxically, it increases also the propensity of member states to put not too much confidence in international verification. If individual states cannot be fully trusted, can an international organization which is composed of them? If some states are suspected to try and cheat their treaty partners, would it then be reasonable to rely only on international verification to catch them red-handed? If international verification can perhaps catch a perpetrator but not prevent him from trying, is it not mandatory for individual states (or groups of states) to take prevention into their own hands?

Questions such as these shaped the background against which the United States and other countries moved ahead in recent years to shore up the non-proliferation regime with initiatives of their own making. None of these initiatives was directed against international verification as such. As a matter of fact, each purported to strengthen or complement it. In particular, the Additional Protocol has received frequent praise from the U.S. Government as a mainstay of nuclear non-proliferation. Yet the net effect was probably to the contrary. The NPT, like other multilateral treaties and their verification systems, was relegated, at least in the predominant American perception, to the role of one useful non-proliferation instrument among others.[8]

Operative instruments that now came to the fore are mostly of a pragmatic nature, seeking solutions to ongoing problems in the short or medium term.

Some of them are of recent origin, others reach back over several decades. Most of them were initiated by the United States, often in a unilateral manner but subsequently joined or adopted by like-minded nations. Thus, long-standing export control agreements such as the Nuclear Suppliers Group (NSG), the Australia Group for chemical and biological agents and the Missile Technology Control Regime (MTCR) were expanded and updated to include the latest technological developments. The Cooperative Threat Reduction (CTR) programme, an American initiative from 1991 to improve the safety and security of nuclear material and sensitive facilities in Russia, was repeatedly renewed and extended beyond its initial cast. The Global Partnership, an undertaking by the G-8 group of industrial countries to support successor states of the former Soviet Union in protecting and safeguarding materials that could be misused for weapons of mass destruction, was launched in 2002. Starting in 2003, the Proliferation Security Initiative (PSI), a group initially of eleven Western countries which has since grown to include important trading and shipping states around the world, set out to coordinate their customs activities and naval operations in order to detect and interdict illegal shipments of proliferation-relevant items in international maritime and air transport.

All these activities typically bypassed the IAEA and the NPT. Verification, if there was any, was left to national surveillance and intelligence services. At the same time, cooperation and networking of intelligence and undercover operations were greatly expanded, though mostly on a bilateral basis and in an ad-hoc fashion. In other words, information was shared and transparency fostered, but only within the limits of political expediency. After September 11, 2001, this applied particularly to efforts to fight international terrorism and to deny sub-national groupings access to means of mass destruction.

Selectivity was also the hallmark of diplomatic endeavours to deal with "rogue states" and persuade them to rejoin the non-proliferation regime. Not all interested parties were invited to take part in such exercises but only those that recognized each other as relevant. In this manner, the United States and Britain held secret negotiations with Libya since 1999, which finally resulted in Libya's renunciation of all weapons of mass destruction in 2003. Six-party talks (with North Korea on one side, the United States, Russia, China, Japan and South Korea on the other) have been going on and off since 2003 with the purpose to make North Korea give up its nuclear weapons programme. With Iran, the "EU-3" (Britain, France, Germany) have negotiated since 2003 to fully lay open its nuclear programme and forgo uranium enrichment as proof of its peaceful intentions.

Diverse as these cases are, they have certain characteristics in common. Although negotiations were not specifically authorized by an international organization or based on a formal agreement, they were generally approved by the rest of the international community. They dealt with countries that were accused of a breach of treaty obligations, the extent of which was, however, under dispute. The aim of negotiations was to bring them back into the fold of loyalists under the roof of international verification. And although the negotiations were seemingly open-ended, there was always the understanding that, should they fail, punitive or compulsory measures would be considered to enforce treaty compliance. Such measures, while not discussed in the open and in detail, might range from diplomatic censure, isolation and trade sanctions all the way to targeted counter-proliferation, military intervention, invasion and regime change.

Drastic options such as these, the latter of which was chosen by the United States against Saddam Hussein in 2003, throw into stark relief the importance of verification to determine the threshold between legitimacy and illegitimacy. It was basically this threshold that was at issue earlier that year when the majority of the Security Council insisted on letting UNMOVIC, the United Nations Monitoring, Verification and Inspection Commission, continue its investigation in Iraq while the United States claimed to have incontrovertible proof of Iraq's weapons of mass destruction. What appeared to be an argument about the best verification instrument was, in effect, a dispute over whether or not pre-emptive military action against Saddam Hussein was necessary and proper.

Verification, as seen in this context, is not simply a technical method of providing evidence but a political strategy to generate legitimacy. When a treaty member is accused of violating his obligations, any remedial action is dependent for its legitimacy on the best available evidence of facts. The interpretation and presentation of facts inevitably walks a very thin line between truth and politics. If two or more verification systems compete with each other, arriving at different conclusions, the most credible verification system becomes the most effective source of legitimacy. But there is a reverse side to this reasoning. To the extent that the legitimacy of political action is based on verification, changing evidence from verification can change the basis of legitimacy.

The Iraq case nicely illustrates this kind of linkage. Four or five types of verification, partly overlapping and partly following each other, produced different evidence and different policy outcomes. Prior to 1991, traditional (INFCIRC/153-type) IAEA safeguards had found no fault in Saddam Hussein's declared nuclear programme. After Iraq's military defeat in 1991, UNSCOM and the special IAEA Action Team, equipped with sweeping investigative powers by the Security Council, uncovered a vast weapons programme in violation of Iraq's treaty obligations. In 2002, again under a Security Council mandate, UNMOVIC and the IAEA Action Team found no evidence of a renewed weapons programme - in contradiction to the U.S. Government's intelligence reports. After Saddam Hussein's second defeat in 2003, the United States installed in occupied Iraq a verification team of its own, the Iraq Survey Group (ISG), which finally came up with a report which in effect confirmed UNMOVIC's and the IAEA's findings.[9]

There is a double irony in this story. The U.S. Government emerged victorious from the military campaign but suffered a severe blow to its political legitimacy from its own verification team. At the same time, it is clear that no international organization could have ever performed such a thorough investigation and reached its conclusion with such an unquestioned degree of credibility as the Iraq Survey Group, a purely national body. From the viewpoint of international verification, this is an ambiguous result.

4 Persistent Problems

Although verification regimes and non-proliferation policies have undergone significant changes in recent years, there are a number of problems that remain unresolved and are likely to persist. These problems relate to the limited reach of verification systems, the inherent limits of verification and the limited utility of verification. They are neither new nor of a transient nature.

The reach of verification systems is determined by the reach of authority upon which they are based. International verification agencies such as the IAEA or the OPCW derive their authority from treaties with sovereign states, and it is therefore limited in several ways: formally by the mandate defined in the treaties and by the number of treaty-bound states, informally by the international agencies' ability to exercise their authority and by the states' ability to exercise their sovereignty. On each of these levels there are serious constraints to the efficacy of international verification.

The mandate given to an international verification agency is in all cases the outcome of a multilateral negotiation in which all parties have sought to retain for themselves as much freedom from external interference as might be compatible with treaty purposes. It is a compromise on the lowest denominator of common interests, restricting international authority to the minimum of necessity. Texts such as the IAEA's comprehensive safeguards agreement INFCIRC/153 and the Additional Protocol abound with clauses expounding in more elaborate detail what the agency must not do rather than what it may do to carry out its task. States are often more wary to enter into a binding safeguards agreement than they are with regard to a formal non-proliferation commitment. Thus, more than three dozen states, some of whom have adhered to the NPT for many years and even decades, continue dragging their feet and avoid bringing their safeguards agreement with the IAEA into force, although the latter would be an essential concomitant of the former. The IAEA Director General, Board of Governors and General Conference regularly admonish these states to fulfil their obligation, but they have no legal claim to enforce it. In consequence, while the NPT is now a treaty with nearly universal membership and validity, its attendant safeguards system is not.

Distrust and resistance against stringent international verification comes mostly from states in the developing areas, where national sovereignty is cherished and anxiously asserted more than elsewhere. This is relevant to the Additional Protocol even more than for traditional safeguards because the Protocol does indeed authorize the IAEA to probe into arcane doings of member states in an unprecedented fashion. Not surprisingly, then, most developing countries refused (until mid-2005) to sign the Additional Protocol, let alone brought it into force, whereas almost all industrial countries did. That may again feed the suspicion, already wide-spread in the developing world, that strengthened safeguards (like export controls and counter-proliferation) are a heinous ploy of the rich countries to supervise and hold down the poor. During the abortive NPT Review Conference of 2005 the rift broke into the open when the industrial countries, almost unanimously, pleaded for the Additional Protocol to be made mandatory for all NPT members - a plea that was rejected, again almost unanimously, by the group of non-aligned developing countries.[10]

The dispute over the Additional Protocol bodes ill for the future balance of the safeguards regime. If the IAEA should hold the authority to search for clandestine weapons activities in industrial countries but not in much of the rest of the world, its role as the global watchdog agency in the nuclear field would become implausible and its international standing seriously impaired. The agency might then risk losing the trust and support of those states on whose contribution (material and immaterial) it is vitally dependent. In such a situation the likely outcome would be for the Additional Protocol to remain inoperative in practice, just as the statutory right of the IAEA to conduct special inspections had remained dormant for many years. Undeclared nuclear activities would have to be searched out by means other than international safeguards. It is open to speculation whether the NPT could survive such a drift of events.

The gloomy scenario is, of course, not inevitable if a sizable number of important threshold states came around to adopt the Additional Protocol. This is by no means impossible. The signatures (but, at this time of writing, not yet ratification) by Iran in 2003 and Libya in 2004 carry particular weight since they demonstrate that states with the reputation of international "rogues" can be persuaded through deft diplomacy to reconsider their previously negative attitude. Others may follow that example.

Even then, however, formal adherence to the Additional Protocol will not suffice to restore faith in the non-proliferation regime. A state's legal commitment to accept the IAEA's strengthened safeguards does not satisfy everybody's demand upon a trustworthy nuclear partnership. The United States as well as the EU-3 have made it clear against Iran that they would not tolerate that country to acquire a fissile material production capability, regardless of its safeguards status.[11] The same position probably applies to the case of North Korea. This means that the presence of a verification system alone, whatever its merits may be, is not enough to create confidence among treaty partners.

The efficacy of an international verification system is limited by the administering agency's ability to exercise its authority and by the ability of member states to exercise their sovereignty. Both are related to each other, mostly (but not necessarily always) in an inverse fashion. The IAEA, like many international organizations, suffers from a permanent shortage of resources (qualified manpower, equipment, finance); the wider its range of responsibilities, the more so. Most importantly, it lacks the ability to impose its will on an unwilling state. In carrying out its safeguards function in a given state the agency depends to a significant extent on the cooperation of that state. Again, the more so when verification involves deep-searching inspection and investigation.

Recalcitrant authorities in an uncooperative country can make life quite difficult for international inspectors, as the IAEA experienced in places such as Iraq, Iran and North Korea. Such difficulties can be overcome with patience and insistence, but it costs time and money. If the uncooperative state seeks to buy time and does not care for money, international verification may reach its limits. In North Korea, inspectors were expelled from the country. In Iraq, they were obstructed, harassed and deceived for years and could hold out only with the extraordinary backing of the Security Council. In Iran, a seemingly unending cat-and-mouse game with the IAEA has not yet reached its final conclusion.

To note that international verification requires the cooperation of authorities in sovereign states points to another problem that has been neglected by scholars and practitioners all too long. A state may be unwilling to cooperate, but it may also be unable for practical purposes. Sovereignty is a concept with an external and internal dimension, and not all states that claim to be sovereign really qualify in the dual sense of the term. There is in the world a number (uncertain, but certainly growing) of weak or failed states which are internationally recognized as sovereign although they hold and rule only parts of their country, and in some cases not even the entire capital city. Such so-called states, many of whom are represented in the IAEA and other international bodies, are to a varying degree infested by armed domestic conflict and civil strife, social disintegration, corruption and organized crime, a shadow economy and the wide-spread absence of law and order. They cannot guarantee to provide what an international verification agency expects from them: effective control of their national territory and its borders, a functioning administration, responsible officials, sound institutions and services, reliable statistics and records, physical security and accessibility, and other things that elsewhere may be taken for granted. What cooperation such countries offer to an international agency, even if in good faith, may be more token than real, and what there is of transparency may be a reflection of anarchy. Authorization to verify reported data or to search for illicit activities in such a place is likely to be a liability for the agency rather than an asset.[12]

The problem of weak and failed states has been recognized by the Security Council in its resolution 1540 of April 28, 2004, in which the proliferation of weapons of mass destruction among non-state actors and terrorist groups is identified as a grave danger to international peace and security. Noting with deep concern the lack of regulatory capability in many states to hold sensitive material, technology and expertise in absolute security, the Security Council "decides that all States shall take and enforce effective measures" to control and prevent the illicit production, holding, financing, trafficking, trading, shipping or other dissemination of such items within their jurisdiction.[13] This is a brave and worthy declaration, but it sounds like whistling in the dark. What the Council "decides" is in fact wishful thinking to the effect that all weak and failed states shall henceforth operate like strong and healthy sovereign states.

To get things straight, it should be noted that the weak-and-failed-state syndrome is by no means confined to the group of non-nuclear weapon states. Among presently or formerly recognized or de-facto nuclear weapon states, at least four (China, Russia, South Africa, Pakistan) have suffered periods of severe domestic upheaval, disorder and disruption, during which the loss of control over nuclear material and nuclear weapons was an imminent danger.[14] The fact that these states stood outside the system of international verification is surely no ground for complacency. Nuclear weapon states were in the past the main sources of proliferation for states; today some of them may be the same for non-state actors and terrorists.[15] International verification could shed more light on their deficiencies. However, the NPT does not allow the IAEA to be active in nuclear weapon states (and the Additional Protocol only in a more symbolic way). For legitimate reasons of secrecy, international verification can play only a limited role in nuclear weapon states.[16]

There are inherent limits to verification which should not be glossed over. On the most general level, verification of treaties against the spread of weapons of mass destruction is faced with several methodological dilemmas and paradoxes. Even with the most intricate techniques and most advanced technologies, any system of verification that seeks to cover a whole country is bound to be less than perfect. A country (like, for instance, Iran) with a vast and varied expanse of land, a population of many millions, a complex social structure and a multi-faceted civilization cannot be fully controlled from the inside, let alone from the outside. If the national government cooperates with the international verification agency, the agency's findings might reach a degree of reliability close to 100 per cent as far as official programmes for weapons of mass destruction are concerned, but certainly less with regard to sub-national or terrorist activities. If the government is uncooperative or is suspected to be cheating, the reliability of verification results is likely to lie below that level.

All verification systems have to come to terms with the fact that they can, at best, prove a breach of contract but cannot prove beyond all doubt the loyal behaviour of contract parties. It is therefore a standard practice among verification experts, generally accepted as reasonable, to live with a residue of doubt and to assume that a reliability somewhere below 100 per cent is admissible and satisfactory. In a world of imperfection, why should a verification system be expected to be perfect? It ought to be kept in mind, however, that determination of what "somewhere" below 100 per cent means is a political decision, not the result of scientific reason or technical optimization. What is the propriety and legitimacy of that political decision when the enormity of weapons of mass destruction is considered?

The criterion of "timeliness" is a well-established measure among safeguards experts to determine what is tolerable in terms of the amount of time that may elapse between detection of an illicit activity and the employment of corrective action by the community of treaty members. Again, the determination of timeliness is a political decision in which scientific facts or technical calculations play only an auxiliary role. If a treaty member state seeks to attain a break-out option, it can develop legitimate components of a weapons capability under the watchful eyes of safeguards inspectors deliberately right up to the point where "timely detection" sets in, and then choose according to its own will whether and when to rush across the threshold and confront the international community with a weaponized fait accompli. The margin of timeliness in such a case could be compressed into a very thin borderline. It is for the verification agency then to stretch the margin to better suit its needs, or to strive for the most rigorous precision at the risk of coming late with its warning, or to blur the borderline at the risk of raising false alarms. Either decision is, once again, a political judgment.

The point being made here is that every verification agency walks a rope between professionalism and politics. Although verification is an exercise in objectivity and impartiality, politicization comes in whenever the critical issue of treaty compliance is at stake. Whether or not it is at stake depends less on the demonstration of factual evidence than on the evaluation of political intent. Factual evidence relates to an incriminated party's behaviour in the past, political intent to its future behaviour. As IAEA Director General Mohamed ElBaradei says for his agency: "We are not God, we cannot read thoughts."[17] Reading thoughts is the political task that begins where verification ends.

When evidence of past misbehaviour suggests a perpetrator's intent to use weapons of mass destruction in the future, time may be of the essence to prevent the assumed intention from turning into reality. Consequently, prevention and pre-emption became frequent catchwords (and, in a few cases, the driving force of military intervention) as soon as instances of treaty violation were seen in combination with terrorist threats. In such a situation, when someone's illegal activities, capabilities and intentions need to be wrapped up in a policy recommendation for decision makers, national intelligence services, rather than international verification agencies, assume the pivotal role. The Iraq case has shown how the combined wisdom of numerous intelligence services can still produce a grossly erroneous policy prescription.[18] National intelligence is not necessarily superior to international verification. And yet, it is obvious that international verification is no adequate substitute for national intelligence when it comes to the ultimate decision for or against preventive or pre-emptive action.[19]

The utility of international verification is limited not only by political constraints but by its very nature. Every verification regime is designed for the purpose of serving a specific treaty and its community of member states. Whatever its shortcomings or merits, it cannot be better than this purpose.

If the treaty is faulty or the membership divided, verification will be no more than a prop against a shaky structure.

The Nonproliferation Treaty, for instance, is mute about the safety and security of nuclear weapons, unclear about the extent of a state's right to own and handle sensitive nuclear material, non-committal about obligations for nuclear technology sharing, security assurances and disarmament, inconclusive about conditions of treaty renunciation, indecisive about the implications of treaty violations. In each of these problem areas, verification cannot play a useful role because the criteria for treaty compliance are ill-defined and the community of treaty members is unable to set things straight or unwilling to face the consequences. As long as member states are not in agreement among themselves, verification cannot contribute much to their cohesion. On the contrary, a smoothly operating common verification system might suggest more mutual understanding and more control over events than there really is.

"Nuclear proliferation", argues the chief of the world's primary verification agency, "is on the rise".[20] That may well be true, but it does not mean that recognition of the fact actually improves the ability of the international community to deal with the problem. International verification can, at best, remind member states of their shared responsibilities.

References

1. This text deals mainly with *nuclear* weapons, non-proliferation and verification because they are the best known, most important and most highly developed. But it applies also to parallels in the chemical and biological field, where appropriate.
2. In the absence of a verification system, this does obviously not apply to the Biological Weapons Convention. More than any other disarmament treaty the BWC has been undercut by dishonest members, most notoriously the Soviet Union with its extensive bioweapons programme in the 1970s and 1980s.
3. For a critical account in this vein see Hans Blix, *Disarming Iraq*, New York 2004.
4. See "IAEA Investigating Egypt and Taiwan", in: *Arms Control Today*, vol. 35, no. 1, January/February 2005, p. 38.
5. For a graphic representation of the Khan network see *Arms Control Today*, vol. 25, no. 2, March 2005, p. 13.
6. Thomas Shea (1999): "Verification of Weapon-Origin Fissile Material in the Russian Federation and the United States", in: *IAEA Bulletin*, vol. 41, no. 4, December, pp.36-39.
7. For a comprehensive analysis of the Additional Protocol and its background see Erwin Häckel / Gotthard Stein (eds.) (2000): *Tightening the Reins: Towards a Strengthened International Nuclear Safeguards System*, Berlin and Heidelberg.
8. See Harald Müller / Annette Schaper (2004): *US Nuclear Policy after the Cold War*, PRIF Report no. 69, Frankfurt/M.; Piet de Klerk, (2003): "Under Fire: Is the World's Treaty Against the Spread of Nuclear Weapons Strong Enough?", in: *IAEA Bulletin*, vol. 45, no. 2, December, pp. 31-33; William Walker, (2004):

Weapons of Mass Destruction and International Order, Adelphi Paper 370, London.
9. Comprehensive Report of the Special Advisor to the DCI on Iraq's WMD, 30 September 2004 (Duelfer Report), http://www.cia.gov/cia/reports/iraq_wmd_2004/.
10. Harald Müller (2005): *Vertrag im Zerfall? Die gescheiterte Überprüfungskonferenz des Nichtverbreitungsvertrags und ihre Folgen*, HSFK-Report 4/2005, Frankfurt/M., p. 15.
11. "Fischer warnt Teheran vor Fehlkalkulationen - Internationale Gemeinschaft wird Schließung des Nuklearkreislaufs nicht akzeptieren", in: *Frankfurter Allgemeine Zeitung*, September 7, 2004.
12. For an elaboration of this theme see Erwin Häckel, (2000): "Implementing Safeguards in Weak and Failed States", in: Häckel/Stein (above, note 7), pp. 141-149.
13. United Nations Security Council, S/RES/1540 (2004): http://www.un.org./Docs/sc/unsc_resolutions04.html; the quotation is from operative paragraph 3.
14. See, for instance, Graham Allison et al. (1996): *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material*, CSIA Studies in International Security No. 12, Cambridge (Mass.).
15. Graham Allison, (2004): *Nuclear Terrorism: The Ultimate Preventable Catastrophe*, New York.
16. See Annette Schaper (2004): *Looking for a Demarcation between Nuclear Transparency and Nuclear Secrecy*, PRIF Report no. 68, Frankfurt/M..
17. *Der Spiegel* (2004): no. 38, September 13, p. 114.
18. The intelligence failure in Iraq has sprouted a great number of critical analyses. See in particular Gregory Treverton (2003): "Intelligence: The Achilles Heel of the Bush Doctrine", in: *Arms Control Today*, vol. 33, no. 6, July/August, pp. 9-11; Lawrence Freedman (2004): "War in Iraq: Selling the Threat", in: *Survival*, vol. 46, no. 2, pp. 7-50; Rolf Ekeus, : "Reassessment: The IISS Strategic Dossier on Iraq's Weapons of Mass Destruction", *ibid.*, pp. 73-88; Kenneth M. Pollack (2004): "Spies, Lies and Weapons: What Went Wrong", in: *The Atlantic Monthly*, vol. 293, no. 1, pp. 115-141; Dennis M. Gormley (2004): "The Limits of Intelligence: Iraq's Lessons", in: *Survival*, vol. 46, no 3, pp. 7-28.
19. For a balanced view on this problem see Joseph S. Nye (2005): "Iraq Lessons Can Avoid Disaster in Iran", in: *The Financial Times*, March 31.
20. Mohamed ElBaradei (2004): "Saving Ourselves From Self-Destruction", in: *The New York Times*, February 12.

Improving Verification: Trends and Perspectives for Research

Roland Schenkel

1 Introduction

The global nuclear non-proliferation regime is confronted with profound challenges which undermine the basic objectives of the Treaty [1]. Most of these challenges are of a political nature and include the lack of participation of some key countries like India, Pakistan and Israel in the NPT regime. A very disturbing phenomenon is the recent withdrawal of a state, North Korea, from the NPT Treaty. The limitation of the enforcement abilities of the IAEA and the Security Council in cases of serious non-compliance of states is another element of serious concern for the future of the NPT system.

As far as verification concepts and technology are concerned, significant progress has been achieved, both in the nuclear material accountancy systems of the operators and in the safeguards verification by inspectorates. The future requirements and R+D developments in this field will be the major topic of this contribution.

A new technological challenge has emerged through the risk that terrorists may use nuclear facilities or nuclear materials and radioactivity to threaten the health and security of citizens. A related concern of renewed urgency is the development of a black market for technology and materials as witnessed through Dr. Khan's network.

The nuclear fuel cycle itself is advancing and R+D is underway to develop the fourth generation of nuclear reactors. These new systems have inherent properties which will increase the proliferation resistance, but require new technologies for verification.

One of the most important gaps in safeguards verification has been closed recently: the provisions in the Additional Protocol to the IAEA safeguards agreements. Some challenges remain and are being addressed. A major cause for concern is the very slow progress on the entry into force and implementation of the Additional Protocol.

2 Current technical challenges for safeguards verification

The development and implementation of safeguards nuclear material accountancy methodology and technology is a success story. The progress achieved since the early eighties, when reliable systems for independent verification were first introduced in safeguards operations, is impressive. It was a considerable "learning process" for all involved: the developers, the operators and the inspectorates.

It appears from the recent safeguards operations reports of the Euratom Safeguards Directorate (now Directorate-General for Energy and Transport (DG TREN), Directorate I) and the IAEA that conclusive safeguards verification systems covering the full range of facilities are available and are performing very well.

2.1 Bulk handling facilities

The European Union has made a particularly important contribution to this success story: the bulk handling facilities available and in operation in the EU have developed many innovative safeguards systems in accordance with international safeguards standards.

Although some of these facilities are not under IAEA safeguards, the systems developed and implemented have been used to assist the IAEA and operators concerned outside the EU to implement methodology and technology of similarly high standards. The R+D community as well as the inspectorates have disseminated and discussed concepts and technical characteristics of these new systems at ESARDA, INMM and IAEA conferences and special workshops [2].

For bulk handling facilities, the major remaining challenge is the further improvement of the efficiency and user friendliness of the systems developed. The combination of all sorts of measurements- optical surveillance, remote monitoring systems for process and inventory control and the authenticated use of operator sensors and equipment- was a major advance in safeguards verification. Data acquisition and intelligent yet reliable evaluation and assessment systems continue to require improvements to reduce the burden on operators and inspectors.

Potential misuse of facilities has also been addressed. Regular design information verification including the use of environmental monitoring can be used to verify that plutonium or highly enriched uranium signatures in facilities are consistent with "normal" operational conditions, for example. In reprocessing facilities, this type of verification could also detect the separation of Neptunium 237. Enrichment facilities are checked in a similar manner through swipe sampling as a complement to the installed measurement and surveillance systems.

2.2 Increasing inventories of nuclear materials

Increasing inventories of nuclear materials are often presented to be a challenge. It has however to be understood that, from a technical point of view, effective systems are available and in place for flow and inventory verification. The challenge therefore consists in improvements to the efficiency in terms of usage of inspector resources. This aspect is particular important for spent fuel storage and shipment to fuel repositories where unattended follow-up systems need further developments. This is addressed in more detail in paragraph 3.2.

2.3 New technologies, new generation of reactors and fuel cycles

Safeguards verification concepts and technology have to keep pace with new technological developments related to the nuclear fuel cycle and to the physical models describing the options for developing and deploying nuclear weapons capabilities. In this area also, substantial progress was achieved following the detection of Iraq's nuclear weapon's programme in the early 1990's. It is important that new production methods for direct-use material, including Neptunium, be closely monitored and followed.

Safeguards inspectorates need to keep abreast of new basic developments in fields such as laser enrichment, accelerator and laser technology and new partitioning and transmutation concepts.

Most of Gen III type of reactors are close to market introduction and should not require new safeguards technology for verification. However, some rather innovative reactors and some Gen IV systems will require more appropriate technical verification systems because of different fuel concepts being proposed, notably if plutonium and minor actinides will be recycled. The very challenging molten salt reactor would require an altogether new safeguards approach as the reactor core is liquid and the reactor concept aims to chemically separate the short-lived fission products to the waste stream rather than the long-lived actinides, which would remain to be further fissioned.

For the innovative reactors with fast neutrons, there is already considerable past experience from the verification of prototype fast breeder reactors. This know-how needs to be maintained.

2.4 Detection of undeclared activities

Strengthened safeguards under the Additional Protocol have as major objective to improve the ability to detect undeclared materials and activities. Powerful new tools are now available and are slowly being introduced into safeguards operations.

Key elements for the success of the technical verification system are the access conditions for inspectors, combined with tools like environmental sampling, satellite imagery, open source information and information supplied by Member States.

Significant progress has been made in these technical areas, some of which is reported in paragraph 3.4.

2.5 Terrorism and illicit trafficking

The recent terrorist attacks highlighted the need to keep close controls on nuclear materials and radioactive materials that could be misused by terrorist groups. The scenarios cover attacks on facilities that could lead to radioactivity being widely spread, crude nuclear weapons production or the development of so-called dirty bombs or the radioactive contamination of supply chains with the objective to threaten the health of citizens. This area includes the fight against illicit trafficking of nuclear materials and the development of technical tools to trace potential transfer routes and the origin of nuclear materials.

A recent survey issued by Lugar [3] about the possibilities of an attack based on nuclear, biological or chemical weapons shows that there is a real risk.

2.6 Dual use materials, proliferation of technology

We have witnessed in the last years the development of networks with the objective to supply nuclear know-how, materials and equipment covering the whole nuclear weapon chain, including deployment systems. This is the most threatening development as countries could go very close to a nuclear weapon deployment capability without breaking the existing non-proliferation rules.

Export controls need to be improved and special tools be developed to counteract these developments; this includes technical means such as identification of suspect containers, analysis of logistics of supply chains and identification of networks and members.

2.7 Proliferation resistance

Concepts for proliferation resistance have been amongst the "magic solutions" of experts since the early developments of safeguards and commercial fuel cycles. The major objective was always to reduce the attractiveness of materials used in commercial facilities for making nuclear weapons, i.e. to avoid the use of clean, low burn-up Plutonium and high enriched Uranium. The advanced fuel cycle concepts as well as some of the Gen IV reactor concepts foresee the recycling of Plutonium and the minor actinides. The high neutron and gamma background of Americium and Curium leads to a "dirty" material which cannot be diverted and used directly and which could not be taken out of a facility without a high risk of radiation and of detection. Some of the R+D work needed to cope with such systems is outlined in paragraph 3.7.

2.8 Verification of excess material and Fissile Material Cut-off Treaty (FMCT)

International verification of fissile materials released from defence programmes presents some new challenges related to classified information and sensitive forms of components. Many of these challenges have been addressed already in developing validated verification systems that do not release weapon design information [4].

For the FMCT, a considerable number of technical instruments are also already available. A particular challenge is to verify the absence of illicit production activities in a plant declared to be out of operation. Again, properties related to nuclear decay may help deliver the solution to use "materials ageing" as an indicator for detection of clandestine activities.

The lack of progress in disarmament may be part of the political and emotional resistance of some countries to accept more control (additional protocol) or even restrictions to explore the peaceful use of nuclear energy as stipulated in the Treaty.

3 Trends and perspectives for Research

The IAEA has summarized the need for new technologies in a document submitted to its Board of Governors in January 2005 [5].

There are two relevant messages:

- "Monitor and address observed deficiencies or vulnerabilities in safeguards approach, equipment and technology and acquire new or improved equipment/ technology where appropriate.
- Develop and/ or use new concepts, approaches, techniques for information analysis and verification activities, especially with regard to enhanced ability to detect undeclared nuclear material and activities. "

Part of the needs of the medium-term strategy has been translated in a paper on "2006 - 2011 IAEA Equipment Development Strategic Plan" [6]. Essential elements of this paper are included in trends and perspectives described in the paragraphs below.

3.1 Bulk handling facilities

Apart from the developments mentioned in paragraph 2.1, safeguards verification in these types of facilities will effectively turn into an operation verification system. There will be less duplication of sensors and measurement systems of operators and safeguards inspectorates, as sophisticated authentication systems will give the necessary assurance against falsification.

In addition, material flow and inventory will be known so well to the inspectorates (near real-time systems) that a diversion of material at a given point will be seen immediately by the impact of this event on parallel or subsequent sensors in the facility. The processes in these facilities can be modelled and diversion scenarios simulated so that appropriate indicators can be developed for automatic evaluation and assessment of the consistency.

An additional help is operator/ inspector "fingerprinting" of input and output materials and the follow-up of the mixing and dilution effects throughout the process area.

The inspection teams must include experts fully familiar with the chemistry and engineering aspects of key bulk handling facilities to be able to check consistency/ anomalies in the process data.

All key operational activities including interventions should be known and understood by these expert inspectors. The know-how of the inspector teams based on full comprehension of key operational aspects of the plants concerned will be an important element to obtain the required assurances.

Environmental sampling is a tool to collect in a strategic manner samples at key points, the signatures confirming the absence of misuse of facilities or clandestine activities: this includes checks on the absence of separation of Neptunium, absence of use of parts of facilities for Plutonium conversion or diversion, check of Plutonium decontamination factors or enrichment levels at strategic points in the facility. The operational "fingerprint" or "pattern" of a facility could be a very powerful tool to monitor the use of the facility.

Another trend to be supported is the replacement of off-site shipment of samples. Techniques, portable or stationary, should now be developed to permit on-site verification of all safeguards samples. In fuel fabrication plants this concept is successfully applied with support of staff of the Joint Research Centre (JRC) of the European Commission.

3.2 Increasing inventories of nuclear materials/ spent fuel management

Having covered the bulk handling facilities separately in paragraphs 2.1 and 3.1, the increasing inventories dealt with here refer to storage of separated Plutonium and spent fuel. Safeguards verification systems for both types of storages are state of the art and the improvements needed are essentially in the area of increased efficiency and reliability of the equipment.

An area where considerable improvements are still needed is the whole verification chain for spent fuel management. The spent fuel handling and transfer cycle still requires a relatively high inspection effort compared to its strategic importance. Ideally, an unattended (item) authentication and follow-up system should be developed in order to reduce inspector presence in reactors and spent fuel ponds.

The huge amount of surveillance and monitoring data obtained in these types of facilities (and in those for bulk handling) calls for a strong reduction of the evaluation effort by addition of sensor technology and/ or intelligent software which permits a maximum of front-end and back-end automated review systems.

A point discussed under paragraph 3.1 could be very useful also in the spent fuel area, namely the wider use of "fingerprinting"; i.e. recording a variety of the inherent properties of a fuel assembly or batch for follow-up of flow and inventory thus adding additional elements to increase tamper-resistance of the combination of unattended safeguards measures.

3.3 New nuclear technologies, new generation of reactors and fuel cycles

Although history shows that most nuclear weapons developments followed "classical" technology via the HEU or Plutonium path, IAEA needs to monitor new developments susceptible to be used to acquire a weapons capability. Although technical risk and economics may be less favourable than with classical paths, the detection risk for some steps may be lower because inspectorates or state services are either unaware or not sufficiently focused on relevant indications.

For the new generation of reactors and fuel cycles, a variety of trends in research can be predicted: for the European priority, the gas cooled reactor, a new verification system adapted to the operational characteristics of the plant will need to be developed. Elements of the previous safeguards concepts for fast reactors will remain valid, but, with advanced technology, both unattended monitoring and surveillance systems need to be developed. The new type of fuel will have an impact on the fresh and spent fuel verification system and will possibly require new head-end characteristics in reprocessing and a modified recycling step depending on the fuel material finally chosen.

Concerning advanced fuel cycles, there are less challenges for verification in the aqueous process developments than in the new dry (pyrochemical) processes.

The good news is that both developments will lead in the future to a "dirty" rather than direct-use end product; the Plutonium will be mixed with minor actinides and a residual level of fission product radioactivity. This increased proliferation resistance comes at the "price" of a somewhat reduced accuracy for the verification of Plutonium by established neutron/gamma measurement techniques. This price is however acceptable as there are sufficient chemical methods available to assure high-level nuclear material accountancy. C/S will become even more important to give the necessary safeguards assurances.

The pyrochemical process verification is more challenging as a variety of new accountancy methods have actually to be developed and tested. Such work is for example underway at the JRC, where a complete hot cell test stand and analytical programme is underway related to partitioning and transmutation, Neptunium separation and safeguards challenges related to future fuel cycles [7].

3.4 Detection of undeclared activities

This is an area where considerable progress has been achieved already, but where an even higher research effort should be supported in the future.

Availability and usage of open source information is growing considerably, in particular as regards sources such as the World Wide Web and satellite imaging.

The problem is finding the needle in the hay stack; the key issue is therefore to develop suitable means to achieve this objective.

The trends and recommendations can be summarised using 4 categories:

Open Source information - satellite imagery

In the use of satellite imagery, the developments and challenges are described in this book by B. Jasani [8]. A major achievement in this field is that, with Ikonos-2 and Quickbird-2, civil observation satellites are now available which get close to the image quality and resolution of military satellites (meter range). More countries are now positioning their own satellite, which is an additional advantage.

In the area of satellite imaging, two technical developments are of key importance: firstly, the search for indicators for unusual or suspect activities to feed to image analysts with locations and type of facilities or activities to look at. Such indicators will pre-dominantly come from open source evaluations and hints/ information from Member States. The second important development is image processing - the huge number of images available need powerful and automated image (pre) processing, analysis and interpretation in order to extract the features of interest [9]. It is clear that software can never replace well-trained image analysts, but, as shown in the reference above, certain standard features of nuclear facilities suitable for a weapons programme can be used in an object-oriented change detection programme including typical ground preparation activities.

A known challenge for satellite image analysts is to detect suspect activities when underground facilities or tunnels into mountains are used in order to reduce the risk of detection. These scenarios are very difficult to model and detect although previous experiences, for example in Israel and some other areas, are available. The IAEA has therefore started a research programme to use ground penetrating radar to search for underground or otherwise hidden rooms [6].

Open source information - electronic searching

The important challenge in the area of open source evaluation is the assessment of the huge amount of published information in the World Wide Web as well as in newspapers, scientific journals, etc. The progress in this field has been described in this book by Schriefer [10] L. Bril and J. Gonçalves [11] and M. Richard [12].

Within the European Commission, the Europe Media Monitor (EMM) has become a major tool for targeted, updated information research covering about 700 websites [13]. It offers a complete interface in all 20 languages of the EU and it operates also in Farsi after the translation of the English nuclear non- proliferation keyword list.

The objective is to automatically discover articles and documents published on the web which can shed light on clandestine nuclear activities or intentions. The web has become the world's mass publishing medium, where one can find an ever changing flux of opinions, information and data. The challenge is to develop Open Source Intelligence tools that can monitor and process that flood of data. Based on discussions with C. Best [14], the following are the most important research trends:

- News Monitoring (Live Web). Nearly every major news source in the world has an on-line live news service. Europe Media Monitor is an example of a real-time system able to identify and process any news report concerning Nuclear Safeguards. These specialised monitoring systems need to scan on a minute-by-minute basis for new articles. Search engines cannot perform this task.
- Search and Retrieval (Static web). The major search engines can discover documents on the web for an investigation. Enhanced search and retrieval tools built on top of these search engines can identify and download the most relevant articles for later processing.
- Specialist Site Monitoring (Live Web). Often analysts need be kept informed of new publications and articles from a range of identified technical sites, bulletin boards or specialist sites. These will not be covered by news monitoring services, but instead need a specialised multi-site monitoring system. The challenge is to detect only new relevant articles and send an e-mail update to the analyst.
- Web Mining (Deep Internet). It is estimated that over 90% of the web is "invisible" to search engines because it is hidden in databases. Web pages are dynamically created on demand and cannot be indexed by search engines. Some sites are protected by password, and automatic crawlers cannot enter. This is an area of research which aims to develop tools which can search across identified sections of the hidden web. This involves developing interoperable search protocols and systems for mimicking manual logins.
- Language Tools and Analysis. Processing large quantities of identified documents needs automated multi-lingual language tools. The functionalities these tools need to address are: 1) Identifying Nuclear Terminology in multi-lingual text, 2) Entity extraction form text (people, places, organisations, emails etc.) 3) Automatic identification of links between entities

4) Keyword identification and document clustering 5) Duplicate identification 6) Visualisation of the extracted information

The goal is to empower an analyst to discover new insights into clandestine nuclear activities extracted automatically from the vast information resources available on the web.

Environmental sampling

This topic has been covered in this book by contributions of Kalinowski et al [15] and Mayer et al [16]. It is possible nowadays to detect valuable signatures of nuclear activities from radiologically insignificant, very small traces of materials; however, also stable isotopes (e.g. noble gases like Xenon produced from nuclear fission) can be used to detect undeclared nuclear activities. It has been shown with swipe sampling that the history of enrichment plants can be well established through particle analysis techniques based on Thermal Ionisation and Secondary Ion Mass Spectrometry (TIMS and SIMS) or other sensitive mass spectrometric techniques. The analysis of swipe samples has been established as part of routine inspection. In 2004, more than 1100 swipe samples were analysed by the IAEA's network of laboratories for particle analysis [17]. Still, there is further research work needed to further improve detection capabilities and streamline processes in order to reduce the analysis costs.

There are two fundamentally different situations in environmental sampling:

For Uranium, there is an omnipresent background of natural Uranium. This leads to the need for identifying the "interesting" (i.e. non-natural) particles or to the need for fairly accurate isotope ratio measurements in bulk analysis.

In particle analysis, particles down to 1 micrometer diameter (equivalent to 3 picograms) are measured. For smaller particles, the counting statistics of the minor isotopes (Uranium -234 and 236) limit the accuracy of the measured isotope ratios and thus the usefulness of the results.

Two improvements are possible: simultaneous measurement of all isotopes (multi-ion counting); this is implemented for SIMS and TIMS in the latest generation of instruments. Secondly, increase the ionisation yield (this research is under way, e.g. using laser resonance ionisation or the cavity ion source). This improves the measurements precision and accuracy of the minor isotope measurement.

For Plutonium, the background is very low (only fall-out Pu), but also the amount of analyte is small. In bulk analysis, presently amounts in the low picogram range and even in the femtogram range can be measured by TIMS or ICP-MS. Again, increasing the ionisation efficiency further improves the detection capabilities (also here laser resonance ionisation appears to be promising, but is still under development).

The major objective for the future must be the increase of sensitivity and selectivity also in view of counter-actions by a potential diverter (clean or dirty plant).

Also fission track analysis remains a powerful tool for identification of particles of interest in particular if it can be used quickly for screening purposes to detect fissile materials [18]. However, rapid and simple methods for screening of samples are required and deserve an R&D effort.

There is the need to develop platforms capable of putting together data (and information) from multiple sources and collected at different times. This is particularly relevant for Additional Protocol activities, where the results of inspections (i.e. data) and declarations, together with other sources (e.g. open source textual information, manuals, satellite pictures, environmental data, trade data, etc.), need to be analysed together. One way of organising this information is by means of Geographical Information Systems. The JRC is already active in this, supporting DG TREN-H.

Wide-area environmental monitoring

The IAEA had undertaken, together with the support of Member States laboratories, a feasibility study on the potential of wide-area air, soil and water sampling techniques to detect undeclared activities.

Keeping in mind the source terms of the signatures considered, and transport and background levels, it appears that atmospheric sampling could be a promising way to detect volatile signatures (example Xenon, Krypton -85) from reprocessing activities. Developments in this direction need to continue also in view of the synergy with the comprehensive Test Ban Treaty requirements.

While there can be other signatures (like - Cs-137) in the closer environment of a facility, for example in soils or waste effluent streams, these methods/techniques are not suitable for establishing a wide-area control network at reasonable costs.

Another trend in Verification technologies is to look for indirect indicators that can be associated with undeclared activities. In particular, the IAEA is interested in assessing a few remote sensing techniques that had been established/ developed for other fields. Example: look for vegetation anomalies, or vegetation stress. This can be achieved with remote sensing indicators, possibly via hyperspectral satellite imaging.

3.5 Terrorism and illicit trafficking

K. Mayer et al [16] have compiled the research activities related to forensic investigations and illicit trafficking. There are only few research establishments which can successfully cover the wide range of technical tools and facilities needed to address this topic.

In order to match the experimental with the "original" fingerprint of materials it is necessary to establish a data base with material signatures covering the commercial sector and many of the R+D facilities in the countries concerned. More micro-structural and impurity-related data need to be compiled and it remains essential that international exercises continue to test and improve the performance of laboratories ("benchmarking") in terms of analytical capability and data interpretation. Major past technical achievements were the improvements in mass spectrometric techniques, surface roughness measurements and the progress in age determinations for Plutonium and Uranium [19].

Another promising effort is to use natural variations in isotopic compositions as an indicator for the geographic origin of the material (example ^{18}O /^{16}O ratio).

Apart from the scientific component of the work, international co-operation to implement suitable action plans in case of crisis situation has to continue. The G-8 Nuclear Smuggling International Technical Working Group (ITWG) provides an interdisciplinary forum for nuclear forensic experts and law enforcement services. The IAEA has issued an number of documents dealing with illicit trafficking and nuclear forensic support [20 - 23]

Several R&D organisations, such as the JRC, have also programmes in place to model the impact of the dispersion of radioactivity based on concept of crude weapons or so-called dirty bombs. Different source terms and radioactive and nuclear materials have been used in the calculations performed [24]. Some of the model assumptions have been validated through explosion tests (without radioactivity) with national authorities. The work in this area is not only important to understand the potential risks to the population, but also delivers valuable information for mitigation of impact and reliable and fast ex post assessments of such events - should they ever occur.

A project is also underway to address the potential threat posed by trafficking of weapons of mass destruction, components thereof, explosives, etc. The approach is based on using open source intelligence (3.4) to gather trajectory data of containers and vessels and the evaluation of data inconsistencies. In tests in some European harbours, the software has demonstrated a 37% hit rate. This development is relevant also to paragraph 3.6.

The development effort in this area also covers advanced tracing and seals systems and portal monitors and sensors.

3.6 Dual use materials, proliferation of technology

Export controls need strengthening and improved co-operation between Member States. Dedicated multilingual software to check (cross-check) systematically accessible information in open sources or specified or protected data bases would be a considerable improvement. Such tools are being developed at the JRC and will be made available to Member States and the international co-ordination bodies for export control.

Independently, special reports on illicit trafficking in this area should be established based on source information analysis. Person, organisation identification and tracking systems are already available and can provide also interaction patterns between persons and/ or organisations.

The developments on container identification and trafficking (paragraph 3.5) are relevant also for the topics described in this chapter.

3.7 Proliferation resistance

It was stated already in paragraph 2.7 that proliferation resistance is not the "magic" solution against diversion from commercial activities. "Safeguardibility", i.e. conclusive, economical and independent verification by an inspectorate, must remain the priority of the development of safeguards approaches. Nevertheless, if a higher proliferation resistance can be achieved without impacting on the safeguardibility, this is clearly a better situation.

Most of the new approaches of proliferation resistance which attempt to model facilities or fuel cycles are based on a quantitative assessment of risk of diversion. It is very doubtful that the "safeguards assurance" obtained by the IAEA or the "diversion risk" in a facility can be quantified.

Some authors appear to try to translate the qualitative term "proliferation resistance" into a "fractional" proliferation.

The major difficulty for quantification comes from the containment and surveillance measures and the inherent difficulty to "quantify" and "value" the tamper-resistance or "tamper proofness" of individual devices against the additional combined assurance derived from different but complementary or even redundant verification results.

3.8 Verification of excess material and Fissile Material Cut- off Treaty (FMCT)

JRC has contributed to this activity through the trilateral initiative between the IAEA, the Russian Federation and the United States.

JRC facilities were used by specialists from this initiative and JRC is ready to continue the support for the testing, certification and authentication of integrated detector technologies and information barriers to measure (material) attributes of materials in shielded containers.

Organisations like the JRC are also continuing to explore the use of heat as a signature and the development of item monitoring and searching systems for these applications. Many of the technologies developed for the detection of undeclared facilities could be used in the FMCT context.

4 Discussion and conclusions

Verification technology and methods are mature and cover quite well the field of "classical" safeguards; i.e. nuclear material accountancy verifications and advanced containment and surveillance systems. This does not mean that R&D in these fields can now be abandoned, but it does not require the high resources of the last 10-20 years. A re-adjustment of priorities is therefore appropriate and increased effort should go into the challenges posed by the detection of undeclared activities.

In the area of "classical" safeguards verification, further development is needed; examples were given in paragraphs 3.1, 3.2 and 3.3. The major trends are more "intelligence" and "user friendliness" in the systems and increasing accuracy of systems and multi-sensor systems.

In bulk handling facilities, the trend will be to verify the "operation" of the facility by well-trained inspectors having good knowledge in the functions and operations of the relevant facilities. Process fingerprinting and fingerprints of signatures outside the hot cells or active areas based on swipe techniques will increase the safeguards assurances concerning undeclared activities. The experience obtained in enrichment plants shows the benefit of these techniques.

Safeguards verification samples should not be shipped around the world for analysis. New technology should be developed to replace such shipments by using portable or stationary systems. Also the authenticated use of the operators' system by a well-trained analytical inspector could be considered.

In the area of detection of undeclared activities, increased efforts are needed. The huge potential of web searching tools and the evaluation of open sources ranging from scientific publications to newspapers needs to be better exploited with new hard- and software solutions. Satellite imaging offers a wide field of challenges and opportunities for R&D as described in paragraph 3.4.

In the area of environmental sampling, the sensitivity and selectivity of the analysis should be pushed to lower levels. The scenario of intentionally "very clean" or "very dirty" facilities to hide evidence requires urgent attention.

Wide area monitoring, while difficult, should not be dismissed from further research. The work should be pursued together with the CBTO to achieve the necessary synergy.

The threat of terrorist attacks requires improvements of physical protection systems, border control equipment for radioactive materials and effective forensic toolboxes to uncover transfer routes and origin of materials. Simulation of dirty bombs and ways to detect, prevent or mitigate and to evaluate ex-post are equally important.

Another priority area is the better monitoring of export controls. The new tools which have been developed for web searching and for container controls should be further developed. Country profiles should be established based on open source information covering the complete weapon's cycle, i.e. including development, deployment and delivery systems.

In conclusion many technical challenges remain to be addressed to improve the non-proliferation scheme.

References

1. Nobuyasu Abe (2005): Challenges and Opportunities for the 2005 NPT Review Conference: Strengthening the Non- Proliferation Regime, High-Level Seminar on Weapons of Mass Destruction, 17 March - Royal Institute for International Relations - Brussels, Belgium.
2. Reference ESARDA homepage: http://esarda2.jrc.it/about/index.html, INMM homepage: http://www.inmm.org/, IAEA homepage: http://www.iaea.org/
3. R. G. Lugar (2005): The Lugar Survey On Proliferation Threats and Responses, http://lugar.senate.gov, June.
4. J. W. Tape (2003): International Safeguards and Verification Challenges, INMM Fall.
5. GOV/2005/8 Medium Term Strategy 2006 - 2011, IAEA, January, Vienna
6. N. Khlebnikov (2005): 2006-2011 IAEA Equipment Development Strategic Plan, IAEA.
7. Abousahl, S.; van Belle, P.; Eberle, H.; Ottmar, H.; Lynch, B.; Vallet; P.; Mayer; K.; Ougier, M. (2005): Development of Quantitative Analytical Methods for the Control of Actinides in a Pyrochemical Partitioning Process, Radiochimica Acta 93, 147-153.
8. B. Jasani, Civil Renaissance satellites opportunities and challenges, this book.
9. I. Niemeyer, Sven Nussbaum, Change Detection - the Potential for Nuclear Safeguards, this book.
10. D. Schriefer, Information Collection and Analysis The International Level, this book.
11. L. Bril and J. Gonalves, Open Source Information Collection, Processing and Applications, this book.
12. M. Richard, Information Collection and Analysis: National level, this book.
13. C. Best et al (2002): Europe Media Monitor, JRC technical note No. T.02.88.
14. C. Best, private communication
15. M.Kalinowski et al, Environmental Sample Analysis, this book.
16. K. Mayer et al, Tracing the Origin of Diverted or Stolen Nuclear Material through Nuclear Forensic Investigation, this book.
17. S. Vogt et al (2005): ACS Annual Meeting, 28 August - 1 September, Washington D.C., USA
18. Stetzer et al (2004): Nuclear Instruments and Methods in Physics Research, A525, 582-592
19. K. Mayer, M. Wallenius, I. Ray (2005): The Analyst, 130, 433-441.
20. IAEA TECDOC 1311 (2002): Prevention of the inadvertent movement and illicit trafficking of radioactive materials, September.
21. IAEA TECDOC 1312 (2002): Detection of radioactive materials at borders, September.
22. IAEA TECDOC 1313 (2002): Response to events involving the advertent movement or illicit trafficking of radioactive materials, September.
23. IAEA Nuclear Security Series No. 2, Nuclear Forensics Support (to be published)
24. A. von Zweidorf et al (2005): ESARDA Annual Meeting, 10-12 May, London, UK

Concluding Remarks

Nicholas Kyriakopoulos

The suffering and agonizing deaths of the soldiers in the battlefields of World War I led to the Geneva Convention banning the use of chemical and biological weapons; the ban was eventually extended to cover development, production and possession, first, of biological weapons and, later, chemical weapons. (BWC 1975, CWC 1996) Hiroshima and Nagasaki produced for the world a macabre demonstration of the destructive force of nuclear energy. At the same time, the atomic bombs that destroyed the two cities, in an ironic twist, prompted the world to contemplate how to harness the same energy for the benefit of mankind. These realizations led to the Nuclear Non-Proliferation Treaty and the Comprehensive Nuclear Test-Ban Treaty. The strongest impetus for arms control came in the immediate aftermath of two disastrous world wars when people had fresh in their minds the destruction brought about by weapons of mass destruction. Toward the end of the 20^{th} century and the beginning of the 21^{st} concerns about the effects on another kind of war on the welfare of mankind are assuming a prominent role. The effects of the war on the environment are not as immediately obvious and gruesome as those caused by weapons; nevertheless their long-term impact on the quality of life is indisputable. There are more similarities than differences between arms control and environmental treaties not only at the conceptual framework as global infrastructures but also at each of their components. The lessons learned from studying the performance of arms control treaties form a natural basis for improving the structure and performance of environmental treaties.

The history of the treaties on biological, chemical and nuclear weapons offers good examples of the complexity of the issues associated with arms control and disarmament. There is no question that revulsion at the horrors of war has generated and continues to generate political pressure to remove weapons of mass destruction from the world arsenal. However, as the history of the treaties on biological, chemical and nuclear weapons demonstrates, revulsion has not been powerful enough to motivate and force the majority of governments to agree to eliminate the various types of weapons of mass destruction. It took less than seven years from the end of World War I for the

Geneva Protocol to be signed, about 50 years for the United States to ratify it, and fifty and seventy-five additional years for the Biological Weapons Convention and Chemical Weapons Convention, respectively, to enter into force. While the Chemical Weapons Convention includes provisions for verification, the Biological Weapons Convention does not. Through a sequence of review conferences, efforts are being made to strengthen the BWC convention with not much progress in sight due to the difficulties on the issue of verification as pointed out by Nixdorff[1]. The effort to ban nuclear weapons could be described as incremental and using a carrot and stick approach; it has been, under the most favorable assessment, only partially successful. The Nuclear Non-Proliferation Treaty ratifies the possession of nuclear weapons by those States that had them at the time of the signing of the treaty and obligates the non-nuclear weapon States to not acquire such weapons in exchange for receiving assistance to develop peaceful uses of nuclear energy and an unenforceable promise by the nuclear-weapon States to negotiate in good faith the eventual elimination of those weapons. The incremental approach produced the Comprehensive Nuclear Test-Ban Treaty, which has been signed by more than 175 States and ratified by more than 125; it has not entered into force because a few indispensable States have not ratified it.

A study of the evolution of these treaties shows that forces more powerful than revulsion at the destruction brought upon by weapons of mass destruction guide the negotiations and determine the outcomes. By adhering to the Geneva Protocol, States assumed the obligation not to use chemical and biological weapons, but were very reluctant to destroy existing stockpiles or cease developing new ones. Serious efforts to achieve a comprehensive ban on these weapons began only after the major military powers had developed nuclear weapons as a more powerful and effective substitute. It is telling that, while the Geneva Protocol prohibits the use of biological and chemical weapons, the NPT does not prohibit the use of nuclear weapons; in this sense, the NPT is much less advanced than the Geneva Protocol along the evolutionary path of arms control. The privileges accorded by the NPT to the nuclear-weapon States could also be interpreted by some non-nuclear-weapon States as justification or incentive to develop or acquire nuclear weapons or, at least, as a disincentive to forgo the development of nuclear weapons. If nuclear weapons are a credible deterrent against aggression for the nuclear-weapon States, why shouldn't they serve the same purpose for any other State? NATO and the Warsaw Pact reached a stable equilibrium state after the Mutual Assured Destruction doctrine became entrenched, because both sides possessed nuclear weapons. Although it is too early to draw any conclusions, India and Pakistan have begun to discuss seriously ways to reduce tensions after both developed nuclear weapons. At the same time, they have not shown any inclination to join the NPT and the CTBT; doing so would impose limitations on their respective nuclear weapons programs. It would not be unreasonable

[1] Unless otherwise noted, names refer to contributions in this volume.

to conclude that some level of parity with the established nuclear-weapon States could be the underlying cause of such reluctance. Similarly, it takes neither strong deductive reasoning nor sophisticated game-theoretical analysis to show causality between the efforts of Iraq, Libya and, presumably, Iran, and the most widely known "secret" of an Israeli nuclear arsenal.

Additional observations about the complexity of the issues associated with arms control treaties can be made about the CTBT and its relation to the NPT. The sole obligation of the signatories to the CTBT is to abstain from testing nuclear devices, the inference being that the nuclear weapons programs sanctioned by the NPT can continue up to the point before a critical reaction can occur. At the same time, States which are not members of the NPT have not been constrained from developing nuclear weapons as the cases of India, Israel and Pakistan demonstrate. While Israel maintains an ambiguous position about its program, India and Pakistan have been eager to announce to the world that they have joined the nuclear club, notwithstanding the unwillingness of the NPT-sanctioned nuclear-weapon States to admit them as new members. The insistence of the original nuclear-weapon States on the exclusivity of their club is in conflict with the reality of the possession of nuclear weapons by States outside it.

The status of the ratifications of the CTBT raises questions about its place and role in the arms control environment. Some States, including the nuclear-weapon States France, Russia and United Kingdom, by ratifying the treaty, have made the binding commitment not to test nuclear weapons; others, such as China and the United States, maintain an ambivalent attitude by signing but not ratifying the treaty, while still others have nothing to do with it. It is interesting to note that the last category comprises the three States, India, North Korea and Pakistan, which seek acknowledgement of their status as nuclear-weapon States. Although there may be specialized explanations for the attitude of each of the ambivalent States, particularly those possessing nuclear weapons, it would not be difficult to draw the obvious conclusion that they prefer to keep their options open in case they decide to improve existing nuclear stockpiles or to develop new ones.

Europe offers an example of another reason for promoting and adhering to arms control treaties. The CFE treaty was signed and ratified when the division of Europe into two opposing military blocks was about to disappear. Dominance of one side over the other was no longer an objective or an option; both sides had the same objective, namely, to avoid accidental conflict through misunderstanding. Thus, the CFE treaty became the mechanism for doing so. Similarly, the European States are enthusiastic adherents to the NPT and supporters of the CTBT, because they have decided that, on one hand, their economic security is achieved in part through the use of nuclear energy and, on the other, their military security lies on cooperation rather than confrontation involving nuclear weapons. Evidently, for that part of the world, the weapon of cooperation is perceived to be more effective than the nuclear one.

Although the articulated reason for negotiating, concluding and implementing arms control treaties is the desire to limit or even eliminate specific weapons, it is clear that military security considerations have a major impact on all three stages. What is not as obvious is the role of economic considerations. These appear indirectly through their impact on the formation of the verification regimes. The verification provisions of the CWC for chemicals in Schedule 2[2] and Schedule 3, as well as some specified chemical facilities have been strongly influenced by the inputs from the chemical and pharmaceutical industries. Paramount consideration has been given to the impact of the verification provisions on "confidential" business information and the intrusiveness of the verification regime. For example, some chemicals which may be used as chemical weapons, but are also produced in large quantities for non-prohibited purposes, have been put on Schedule 3, because the cost of establishing a verification regime to verify diversion was deemed unacceptable. Similarly, the information contained in the declarations by the chemical industry and the scheduling of inspections in chemical facilities have been determined less on verification requirements and more on intrusiveness and cost. Daoudi and Trapp have identified some verification steps mandated by the treaty that have not been very useful and utilize resources that could be used more effectively elsewhere. In the trade-off between effectiveness and cost of verification, priority has been given to reducing costs rather than increasing effectiveness.

Similar considerations impede progress in the negotiations to strengthen the BWC. The cost, in terms of complexity and intrusiveness, of constructing an "effective verification" regime, however the term may be defined, has been stymieing progress for years. The problem is far from trivial. Research on infectious diseases takes place in laboratories under highly controlled environmental conditions. The same laboratories and the same research could also be used in the production of agents used in biological weapons. There are many such laboratories around the world; they could be made relatively small and hidden practically anywhere. Although one could design a verification regime to detect non-compliance in declared facilities, the cost of doing so might be deemed unacceptable considering that the probability of detecting undeclared facilities would be rather small. The difficulties UNSCOM/UNMOVIC[3] had in verifying the complete destruction of Iraq's biological weapons and providing assurance that Iraq had not resumed the biological weapons program are a telling example of the complexity of a BWC verification regime.

Economic considerations, in the form of economic security, form the common base between arms control and environmental treaties. The principal rea-

[2] The chemicals subject to verification by the CWC have been put into three groups, Schedule 1, Schedule 2 and Schedule 3 using a set of criteria including the risk the chemicals in each of the schedule pose to the CWC. Schedule 1 is subject to the most stringent verification while schedule 3 the least.

[3] United Nations Special Commission/United Nations Monitoring, Verification and Inspection Commission.

son for the disputes involving the Kyoto Protocol has been economic, although questions have also been raised about the severity of the impact of hydrocarbon emissions on the climate. While in arms control treaties the economic impact is manifested through the verification regime, in the Kyoto Protocol economic issues arise in the setting of and adhering to the goals. Some States have argued that the cost of achieving the emission targets is unacceptable, because it would have severe adverse impact on the overall economy and would give unfair advantage to some other States. While the economic arguments involving arms control treaties may be reduced to the simple expression "it costs too much to verify compliance", the economic argument applied to the Kyoto Protocol is "it costs too much to achieve compliance". In both cases, the price of achieving the desired outcome is judged to be higher than the future benefits. Thus, the cost of implementing a treaty that operates effectively, either in terms of achieving its goals or verifying compliance, is viewed as unacceptable. Consequently, the idealism of the treaties expressed through the all-encompassing goals is in conflict with the realities of military and economic security. Reconciling the two is not an easy task as the contributions to this volume have shown.

Another area where complexity and ambiguity enter into the picture is on the question of compliance. The CTBT and CWC require "verification of compliance" and "international verification of compliance", while the NPT does not use the word at all; instead, it refers to "verification of the fulfillment of its obligations", which is equivalent to verification of compliance. That is an impossible task. The verification regimes cannot generate such an outcome, because these and other arms control and environmental treaties do not specify the attributes of compliance, only those of non-compliance. The initial nuclear safeguards system was designed to detect diversion of nuclear material. The absence of detection does not necessarily imply compliance as the Iraq case has demonstrated. For measurable attributes such as "nuclear explosion" and "use of chemical weapons" the outcomes can only be expressed in terms of detection probabilities and confidence levels, because the decisions are based on measurements. For example, if a detection threshold for the verification regime of the CTBT is set lower than the detection capability of the International Monitoring System, low yield explosions would be missed and non-compliance would not be detected. Thus, the constraints built into the verification regimes due to economic and military security considerations, in combination with the limitations imposed by technology, reduce the probability of detecting non-compliance and the confidence in the decisions of the detector.

A further complication arises from the multiple obligations assumed under the various treaties. To detect violation of each of those obligations the verification regime needs to have corresponding sets of thresholds for the detection probabilities and confidence levels. The question arises whether the detection probabilities and confidence levels for each of these obligations should be the same or different. This raises the issue of the significance of each violation vis--vis the "object and purpose" of a treaty. Not all violations are of equal importance or pose equal risk. Detonating a nuclear device[4] is a clear violation, because the specific act is explicitly prohibited and detectable with a high probability. Delaying permission to an inspection team on a challenge inspection to enter a State is also a violation. Serious as the action of denial may be, it cannot be considered as having the same detrimental effect toward the "object and purpose" of a treaty as building a chemical weapon or detonating a nuclear device, even if the reason for the denial was to reduce the probability of detecting a more serious violation. Furthermore, the host country could make a case that the denial of entry might be justifiable to some degree. Of even less significance would be a failure to submit required declarations on time, or to provide incomplete information. Ranking violations on the basis of risk to the primary purpose of a treaty would help clarify the meaning and significance of non-compliance for multiple obligations.

The Chemical Weapons Convention requires the member States to have destroyed all chemical weapons stockpiles in their possession within ten years from the entry into force. For a number of technical and economic reasons, that goal is nowhere close to being reached although the destruction process moves forward. Technically or legally those States are in non-compliance with that particular obligation. Does it really matter as long as the destruction proceeds in a verifiable manner? In hindsight, the ten-year limit might have been too short. Would a fifteen-year limit have been more realistic? Maybe, twenty years? Maybe, no fixed time limit? Similar questions can be raised about the various types of inspections and their contribution toward the detection of non-compliance. If one were to classify the various obligations listed in a treaty in order of significance, the conclusion would be reached that the design of a monitoring system to detect violations should be such that the probability of detecting non-compliance with hierarchically ranked obligations should be proportional to the ranking order of the obligations. The practical implication of such an approach would be reallocation of resources to optimize the performance of the verification regimes. If, as noted earlier, inspections mandated by the treaty do not generate much useful information, why should the OPCW expand resources on them? For the CWC and similar treaties, instead of requiring the verification regime to expend resources on all obligations regardless of significance, it would be more efficient and cost-effective to concentrate on detecting non-compliance only for the most significant ones. While it is possible to classify quantifiable violations on the basis of risk, the same cannot be done for the qualitative ones such as "not encourage or induce anyone..."; worse, qualitative violations cannot be detected because they cannot be measured. This raises the question whether such obligations should even be listed in a treaty. Thus, in designing a system to detect non-compliance, one needs to take into account not only the distinction between

[4] The term is used rather loosely; Richard has pointed out that there is no precise definition of nuclear detonation.

qualitative and quantifiable obligations, but also the relative significance of the quantifiable ones.

Another issue of resource re-allocation arises from the relationship between the mechanistic application of "reasonable" rules and the reality of the operation of the treaties. Take for example the application of safeguards to the nuclear fuel cycle for peaceful uses. The IAEA allocates the routine inspection effort on the basis of the size of the fuel cycle; as a result more than 80% of the inspection resources are spent in Canada, Germany and Japan, States that have repeatedly renounced the nuclear weapon option. At the same time, as Richard and others have pointed out, the most serious nuclear proliferation has taken place in other States both within the NPT and outside. The cases of Iraq, North Korea and South Africa raise an intriguing question. If an NPT State with limited nuclear activities and partially developed industrial base can develop a nuclear weapons program undetected by the IAEA safeguards, would such a system be able to detect a similar program in a State with extensive nuclear fuel cycle activities and sophisticated technological base? The answer to this question is an essential input for a proper evaluation of the effectiveness of the safeguards approaches. As Cooley, Schriefer and Schenkel have pointed out, the Integrated Safeguards System based on the Additional Protocol aims to correct the deficiencies of the safeguards approach as practiced in the past. The goal is to view the State as a whole and consider factors in addition to those directly related to the nuclear fuel cycle. The broadened information base includes data provided by the States, data collected by the IAEA using the legal authority under the Additional Protocol and open source data. A major research challenge is how to develop concepts and tools for using this additional information effectively.

The essential element of the detection system is the decision-maker. The NPT in Article III implicitly designates the IAEA safeguards system as the detector by requiring acceptance of safeguards "for the exclusive purpose of verification of the fulfillment of its obligations". It should be noted that the treaty is silent about verification of all obligations under the NPT. On the other hand the CWC and the CTBT are ambiguous at best on the identity of the decision-maker. Both treaties mention "international verification of compliance" without specifying the identity of the verifier, the impossibility of such verification notwithstanding. It is significant that both treaties are silent on the designation of the detector. Instead, they raise the issue indirectly by referring to "concerns about non-compliance"; the implication being that anyone could raise such concerns. In both treaties the respective Conferences of the States Parties are responsible for addressing these concerns, for taking measures "to ensure compliance" and to "redress situations of non-compliance". The CWC empowers the Executive Council to "consider...cases of non-compliance", as does the CTBT with a slightly different language "consider any concern raised by a State Party about possible non-compliance". Member States interpret such language to mean that each State makes its own decision about non-compliance, in effect, creating a system of multiple detectors. Redundancy in the number of detectors has the potential of increasing the detection probability, if the detection criteria are similar and the detectors process the same type of information. When multiple decision-makers are used to detect an event, the outputs of the decision-makers need to be combined in order to arrive at a single decision using some established rule. Typically, the rule is a form of voting, such as majority or some other weighting scheme. However, this is not the case for the decision-making mechanisms of the treaties. Each State may use its own criteria which could differ from State to State. Also, the input information used by the States is not necessarily the same. States may use information collected independently on their own in addition to the information collected by the monitoring system of a treaty. As a result, discrepancies among the outputs of the detectors are bound to arise. The uncertainty inherent in the decisions of the multiple detectors in combination with the lack of a clearly defined mechanism for combining them into a single decision about non-compliance is most likely to increase the uncertainty of the detection of non-compliance. The ambiguous language used in the CWC and the CTBT, by sidestepping the question of who is the ultimate decision-maker about non-compliance invites indecision and abuse. The case of the missing weapons of mass destruction in Iraq illustrates the dangers inherent in having States make their own decisions about non-compliance without an independent objective mechanism to verify them.

Even if one would interpret the ambiguous language to imply that the determination of non-compliance is made either by the Executive Council or the Conference of the States Parties, questions about the value of the decision could still arise. These bodies are political and their composition reflects, inter alia, geographical considerations. Decisions taken by these bodies about non-compliance could be based as much on factual as on political considerations. Such decisions, absent an objective detection mechanism, have a high probability of being false positives, namely, unsupportable by the underlying factual evidence. In an effort to make determination of non-compliance a technical rather than political issue, the Kyoto Protocol envisions a system whereby national communications concerning emissions are subject to an in-depth review by an international team of experts chosen from a roster and coordinated by the secretariat. It is a model worth considering for arms control treaties.

The lack of a scheme to classify obligations in order of significance and of an objective and reliable detector has a significant impact on the probability of undertaking "necessary measures" to ensure compliance. Treaties provide for consultations to resolve concerns about non-compliance. If consultations fail to resolve the issue, sanctions may be imposed, but they rarely are. As Carlson has observed in his contribution, four States, Iraq, Romania, North Korea and Libya were detected to be in non-compliance for having violated their safeguards agreements, yet there have not been any consequences. One could draw different conclusions from the lack of action; these could range from the violations were not very significant to the lack of an effective mechanism to impose appropriate measures, whatever these might be. Even in cases where non-compliance with the primary obligations under a treaty has been self-evident, as in the case of the use of chemical weapons by the Iraqi Government against the Kurds, neither measures were taken to ensure compliance, namely, to stop the use of these weapons, nor were any penalties applied to Iraq for violating the Geneva Convention. The lack of a credible mechanism for enforcing compliance is not limited to arms control treaties; as MacFaul has observed, the Kyoto Protocol suffers from similar weaknesses.

The broad expression "take the necessary measures to ensure compliance" can almost be interpreted as an escape clause for inaction. Although the UN is the only world body with the legal authority to enforce sanctions against a State that has not complied with its obligations, it is also the place where actions of that nature are difficult if not impossible to be taken. However credible a finding on non-compliance may be, it is not necessarily that it alone is the determining factor for taking the "necessary measures". In a political body, political considerations prevail and sanctions might not be applied even in a case of highly probable non-compliance. Conversely, similar considerations may result in sanctions even in ambiguous cases characterized with low probability of non-compliance. Thus, the concept of sanctions as it appears in existing treaties, although intellectually appealing, it is of little practical use, because it cannot be implemented effectively. If one is to take seriously the idea that there are costs for not complying with the obligations assumed by ratifying a treaty, then a new model is needed. To avoid introducing extraneous factors into an essentially technical decision, detection of non-compliance should be a strictly technical function performed by an independent authority. To make the sanctions credible, the cost of non-compliance should be calculated to ensure that it has a deterrent effect and that it has a high probability of being imposed on the violator. The political environment in which such decisions are made is not conducive to the creation of a causal relationship between non-compliance and sanctions. Such considerations being inevitable, other approaches need to be considered in order to minimize the impact of the political considerations on the decisions about non-compliance and the imposition of sanctions. One possible option could be to list the quantifiable obligations in the treaty and specify penalties associated with non-compliance with each of them. If such a model is politically difficult to incorporate in a treaty, doing away with the concept of unenforceable sanctions might be a more realistic alternative. Having sanctions as an option but not applying them is cases of confirmed non-compliance does more damage to the credibility of a treaty than not having them at all.

In this volume we have presented a comprehensive overview of multilateral arms control treaties, a unified framework for analyzing their performance and an approach for improving the structure and operation of existing and future treaties. Although arms control will continue to be an aspiration of mankind, concerns about the quality of life will keep increasing the pressure for controlling the pollution of the environment. The similarities between arms control and environmental treaties are many. Both apply to activities of States, be they production of military weapons or pollutants, a euphemism for environmental weapons. Both require compliance with specific obligations. Both envision monitoring systems for collecting information to verify compliance. Both require the imposition of penalties in case of non-compliance. Environmental treaties with verification regimes are a relatively recent appearance compared to arms control treaties. Because of the many similarities between the two areas, it is natural that the experiences from the operation of the arms control treaties and the lessons learned over the past decades should be used to improve the design and operation of environmental treaties. If one looks beyond the labels and the politics surrounding both kinds of treaties, it quickly becomes apparent that treaties in the two areas have identical infrastructures. Both rely on sensors to perform measurements, communications to transmit data and computers to process and analyze information and both use a decision-making mechanism to detect non-compliance. Both are best viewed as integrated systems in which the variables are similar although their values might be different.

The sections on technologies, methodologies and synergies cover the means by which the information used for detecting non-compliance is generated, collected and analyzed. The broad heading reflects the philosophy of this book that verification regimes are systems consisting of interconnected components that provide specified services. The individual components are hardware and software. To provide the services needed to detect non-compliance it is necessary to develop methodologies for integrating the components into a verification system. The topics have been selected not for the purpose of providing a comprehensive overview, but to give a flavor of the diversity of the scientific disciplines that need to be brought into play in order to construct a detector of non-compliance. Development of an effective verification system needs to begin with the formulation of formal models as, for example, the material accountancy and control model for the nuclear fuel cycle. Avenhaus and Canty have given three examples of models to illustrate the applicability of mathematical modeling to the various components of what we have referred in the beginning of the book as the treaty process. Similarly, Kalinowski et al identify the need for modeling atmospheric transport phenomena for use in monitoring both arms control and environmental treaties. Models are needed for solving problems ranging from conceptual ones, such as whether or not a State should participate in a treaty to operational ones, such as how an inspector should spend most effectively an allotted inspection time, or how to optimize the location of environmental monitoring stations.

Remote sensing technologies capable of generating optical, infrared, multi-spectral, radar and hyper-spectral images have played a role in some treaties such as CFE, but they have not yet been utilized to the fullest extent of their potential, although they are not precluded from being incorporated into the monitoring systems of treaties such as the CWC, CTBT and NPT. The first two have a general provision for incorporating new technologies into the monitoring systems, while the NPT requires acceptance of safeguards with no reference to specific technologies. Nevertheless, incorporation of new technologies and in particular remote sensing is not that easy because the approval procedures for modifying monitoring systems involve political considerations. Witness the difficulties faced by the IAEA in deploying cameras for remote surveillance of the spent fuel pools. One should make the distinction between two categories of remote monitoring technologies. The first consists of instruments in situ transmitting locally collected information to a remote location. The second category consists of instruments collecting the information remotely and processing the data either at the point of collection or at some other remote location; this category is properly referred to as remote sensing. Remote monitoring by in situ instrumentation is applicable in cases where the measurements points are known and are not expected to change over time, such as the safeguarded nuclear facilities under the NPT and the monitoring stations of the International Monitoring System of the CTBT. As Richter has observed, a strong motivation for using remotely monitored in situ instrumentation is the desire to reduce the number of inspections at declared facilities, and to improve the timeliness of the transfer of information from a facility to the IAEA. The technologies for remote monitoring of instruments reliably and securely are well developed and are not unique to the monitoring systems for arms control and environmental treaties.

The importance remote sensing is recognized by the establishment of the Global Monitoring for Security and Stability (GMOSS) Network of Excellence in the European Union described by Shepherd; the program aims to develop the capacity for global monitoring using earth observation satellites. Satellite imaging provides very useful information if one knows where to look for it. In monitoring for non-compliance remote sensing needs to be used in conjunction with other indicators in order to identify locations where suspect events might have occurred. A promising area where some work is being done is the combination of satellite imagery with seismic data from the International Monitoring System of the CTBT to improve the location detection capability of the verification system.

The development of monitoring technologies has proceeded along a rather orderly path laid out by the verification regimes. Each treaty specifies places and activities to be monitored, variables to be measured and, generally, the times when measurements need to be taken and the means by which the measurements are to be performed. For example, nuclear safeguards are applied to declared facilities covering the entire nuclear fuel cycle; measurements are taken at inventory control points in such a manner as to ensure continuity of information; they are performed by inspectors and, in the absence of inspectors, by unattended instruments. These parameters have been sufficient for the engineers to develop appropriate instrumentation either by modifying instruments designed for other uses or developing specialized instruments for use in monitoring specific treaties. The contributions of Altmann and Richter have provided a comprehensive overview of existing technologies and have identified monitoring applications for which new technologies need to be developed. They have also surveyed some new and emerging technologies, such as nanotechnology and unattended sensor networks which could be used to design monitoring systems with increased capabilities and effectiveness.

The broad overview of technologies has been complemented by contributions on techniques to illustrate the point that the development of monitoring and verification systems needs to have depth as well. The contribution by Niemeyer and Nussbaum on techniques for detecting changes through remote imaging illustrates the potential of algorithmic approaches for the extraction of information from publicly available data. In it important to distinguish between publicly available information and that collected and analyzed by the States clandestinely. For example, information collected by national technical means, such as reconnaissance satellites, may be made available for international verification of treaties, but such information is filtered. The secrecy surrounding the data collection systems and the processing of the data introduces uncertainty about the integrity of such information and, consequently, it may have a negative impact on the confidence level of the decision of the detection mechanism. The transparency inherent in the data collected and processed by systems and techniques in the public domain can only help increase confidence in a verification regime.

The discovery of the A. Q. Khan network generated a need for research and development in a different direction from that set by the monitoring requirements of the treaties. Those requirements are based on a treaty framework setting up relations among States. For cases involving non-State actors or clandestine operations by States, the conventional treaty framework has proven inadequate; new approaches are needed. Mayer has given some examples of nuclear forensic techniques to illustrate the applicability and potential of the discipline of nuclear forensic science. Trying to detect the origins of samples of nuclear material resembles more a conventional police investigation than the operation of a treaty verification regime. In view of the well founded fears that weapons of mass destruction could proliferate clandestinely among States, among non-State actors and between States and non-State actors, some important issues need to be addressed. The first issue is scientific and technological; namely, how does one construct a mechanism for detecting clandestine international networks dealing with weapons of mass destruction? A related issue is the detection of the movement of components of such weapons in the absence of prior knowledge of the existence of these networks and of the identity of the items transported through them. Equally important is the question of the adequacy of the existing treaty framework for the application of forensic techniques at the international level.

A recurring theme throughout this volume has been the necessity to develop an integrated approach for detecting non-compliance through the merging and processing multiple sets of data. Techniques for collecting, storing and manipulating data developed for various other applications are also applicable to the processing of verification data. Similarly, the structure and operation of information processing systems of the verification regimes discussed in this volume are not much different from those of information systems of other large organizations. The problems begin when the issues that need to be addressed pertain to the types and quantities of data that need to be collected, processed and stored, and to the operations that need to be performed on the data in order to generate the outputs expected by the detection mechanism. There are no substantive information processing problems for verification regimes that are well-defined, such as safeguards for declared nuclear facilities, or monitoring for nuclear explosions. On the other hand, there are major challenges in specifying the functions of the information processing system for incompletely specified systems such as integrated safeguards. The desired output of the safeguards system is known. How to go about generating it is still an unanswered question.

From the component perspective, monitoring and verification technologies could be classified as general purpose, special purpose and hybrid. General purpose, or commercially available, technologies are those which have been developed for other uses and are also usable without modification in verification regimes. Examples range in order of complexity from temperature sensors to satellite imaging technology. On the other hand, there are components that are specifically designed for use in treaty monitoring systems. Typically, these are instruments that are portable, or need to operate unattended in remote facilities, or perform measurements that have no other use except in a particular verification regime, such as nuclear safeguards. In between, one can define a hybrid class which comprises instruments that have been developed for other applications and can be used, with minor modifications, in verification regimes. For example, gas chromatographs-mass spectrometers used for analyzing samples in the CWC verification system are general purpose instruments that incorporate have special filters for blocking information on all chemical compounds except those specified in the treaty.

Of the three categories of technologies, the special purpose instruments present a unique problem. The total number of such instruments needed for the verification regime of a given treaty is small and the customer for the instruments is only the international organization for that treaty giving rise to a monopsony. The limited production and the single customer create uncertainties about the stability of the supply and the cost of such limited number of specialized items. Suggestions for solving this difficult problem have ranged from coordinating and possibly unifying research and development activities across treaties to the creation of a specialized international infrastructure to ensure continuity of supply and containment of costs for such special purpose items. The problem is not as severe for the hybrid technologies. Developing a piece of software does not require the same capital investment as the setting up of a production facility for a hardware item. Similarly, the development of models, system architectures and algorithms for converting verification requirements into integrated systems can be done by the existing infrastructure of universities, national research centers and private research and development organizations.

From the analyses of the treaties covered in this volume, it has become clear that the identified problems and weaknesses are associated not so much with the monitoring technologies, as with the structural weaknesses of the verification regimes and the mechanisms for enforcing compliance. These fall into two broad categories, those caused by political and economic constraints, e.g., limitations in the number and type of inspections, unwillingness or inability to enforce compliance, etc, and those caused by the lack of verification concepts and methodologies and effective mechanisms for enforcing compliance.

Before one reaches the stage where political decisions about imposing penalties for non-compliance or enforcing compliance are made, there is a need to have objective mechanisms for detecting non-compliance and for developing effective control functions to enforce compliance. Difficult as the political decisions are, as the history of the operation of the treaties has demonstrated, they become practically impossible, if they are not based on information generally accepted as objective. Such information can only be generated by the rational approach embodied in the scientific method. By viewing the treaties as systems with defined infrastructures, we have endeavored to set the foundations for a scientific discipline to study systematically the class of multilateral treaties that contain the elements of monitoring, verification, and sanctions as their major components. The main area of activities would be to integrate available technologies and analytical tools for the purpose of optimizing detection of non-compliance.

As it should have become evident by now, the purpose of this volume is neither to denigrate the treaties by pointing out weaknesses and problems, nor to provide easy answers to those problems. We have identified issues and raised questions in order to help understand the complexities of multilateral treaties with requirements for detecting non-compliance. The listing of the problems associated with negotiating, concluding and implementing arms control treaties is not intended to create pessimism; on the contrary, these problems should be viewed as challenges to be overcome in moving toward the desirable end of arms control. Furthermore the experience gained from studying the performance of arms control treaties should become a valuable input in the effort to improve future treaties not only for arms control but also for the protection of the environment. Through a rational and dispassionate approach, we have identified a number of areas where scientific analysis can help minimize weaknesses and solve problems. The realism resulting from taking a rational approach neither negates nor is it in conflict with the practice of setting broad and ideal goals even in such emotionally charged areas as arms control and environmental protection. Although the expectations created by the idealism of the goals can and often does lead to disappointment and disillusionment in the attempts to achieve them, the response should not be one of resignation but of perseverance to get closer to these ideals. Improvements are made in the search for them. In other words, the value of the goal lies primarily in the efforts to achieve it. To quote Cavafy[5]

As you set out for Ithaka hope
your road is a long one,
full of adventure, full of discovery.
Laistrygonians, Cyclops,
angry Poseidon-don't be afraid of them:
you'll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.
Laistrygonians, Cyclops,
wild Poseidon-you won't encounter them
unless you bring them along inside your soul,
unless your soul sets them up in front of you.

Hope your road is a long one.
May there be many summer mornings when,
with what pleasure, what joy,
you enter harbors you're seeing for the first time;
may you stop at Phoenician trading stations
to buy fine things,
mother of pearl and coral, amber and ebony,
sensual perfume of every kind-
as many sensual perfumes as you can;
and may you visit many Egyptian cities
to learn and go on learning from their scholars.

Keep Ithaka always in your mind.
Arriving there is what you're destined for.
But don't hurry the journey at all.
Better if it lasts for years,
so you're old by the time you reach the island,
wealthy with all you've gained on the way,
not expecting Ithaka to make you rich.
Ithaka gave you the marvelous journey.
Without her you wouldn't have set out.
She has nothing left to give you now.
And if you find her poor, Ithaka won't have fooled you.
Wise as you will have become, so full of experience,
you'll have understood by then what these Ithakas mean.

---

[5] CAVAFY, C. P.; C. P. CAVAFY. ©1972 Edmund Keeley and Philip Sherrard. Reprinted by permission of Princeton University Press.

List of Authors

Altmann, Jürgen
Universität Dortmund, Experimentelle Physik III, Germany
Altmann@EP3.Ruhr-Uni-Bochum.de

Avenhaus, Rudolf
Universität der Bundeswehr München, Germany
rudolf.avenhaus@unibw.de

Baute, Jacques G.
International Atomic Energy Agency, Vienna, Austria
j.baute@iaea.org

Bernstein, Adam
Lawrence Livermore National Laboratory, Livermore, USA
bernstein3@llnl.gov

Bril, Louis-Victor
European Commission - Joint Research Centre, Ispra, Italy
louis-victor.bril@jrc.it

Bowden, Nathaniel
Sandia National Laboratories, Albuquerque, USA
nbowden@sandia.gov

Canty, Morton
Research Centre Jülich, Systems Analysis and Technology Evaluation (STE), Jülich, Germany
m.canty@fz-juelich.de

Carlson, John
Australian Safeguards and Non-Proliferation Office, Barton, Australia
john.carlson@dfat.gov.au

Chartier, Bernard
Commissariat à l'Energie Atomique; Direction des Applications Militaires Direction Matières Surveillance, Environnement Centre d'Île de France Bruyères, le Châtel, France
bernard.chartier@cea.fr

Cooley, Jill N.
International Atomic Energy Agency, Vienna, Austria
j.cooley@iaea.org

Daoudi, Mohamed
Organisation for the Prohibition of Chemical Weapons, OPCW, The Hague, The Netherlands
daoudi@wanadoo.nl

Feichter, Johann
Max Planck Institute for Meteorology, Hamburg, Germany
feichter@dkrz.de

Gonçalves, João G.M.
European Commission - Joint Research Centre, Ispra, Italy
joao.goncalves@jrc.it

Häckel, Erwin
Deutsche Gesellschaft für Auswärtige Politik, Berlin, Germany
erwin.haeckel@t-online.de

Jasani, Bhupendra
Kings College London, UK
bhupendra.jasani@kcl.ac.uk

Kalinowski, Martin B.
CTBTO PrepCom Provisional Technical Secretariat, Vienna, Austria
Martin.Kalinowski@ctbto.org

Kyriakopoulos, Nicholas
The George Washington University, Washington, DC, USA
kyriak@gwu.edu

MacFaul, Larry
The Verification Research, Training and Information Centre (VERTIC), London, UK
larry.macfaul@vertic.org

Mayer, Klaus
European Commission, Joint Research Centre, Institute for Transuranium Elements, Karlsruhe, Germany
mayer@itu.fzk.de

Nixdorff, Kathryn
Darmstadt University of Technology, Department of Microbiology and Genetics, Germany
nixdorff@bio.tu-darmstadt.de

Niemeyer, Irmgard
Freiberg University of Mining and Technology (TU Bergakademie Freiberg) Institut of Mine-Surveying & Geodesy, Freiberg, Germany
irmgard.niemeyer@tu-freiberg.de

Nikkinen, Mika
International Atomic Energy Agency, Vienna, Austria
nikkinen@iaea.org

Nussbaum, Sven
Research Centre Jülich, Systems Analysis and Technology Evaluation (STE), Jülich, Germany
s.nussbaum@fz-juelich.de

Poucet, Andre
European Commission - Joint Research Centre, Ispra, Italy
andre.poucet@cec.eu.int

Ray, Ian
European Commission - Joint Research Centre, Institute for Transuranium Elements, Karlsruhe, Germany
ray@itu.fzk.de

Richard, Michel
Commissariat à l'Energie Atomique; Direction des Applications Militaires Direction Matières Surveillance, Environnement Centre d'Île de France Bruyères, le Châtel, France
michel.richard@cea.fr

Richter, Bernd
Research Centre Jülich, Systems Analysis and Technology Evaluation (STE), Jülich, Germany
b.richter@fz-juelich.de

Rosenstock, Wolfgang
Fraunhofer Institut für Naturwissenschaftlich-Technische Trendanalysen (INT), Euskirchen, Germany
wolfgang.rosenstock@int.fhg.de

Schenkel, Roland
European Commission - Joint Research Centre, Brussels, Belgium
roland.schenkel@cec.eu.int

Schlosser, Clemens
Federal Office for Radiation Protection (BfS), Freiburg, Germany
c.schlosser@bfs.de

Schriefer, Dirk
International Atomic Energy Agency ,Vienna, Austria
dirkschriefer@netscape.net

Shepherd, Iain
European Commission - Joint Research Centre, Ispra, Italy
iain.shepherd@jrc.it

Stein, Gotthard
Research Centre Jülich, Systems Analysis and Technology Evaluation (STE), Jülich, Germany
g.stein@fz-juelich.de

Stein, Marius
Canberra Aquila, Inc., Albuquerque, USA
mstein@aquilagroup.com

Trapp, Ralf
Organisation for the Prohibition of Chemical Weapons, OPCW, The Hague, The Netherlands
ralf.trapp@gmail.com

Wallenius, Maria
European Commission, Joint Research Centre, Institute for Transuranium Elements, Karlsruhe, Germany
wallenius@itu.fzk.de

Zwilling, Marc
Unité Française de Vérification, Base aérienne 110, France
ufv@wanadoo.fr

Index