INFORMATION SECURITY of an NRF-BASED METHOD for WARHEAD VERIFICATION

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Objective

Determine the information security of a physical cryptographic warhead verification (PCV) method based on nuclear resonance fluorescence (NRF).

Background

PCV is a template approach to verification of a candidate warhead by matching it to a reference warhead of known authenticity.

This proposed protocol uses transmission of an electron source through the warhead to measure induced secondary NRF emissions following impingement on an encrypting foil.

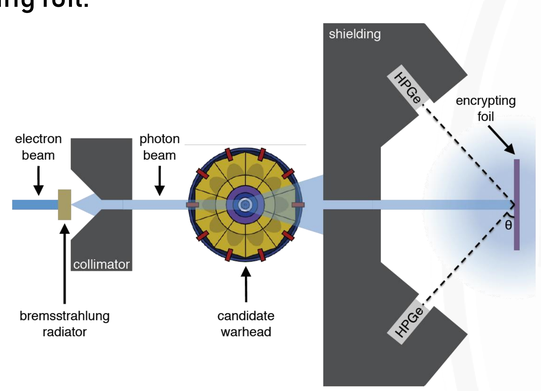

Figure 1. Diagram of the PCV measurement apparatus.

The procedure is information secure for monochromatic sources, but the use of a bremsstrahlung source may compromise the security of sensitive warhead information.

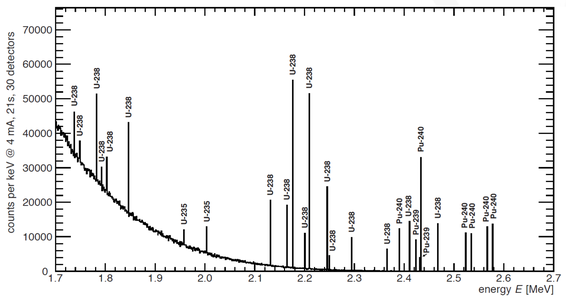

Figure 2. Black Sea warhead template NRF spectrum.

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Technical Work and Results

Warheads used in this simulation are based on design parameters estimated from the Black Sea Experiment warhead.:

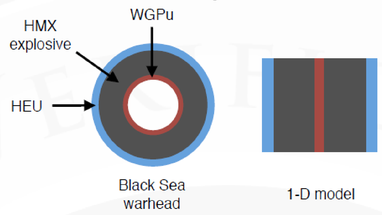

Figure 3. Diagram of the Black Sea warhead and 1-D model showing cross section of material encountered by a pencil beam traversing the warhead center.

The NRF absorption cross section can be calculated using a modified single-level Breit-Wigner NRF absorption cross section:

$$\sigma_r(E) = \sqrt{\pi} g_r \left(\frac{\hbar c}{E_r}\right)^2 \frac{1}{\Delta_{\text{eff}}} \int_{-\infty}^{\infty} \frac{\Gamma_{0,r}\Gamma_r}{(z-E_r)^2 + (\Gamma_r/2)^2} \exp\left[-\frac{(z-E)^2}{\Delta_{\text{eff}}^2}\right] dz$$

The observed NRF count rate depends on the isotope areal densities in the warhead, the isotope number densities in the foil, the foil thickness, and the initial beam flux:

$$n(E, E', \theta) = \int_{-2\sqrt{2}\Delta_{\text{eff}}}^{2\sqrt{2}\Delta_{\text{eff}}} \phi_t(z) b_{E,E'} \left[\mu_{\text{NRF}}(z)\right]_i \frac{1 - \exp\left[-\alpha(z, E', \theta_d)\mathcal{X}\right]}{\alpha(z, E', \theta_d)} dz.$$

The differential intensities of neighboring pairs of NRF peaks are modeled using Kramer's Law : $\frac{I(E_1)}{I(E_2)} \approx \frac{E_2(E_0 - E_1)}{E_1(E_0 - E_2)}$

The signed relative error for the estimated areal density of isotope j is defined as: $\epsilon(\hat{A}_j) \equiv \frac{\hat{A}_j - A_j}{A_j}$

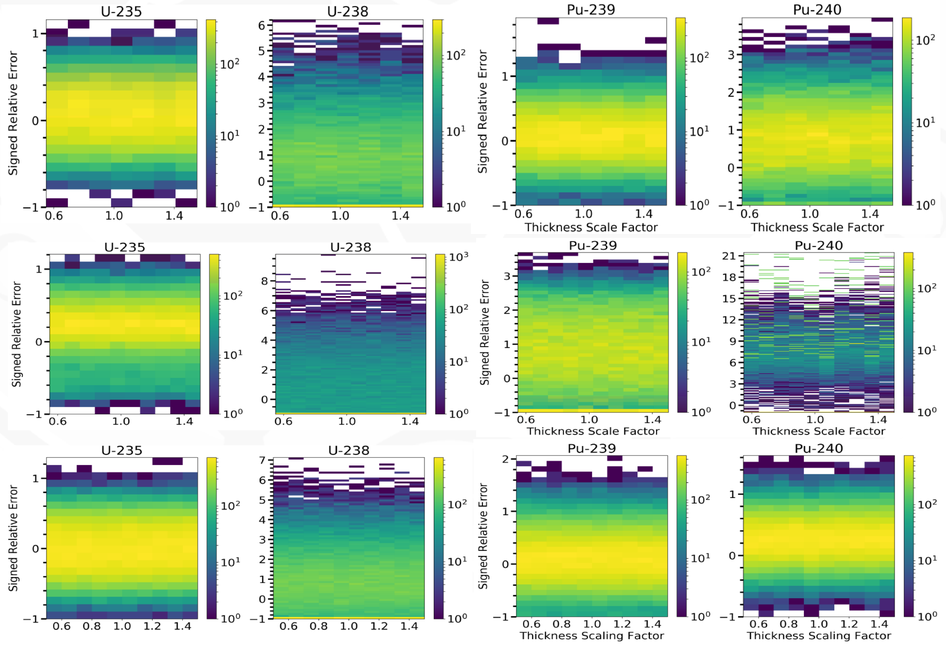

Figure 4. Error distribution plots for (i) 2.6MeV bremsstrahlung source, (ii) 2.16MeV bremsstrahlung source, and (iii) aged weapons-grade plutonium.

Mission Impact

This work supports the NNSA's mission to enable verifiable nuclear weapons reductions through CVT Thrust Area 5: Disarmament Verification.

The CVT enables engagement with academics, and national lab researchers, and fellow graduate students to facilitate the development of novel, information-secure verification protocols.

Conclusions

For 2.6 MeV endpoint energy bremsstrahlung beams, warhead areal density of U-235 and Pu-239 can almost always be estimated under 100% relative error, with larger errors for U-238 and Pu-240.

Lowering the source endpoint energy to 2.16 MeV effectively disrupts the inference procedure for Pu-239 and Pu-240.

Relative error on Pu-240 is lowered for warheads containing aged weapons grade plutonium.

While this verification protocol may be a powerful tool for verifying nuclear weapons, caution must be taken to mitigate or prevent the disclosure of sensitive information to inspectors through measurements.

References

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