Neutron Resonance Transmission Tomography for Zero-Knowledge Warhead Verification

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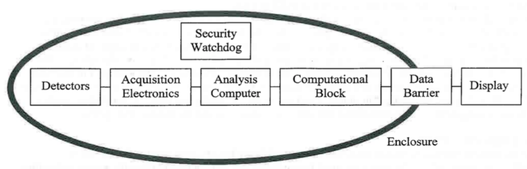
Introduction

The national laboratories specify seven primary qualities needed for a viable verification system (Hamilton 1999):

- preventing unauthorized operation and use,
- protecting classified data,
- preventing unauthorized and undetected modification of the system,
- not producing false negatives,
- being transparent (to facilitate inspection),
- including diagnostics that verify correct operation without disclosing classified data,
- detecting errors during operation.

Approaches can be **template**-based or **attribute**-based with active or passive interrogation. Previous approaches have utilized electronic **information barriers** to protect sensitive design information, including CIVET (Brookhaven 1988), TRIS (Sandia 2000), and NMIS (Oak Ridge 1990).

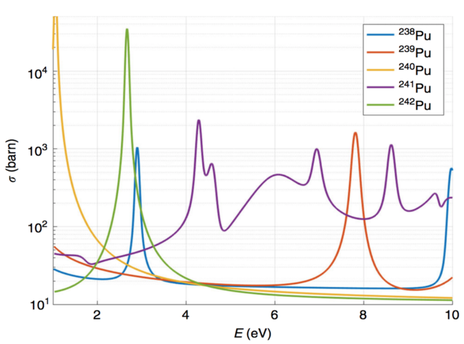


A model for information barrier design. Direct measurements, acquisition electronic (multi channel analyzers), and data analysis are performed before a final data barrier. The inspector receives a Boolean output (TRUE for weapon, FALSE for counterfeit). (Williams 2005)

More recent work has utilized zero knowledge protocols and physical cryptography as an alternative to electronic encryption (Glaser 2014). This experimental utilizes physical-cryptography and epithermal neutron imaging for information-secure and **isotopically sensitive** warhead verification.

NRTA

A new verification system using epithermal neutron transmission analysis. Using TOF techniques with 1 to 20 eV neutrons, **NRTA** can be used to determine the isotopic compositions of interrogated warheads.

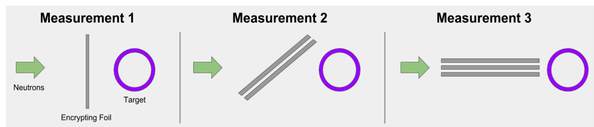


Neutron absorption resonances are plotted for a variety of plutonium isotopes. The unique shapes of these spectra allow precise reconstructions of isotopic abundances in interrogated material. (Hecla 2018)

Methods

Experimental Approach

The experimental setup consists of two objects: a "pit/hoax" object and a piece of encrypting foil. Using a tomographic-like process, rotations of the pit are combined with randomized changes in the thickness and enrichment of the foil. By comparing a the signatures from NRTA, the interrogated object can be verified as genuine or hoax.

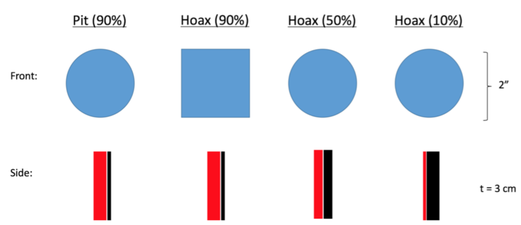


The three configurations for the pit measurements. In an actual inspection regime all three rotational degrees of freedom might be used and the rotation randomized. For this proof of concept we rotate along a single axis at angles of 0, 45, and 90 degrees.

Materials

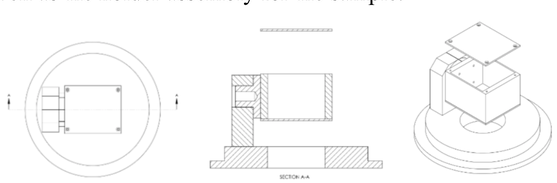
To simplify the manufacturing process the pit object is a solid cylinder instead of a hollow sphere. The geometric hoax is a parallel piped of equal thickness. The geometric verification principle would be similar for other geometries.

We use mixes of molybdenum and tungsten as substitutes (both have unique resonance structures in the epithermal region).



The planned pit and hoax combinations for the experiment. These objects include a *true* template warhead (cylinder 90%), a geometric hoax (piped 90%), and two isotopic hoaxes (cylinders 50% and 10%).

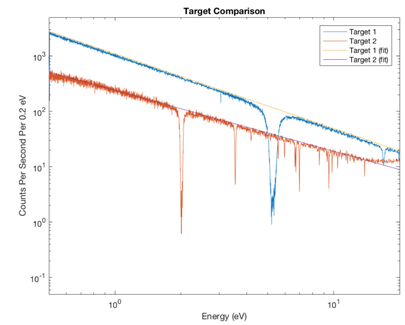
The holder consists of a mounting plate for the beam line as well as the holder assembly for the sample.



The holder is contains a mounting assembly to fix the sample to beam line. The encrypting foil is fixed directly to the mount. The holder contains the actual put and hoax samples.

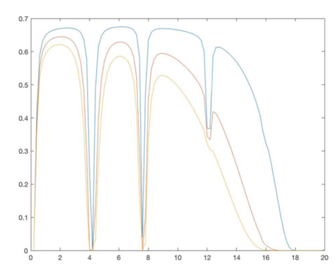
Beam

Measurements will be performed at the RPI Gaerttner LINAC center. Neutrons are produced via spallation of 60 MeV electrons in tungsten, and the beam is then thermalized with ~3cm of polyethylene.



Flux comparisons for alternative targets on RPI neutron beam at the Gaerttner LINAC center. Flux profiles obey a power law with a few resonances from films of material left in beam during run. Data courtesy of Yaron Daron, RPI.

Molybdenum and tungsten for Pu-239 and Pu-240 for various pit configurations. Using a power law spectrum with a slope of -1.35 (slope of neutron flux from target 1), the following spectra is obtained:



Transmission curves for various enrichments of 1cm of material are shown for shown. Note the significant differences between the spectra. The enrichments are 90% (blue), 50% (red), and 10% (yellow).

Chi-Squared Tests

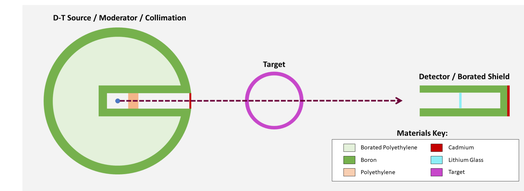
All chi-squared tests were conducted with 91 degrees of freedom corresponding to 91 equally sized bins between 0.2 eV and 18 eV. The p=0.001 critical value for a chi-squared test with 91 degrees of freedom is 138. Chi-square increases linearly with time for this experimental set up.

Chi-Squared Rates (Target 1)

	Normalized	Unnormalized
10%	20.924	40.515
50%	8.954	16.031

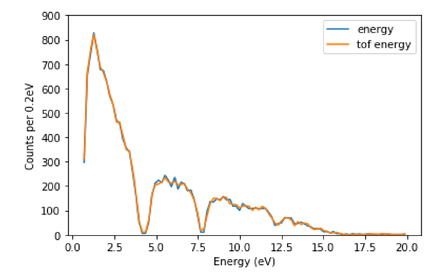
DT Simulations

Examining the potential use of a thermalized DT-source for an epithermal imager. The source is surrounded with a sphere of borated polyethylene and thermalized in boron plated collimator. The detector is shielded with a boron and cadmium shield.



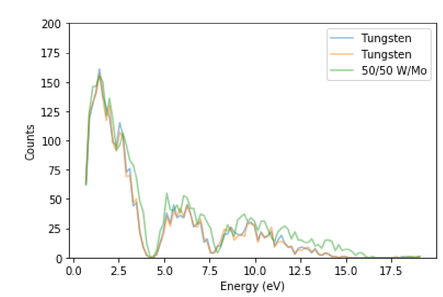
The borated poly sphere has a radius of 75 cm with 10 cm of boron plating. The beam is moderated with 4 cm of polyethylene with a cadmium screen (5mm) to filer out thermal neutrons..

Ignoring pulse smearing (rise and fall times) from the source itself, this geometry gives a highly accurate TOF reconstructed energy spectrum, shown below:



Geant4 simulation of the incident neutron energy and TOF-reconstructed energy in the detector. Using a distance parameter of 1.9 meters, and 1.5e9 events, we obtain highly resolved resonance structures.

A sensitivity analysis shows an ability to distinguish between 2cm of tungsten and a 50/50 tungsten/ molybdenum mix. The chi-squared value of spectra separation is 270. Chi-squared critical value for 100 degrees of freedom is 149 (p=0.001).



Geant4 simulations using 4cm moderated DT source and 3e8 events. Corresponds to approximately minute long measurement times using MIT DT-source.

New DT sources approach intensities which will shrink required measurement times considerably. Ongoing research has suggested that the radius of the borated poly sphere could be decreased further to improve portability.