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Author(s): Hauck, Danielle K.
MacArthur, Duncan W.

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Benefits of a "Presence of Fissile Material" Attribute for Warhead Confirmation in Treaty Verification

Danielle K. Hauck and Duncan W. MacArthur
Los Alamos National Laboratory, MS E540, Los Alamos, NM 87545

ABSTRACT

Recent work in attribute measurements for treaty verification has resulted in a growing list of potential warhead attributes and increasingly complex measurement methods for confirming them. However, the ability to successfully negotiate a monitoring regime is often inversely related to the number of attributes and the complexity of their measurement methods. We suggest that instead of increasing the number of detailed attributes, we cut directly to confirming the defining property of a viable warhead pit; the presence of fissile material. We review the benefits and plausibility of warhead confirmation based on two attributes only: the presence of fissile material and the presence of high explosives. We also provide a preliminary review of the technical options for confirming the presence of fissile material and the associated technology-based and potential policy-based challenges to implementation.

INTRODUCTION

The verification approaches used in existing arms reduction treaties do not involve measurements to confirm that an item is a warhead. For example, while New-START is a bi-lateral agreement intended to limit the number of warheads, the verification strategy is focused on limiting delivery vehicles that are carrying the warheads in question and confirming that no delivery vehicles are carrying undeclared nuclear warheads. Therefore, the primary measurement challenge associated with New-START is to confirm that items *are not* warheads.

Depending on the path of future arms control treaties it could become important to confirm that certain items *are* warheads. Potential monitoring regimes requiring warhead confirmation include verified dismantlement and warhead lifecycle monitoring. In the former, items may be confirmed to be warheads prior to being dismantled, and in the latter, movements of items that are declared to be warheads might be monitored over long periods of time.

Confirming that a declared item *is* a warhead is relatively complicated compared to the political-technical exercise of confirming that an item *is not* a warhead. The state-of-the-art in determining if an item is a nuclear device lies in the emergency response community and is well-developed. However, in an arms control scenario, details regarding mass, physical arrangement and composition of fissile material (FM) and high explosive (HE) are sensitive weapon design information that must be protected by the host country. The warhead confirmation challenge within treaty verification arises from the host party's goal to provide the monitoring party with appropriate confidence that the item is a warhead *without* revealing sensitive design information.

One possible approach to warhead confirmation is attribute measurement.[1] Negotiated characteristics (or attributes) of the item are measured and a non-sensitive display of the results is shared with the monitoring party. The attributes are chosen to demonstrate that the item is reasonably consistent with a legitimate warhead. To render the attribute display non-sensitive, measured values are often compared to negotiated thresholds. Attribute measurement systems (AMSs) have not been used in treaty verification to date. However, several AMSs have been developed for testing and evaluation purposes. The attributes that have been used in previous and on-going AMS development projects include:

- Presence of plutonium (Pu) [2,3,5,6,7]
- Mass of Pu greater than 500g [2,3,4,5,6,7]
- Pu-239/Pu-240 ratio greater than 0.9 [2,3,4,5,6,7]
- Symmetry of the Pu [2]
- Pu age (i.e. time since separation of Am from Pu) greater than 25 years [2,4]
- Absence of oxide [2]
- Presence of uranium (U) [3,6]
- Mass of HEU greater than 25 kg [3,6]
- Enrichment of uranium greater than threshold [3,6]
- Presence of HE [3,6,7]
- Mass of HE greater than threshold [3]

Some attributes require more than one measurement technique to arrive at a final answer and the measurement systems can grow to be quite complex. Early AMS designs focused on confirmation of the Pu-based attributes. However, the desire to extend attribute measurement capability to include HEU-bearing items has resulted in additional potential attributes for the presence, enrichment and mass of HEU. The HEU attributes are significantly more difficult to measure, adding to the intrusiveness of the monitoring regime. Several complex measurement approaches are being suggested for confirming the presence and mass of HEU, including imaging and combinations of gamma spectroscopy, passive neutron counting and active neutron counting.

The ability to negotiate a monitoring regime is often inversely related to the number of attributes and the complexity of their measurement methods. For an attribute to be viable the host party has to be willing to declare that the monitored warheads have that property. A host country may be uncomfortable with allowing a monitoring country to confirm several different attributes, especially on a series of identical warheads.

Viable warhead confirmation in a host facility requires the ability to measure attributes that are simultaneously less intrusive and provide greater confidence in warhead identity. We suggest that instead of increasing the number of detailed attributes (and hence, both measurement system complexity and regime intrusiveness), we go directly to confirming these simple properties of a viable warhead pit;

- Presence of FM, and
- Presence of HE.

Warhead confirmation based on the presence of both FM and HE would be both plausible and useful. These attributes are less intrusive and, potentially, at least as definitive as more conventional attributes. The simplified FM attribute (as opposed to separate Pu and HEU attributes) eliminates the need to declare the types of FM in the warhead.

Measurement systems are currently available for confirming presence of HE, such as the Portable Isotopic Neutron Spectroscopy (PINS) System, developed at INL and commercially available from Ortec. [8] The PINS system is based on the presence of hydrogen and nitrogen in ratios consistent with high explosives. Confirming presence of HE is at least as difficult as confirming presence of HE and additional research into would be useful. However, the remainder of this paper is dedicated to the issues around implementing a "Presence of FM" warhead attribute.

The definition of FM in the field of nuclear engineering is a material that can be induced to fission by neutrons of any energy and encompasses a broad range of isotopes including U-233, U-235, Np-236, Np-238, Pu-236, Pu-237, Pu-239, Pu-241, etc. [9] For verification purposes FM could be defined based on material composition in the same vein as the IAEA guidelines for the definition of HEU (20% U-235) and "weapons grade" Pu (90% Pu-239). [10] However, we suggest a "Presence of FM" attribute in which FM is defined as a material that can sustain an explosive fast neutron chain reaction, and therefore be viable for use in the fission primary of a weapon. This is the definition of FM which will be used in the remainder of this paper. The primary isotopes of interest according to this definition are U-235 and Pu-239, although additional isotopes such as Np-237 are also viable. [11]

METHODS FOR CONFIRMING PRESENCE OF FM

The research path for most attribute measurement development is to first identify quantities that can be measured using existing techniques, and second to consider which of these quantities may be a useful indicator for a warhead. We suggest the opposite approach of identifying an attribute (e.g. presence of FM) that would be both useful and viable for warhead confirmation and then challenging the community to identify a technical means to confirm the attribute. We feel that "presence of FM" is a useful attribute which warrants additional research into potential measurement approaches.

Table 1 provides a preliminary list of approaches that can be used to confirm "presence of FM" with various degrees of confidence. For example, confirming that a material multiplies neutrons does not guarantee the presence of FM, but it does provide strong evidence for its presence. Table 1 is not intended to be an exhaustive list of measurement approaches. Some of the potential measurement approaches are discussed briefly below, organized by the material characteristic that they can be used to confirm, and which provide evidence for "Presence of FM". The discussed measurement approaches vary in their degree of technical readiness and the degree of confidence provided by a measurement approach also depends on the quality of the measurement and the analysis method used.

Table 1. Measurement approaches that can provide some degree of certainty in the presence of FM. The primary goal is to confirm the presence of FM according to the common arms control definition, that is, the presence of material that can be used in the fission primary of a nuclear warhead.

Measurement Approach	Confirms
Gamma spectroscopy (potentially not sensitive enough to detect U-235)	Presence of Pu-239 or U-235
Neutron interrogation and neutron counting to confirm neutron multiplication	Presence of material that multiplies neutrons
Neutron interrogation and gamma spectroscopy to confirm presence of fission product gamma rays	Presence of material that undergoes fission when induced by neutron interrogation

Presence of Pu-239 or U-235

The "presence of Pu-239" and "presence of U-235" are usually considered separate attributes. However, one option for confirming presence of FM is to define it as a single attribute "presence of either Pu-239 or U-235". It is not necessary that the presence of Pu-239 and U-235 be detected using the same measurement approach.

The presence of Pu-239 can usually be confirmed through passive gamma spectroscopy. The presence of U-235 can be obtained from passive gamma spectroscopy in circumstances of low self-shielding by U or other dense materials. In that situation, passive gamma spectroscopy could be used to check for presence of either Pu-239 or U-235, which can then be reported as a single attribute.

However, in many warheads passive gamma spectroscopy is not feasible for detecting U-235, and it might be necessary to use two different measurement approaches for Pu-239 and U-235.

Presence of material that multiplies neutrons

The multiplication of neutrons is not a unique indication of FM, given the existence of other types of neutron multiplying sources (e.g. isotopes that undergo (n,xn) reactions). However, neutron multiplication is a strong indicator of FM. Correlated neutron counting can be used to confirm neutron multiplication. The quality of the neutron counting measurement and the sophistication of the analysis method will determine the ability to differentiate between plausible warhead materials and other types of neutron multiplying sources. Detecting neutron multiplication from U-235 would likely require active interrogation with a neutron source.

The degree of neutron multiplication and length of fission chains following a neutron pulse indicate the presence of material that can sustain a neutron chain reaction, which provides higher confidence in the presence of FM than simply the presence of neutron multiplication. However, additional details of the approach need further research and agreed thresholds on neutron multiplication or fission chain length may be needed.

Presence of material that undergoes fission when induced by neutron interrogation

The presence of fission product gammas following neutron interrogation indicates that the material in the item underwent fission. This approach confirms that the item contains fissionable material, but does not confirm the presence of material that can sustain a chain reaction. (This approach to confirming the presence of fissioning material is very similar to the Nuclear Car Wash. [Ref])

Active neutron counting and neutron induced gamma spectroscopy could be combined to simultaneously confirm that the material undergoes fission and multiplies neutrons. This combined approach may provide the best confidence in the presence of FM using existing technologies. However, the potential need for measurement thresholds and details of the approach for this application require further research.

Presence of material that can be used in the fission primary of a nuclear warhead

A measurement technique to confirm that an items contains material that is viable for the fission primary of a nuclear warhead would be valuable. There are three primary issues that must be addressed to directly confirm presence of FM: (1) development of a measurement approach which is technically capable of confirming presence of the FM, (2) the sensitivity of the constraints which make material viable for use in a primary and (3) the dependence of material constraints on the engineering sophistication of the warhead. A material's usability as a fission primary depends on the composition of the material, the configuration after ignition, and the total mass of the material, all of which are sensitive information and all of which depend on the design of the warhead.

MEASUREMENT ISSUES

Any measurement methods used to confirm the presence of FM would have certain constraints and complicating issues in common.

- **Active measurements** – most of the plausible approaches to detecting HEU will involve an active measurement with an interrogation source, most likely a neutron source. Measurement approaches should avoid increasing dose to workers. Safety certification for the facility will be more difficult with active measurements.
- **Information barrier** – any measurement methods must be automated behind an information barrier to prevent release of any measurement data other than the agreed attributes.
- **Unclassified algorithms** – The algorithms used to determine the attribute results must themselves be unclassified (unless an agreement to share classified information is

implemented). Therefore, the algorithms cannot use warhead design information to create a robust measurement technique.

- **FM configuration** - The FM in warheads is in a different configuration prior to operation is and altered (e.g. through gun-type or implosion devices) to create a super-critical assembly. Properties of the material (e.g. degree of neutron multiplication) prior to initiation would depend on the warhead design.

SUMMARY & CONCLUSIONS

Future treaties may require the ability to confirm that items are warheads without releasing design information. One of the approaches to warhead confirmation is attribute measurement. Negotiated characteristics of the item are measured and the results are shared with the monitoring party. Recent work in warhead confirmation has resulted in a growing list of potential warhead attributes and increasingly complex measurement methods for confirming them. The ability to negotiate a monitoring regime is often inversely related to the number of attributes and the complexity of their measurement methods. We suggest an alternative approach of using presence of both FM and HE as attributes for warhead confirmation.

Confirming presence of FM is non-trivial. A measurement approach combining presence of fission products and presence of neutron multiplication may provide the best confidence in the presence of FM using existing technologies. However, the potential need for measurement thresholds and details of the approach for this application need further research. Certain measurement issues will need to be addressed, such as the need for active measurements and developing automated and non-sensitive algorithms to evaluate measurement data and output an attribute result.

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