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Arms Control Verification Technologies

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Abstract:
Nuclear arms control treaty verification scenarios present unique challenges which are not always present in safeguards. These challenges include safety related concerns when working on or near warheads, information security when measuring radiation output of weapon systems and unknown material compositions. Conversely, there are many areas in which arms control and safeguards overlap, such as authentication and certification concerns, quantification of trust or confidence and chain of custody.

Sandia National Laboratories is engaged in research and development activities aimed at enabling future arms control agreements. As part of this R&D effort, Sandia develops technical solutions in the areas of radiation detection, tamper indicating seals and unique identifying tags. Additionally, we develop tools for authentication and certification of treaty verification hardware, as well as participate in multilateral cooperative exercises aimed at exploring advanced approaches to potential future arms control scenarios. This paper presents an overview of these activities, as well as some ideas for future engagement.

Keywords: Arms Control; Verification; Treaty Monitoring

Introduction

Arms control and safeguards technologies play vital roles in each of the non-proliferation regimes that seek to reduce the spread and development of nuclear material and weapons. Arms control agreements and treaties seek to prevent vertical proliferation within a state that has already developed a nuclear weapon. These agreements aim to control the development, production, stockpiling, proliferation, distribution or the usage of a particular weapon type or its delivery systems. Safeguards are meant to prevent the diversion of dual-use technologies from peaceful uses to military applications. Both safeguards and arms control missions are accomplished using combinations of monitoring, detection, and verification technologies.

While the two technologies have similar goals and uses, there is currently an underutilization of arms control technologies. The amount of treaties and agreements that rely on arms control technologies is very small when compared to the relatively large volume of states and facilities that are currently monitored by safeguards technologies. To increase utilization, and thereby trust, in existing arms control technologies, efforts could be made to co-develop and/or implement arms control technologies into safeguards applications. The following presents an overview of some technologies developed by Sandia National Laboratories for the purposes of arms control verification, with the potential to offer novel capabilities to the safeguards regime.

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Application of arms control technologies in safeguards

Arms control technologies such as seals and tags are used to prevent access or tampering with previously verified materials. These devices are already widely used throughout the nuclear safeguards regime and serve as an example of the overlap in mission requirements between the arms control and safeguards regimes. However, detection systems such as those that monitor or characterize nuclear material are used differently within the two verification regimes. In arms control inspections, information barriers are typically used in conjunction with detection systems to reduce the amount of information gained by the visiting state in a survey or inspection. These systems are designed to allow for verification, with significant confidence,to conclude that host states are still beholden to their agreement obligations, without revealing sensitive information.

Current Applications

Currently, there are only two major arms control agreements in place, the Intermediate Range Nuclear Forces Treaty (INF) and the New Strategic Arms Reduction Treaty (New START). The INF Treaty was originally struck between the U.S. and Soviet Union to reduce tensions by eliminating all missiles with a range of 500 to 5,500 kilometers. The INF treaty was verified through a combination of satellite observations, on-site inspections and monitoring systems. However, the US is currently on track to withdraw from this treaty on August 2, 2019. New START sought to build off its predecessor the Strategic Arms Reduction Treaty (START) and further reduce offensive arms between the U.S. and the Russian Federation. This treaty has been verified using on-site inspections, along with data and telemetry exchanges on an agreed number of ICBM and SLBM launches. Unless extended, the New START Treaty will expire in February of 2021.

Thus far, neutron counters have been a primary means of absence verification in these bilateral arms control agreements. Figure 1 illustrates a neutron detector developed by Sandia National Laboratories for use in absence verification measurement procedures during New START inspections.

Figure 1 - Radiation Detection Equipment Developed for New START Absence Verification Measurements

In contrast to arms control technologies, safeguards technologies have been widely adopted for use by the International Atomic Energy Agency to ensure that nuclear material is not being diverted from peaceful uses to create nuclear weapons or explosive nuclear devices. As of April 2019, the IAEA implements safeguards in 182 different countries. These agreements between the host state and IAEA utilize a wide array of detection, monitoring and verification techniques. Where safeguards technologies are adopted by the IAEA, a foundationally multinational agency, arms control technologies have historically been developed in a closed bilateral negotiation process. The multilateral development approach for safeguards allows for states, as well as the international research community to become more familiar with current technologies and suggest improvements.

Proposed Applications

In an effort to provide solutions for potentially moving beyond absence verification via neutron counting, Sandia National Laboratories has worked to develop several concepts for warhead confirmation. These concepts can often be grouped into one of several categories of arms control technologies: Template Measurement Systems, Attribute Measurement Systems and the Zero-knowledge Protocol. From the initial concept stage of the development lifecycle, the design methodologies for these technologies consider the inevitable authentication and certification process that would precede adoption into any arms control treaty.

An example template measurement system is the Trusted Radiation Identification System (TRIS) [1]. TRIS utilizes a trusted processor with information barrier to measure a gamma radiation spectrum from an item of interest, compares that against previously acquired spectral templates, and gives a general yes/no/failure indication to an inspector (Figure 2). This method is able to perform highly intrusive gamma spectral analysis without ever revealing sensitive information to an inspector.

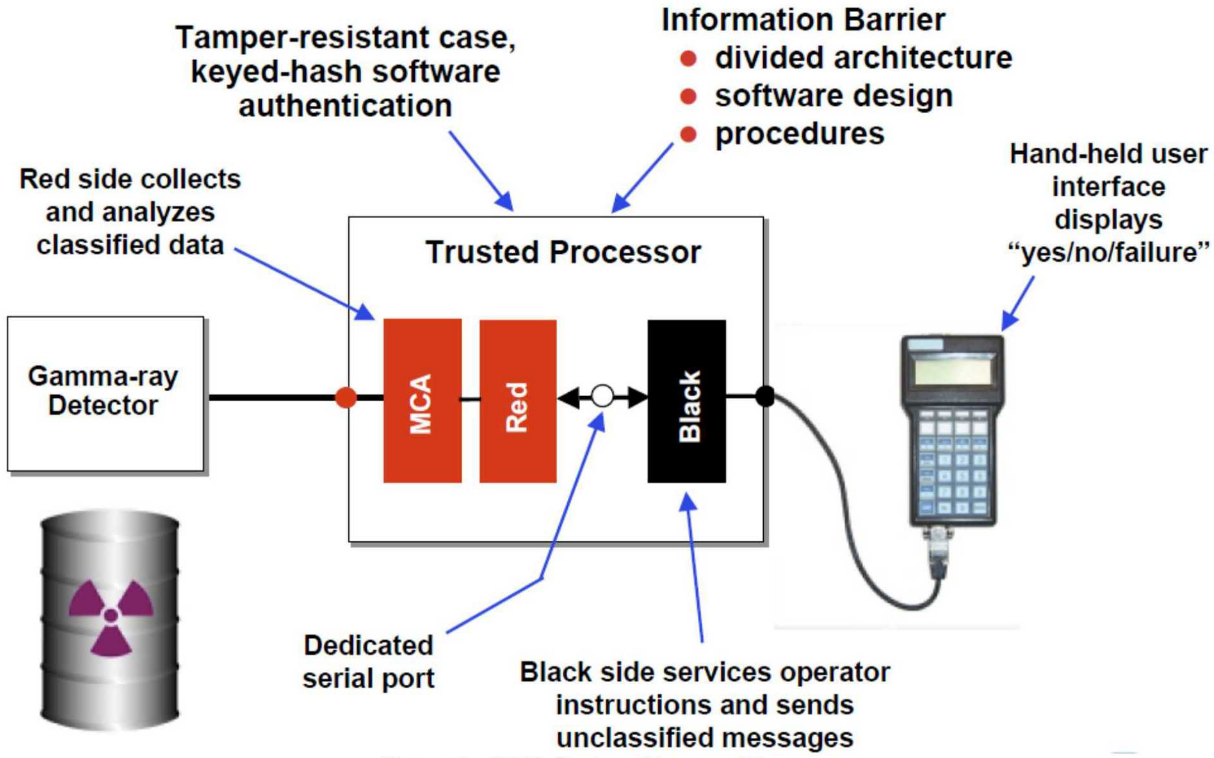

Figure 2 - TRIS System Diagram [2]

The Minimum Mass Estimates for Plutonium Algorithm [3] is an example of what we consider an attribute measurement system. The intent of these systems is not to exactly match an object of interest to an exemplar template, rather to confirm the presence of a material of interest, in this case weapons grade plutonium. This algorithm is capable of demonstrating that an inspected item contains more than a deliberately low amount of plutonium or simple neutron source, without revealing sensitive weapons design information.

The key aspects for this algorithm are to confirm that the amount of plutonium exceeds a declared threshold and the ratio of Pu-240 to Pu-239 is consistent with weapons-grade plutonium, using only high purity germanium measurements. This is achieved via spectral deconvolution, which enables estimations of Pu-240/Pu-239 ratios as well as the amount of scattered source radiation (Figure 3).

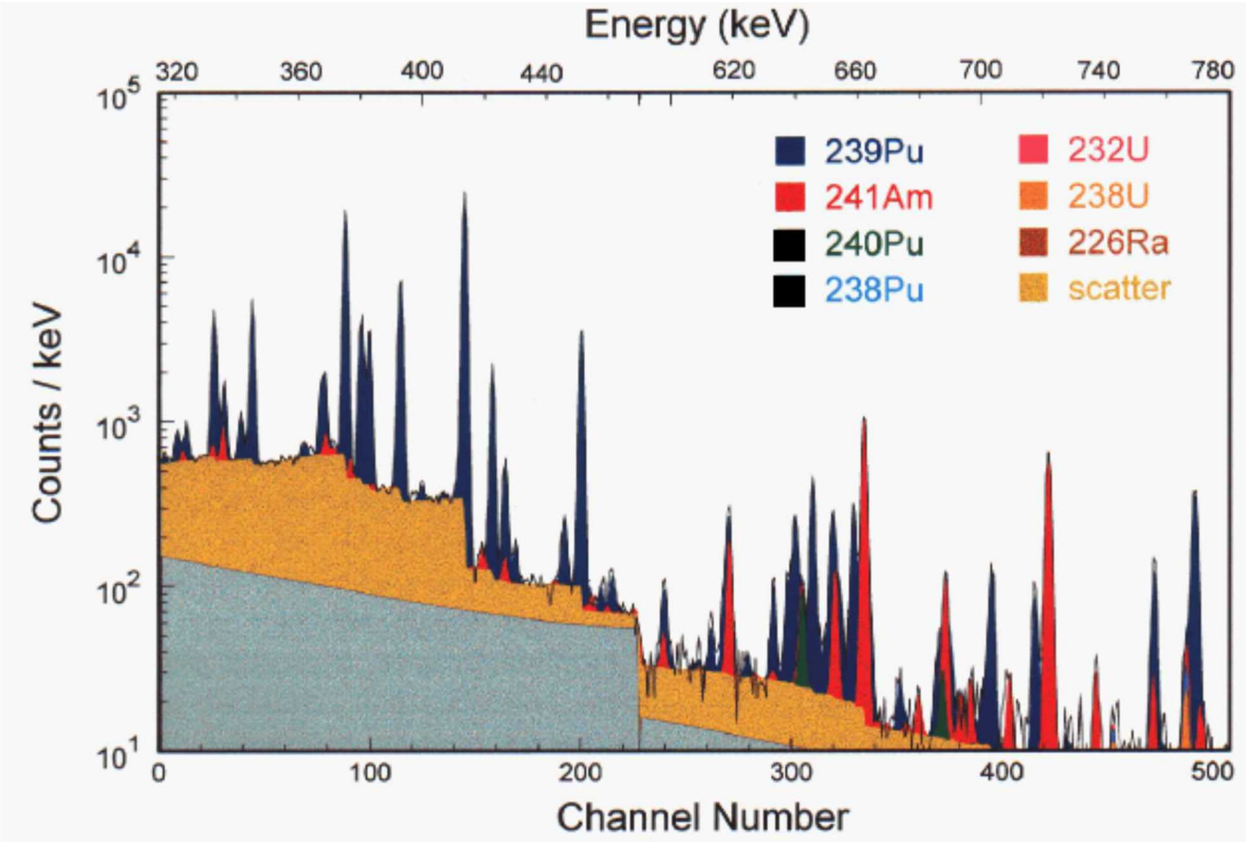

Figure 3 - Plutonium Spectral Deconvolution for Minimum Mass Estimate [3]

A concept which combines aspects of both template and attribute measurement systems is the Unclassified Radioisotope Algorithm [4], which avoids the collection and storage of a potentially sensitive gamma spectrum upfront, processing each incoming pulse in list mode. By constructing simple weight arrays (consisting of -1, 0 or +1 weight values) of desired and undesired pulse heights prior to a measurement, you can then construct scalar values from a set number of pulses counted (Figure 4).

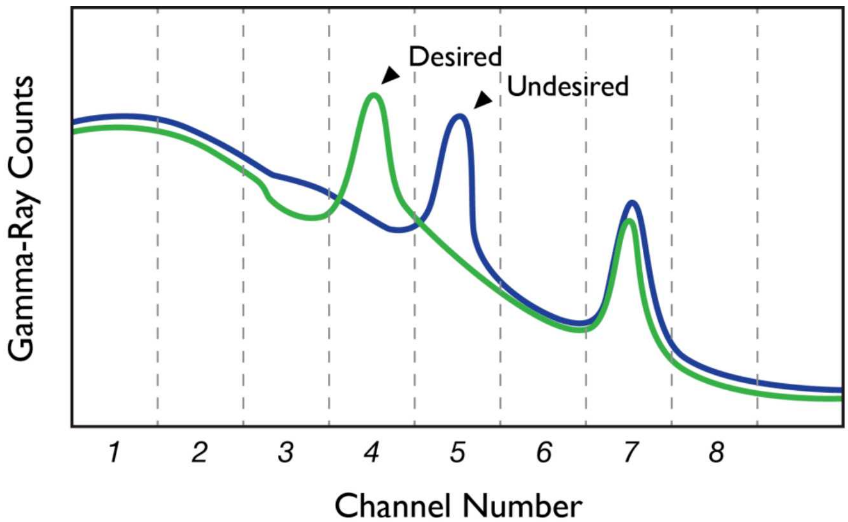

Figure 4 - Desired vs. Undesired Spectra

These scalar weight values at the end of a measurement can then be compared to expected scalar values from both desired sources (e.g. weapons grade plutonium) and potential undesired sources (e.g. reactor grade plutonium). By weighting and de-weighting appropriate regions of the spectra, clear discrimination even in the presence of shielding between desired and undesired sources (Figure 5) can be achieved without ever recording sensitive information such as a gamma radiation spectrum.

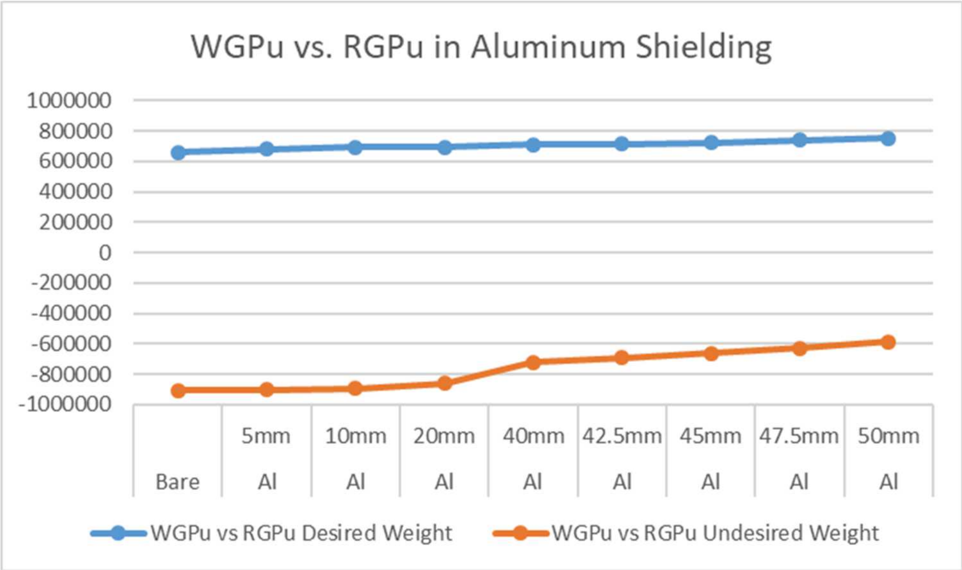

Figure 5 - Unclassified Radioisotope Algorithm Performance Estimate

An alternate approach to warhead verification which does not require a prior knowledge of the treaty item characteristics, or the recording and processing of sensitive data, is the Zero Knowledge Protocol. An example of this is CONfirmation using a Fast-neutron Imaging Detector with Anti-image Null-positive Time Encoding (CONFIDANTE). This concept uses time encoded imaging with an anti-image null-pattern coded aperture to compare two radioactive objects declared to be equal (Figure 6).

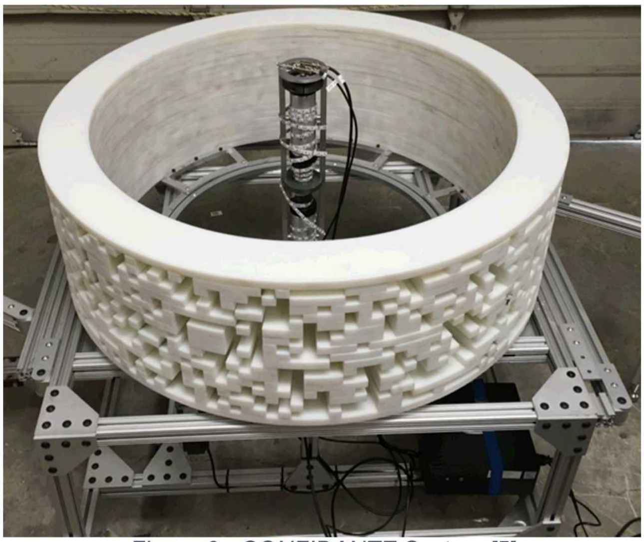

Figure 6 - CONFIDANTE System [5]

The idea with CONFIDANTE is that each open aperture on one side will have a closed aperture exactly opposite, and vice versa. Therefore, if the two items are identical, the net count rate from the single pixel detector located in the center of the cylindrical coded aperture array would be consistent with Poisson noise (Figure 7). This approach enables relatively high resolution imaging, yet avoids the measurement and storage of sensitive information.

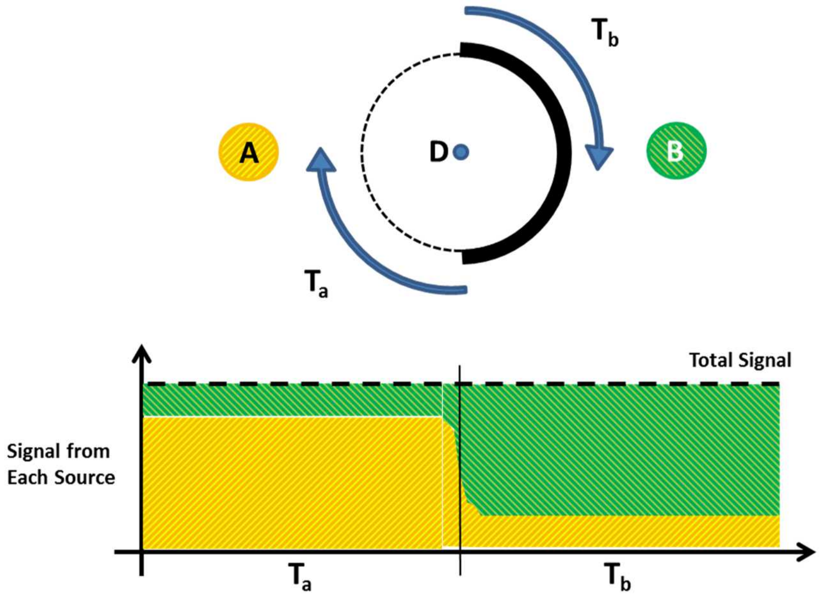

Figure 7 - Null Image Concept [5]

Challenges with implementation

A potential downside to utilizing arms control technologies in safeguards applications might involve potential competition between the two technologies. Rather than performing a competitive downselect of the two, both technologies can be used in conjunction. A greater level of confidence can be reached regarding compliance if a state passes multiple independent compliance tests. Additionally, having multiple systems capable of measuring similar phenomenologies can offer increased operational flexibility for off-normal situations. However, with increased verification efforts comes increased costs.

To reduce the financial strain placed on the IAEA for implementing safeguards, arms control technologies can potentially be used to reduce the amount of inspection visits. Inspection visits can be reduced by implementing both types of technologies to increase compliance confidence between inspections. By subjecting a country to increased monitoring using both technologies, a lower amount of inspections might be needed to verify compliance. In some scenarios, states may feel this method of verification to be less intrusive since site operations will not be hindered by the on-site inspections. The perceived reduction in intrusiveness also provides a greater feeling of autonomy and privacy to the state. This scenario can be used to ease new safeguards signatories into more intrusive and comprehensive modes of verification, and eventual arms control agreements after trust is built. This may be an effective way for arms control talks to resume as current agreements like the INF and New START expire within the next few months and years.

Conclusion

Despite the appreciable differences in the arms control and safeguards verification regimes, such as information sensitivity, operational constraints and the sheer volume of use cases, the driving requirement for open development (i.e. the ability to authenticate and certify a verification technology for use in a treaty verification scenario) can lead to the development of algorithms and technological solutions which are inherently exportable and easily transferred to international treaty partners. By encouraging technological cross-talk between arms control and safeguards, the resulting increased usage can ultimately lead to increased confidence and trust in the arms control systems. Thus, increased familiarity with well-documented technologies can encourage the adoption of more rigorous verification technologies, resulting in more secure confidence building treaties.

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