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Confirmation of Nuclear Treaty Limited Items: Pre-dismantlement vs. Post-dismantlement

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Abstract:

One of the key factors in verification of future nuclear disarmament treaties will be the confirmation, by a monitoring party, that declared treaty limited items (TLIs) are consistent with the declaration made by the host country. A significant part of this confirmation is supplied by a radiation measurement system that confirms the declared radiation characteristics of the TLI. These radiation measurements can take the form of measuring declared attributes of the TLI, comparing declared TLIs with a pre-existing template, or some combination of the two techniques. Treaties including TLI dismantlement form an important subset of general disarmament treaties. In a dismantlement scenario, the required radiation measurements can be performed either before or after the TLI is dismantled (or at both times). Pre-dismantlement measurement may give additional confidence that the item is truly a TLI but may be technically challenging while post-dismantlement measurement can offer additional confidence that the item has been truly dismantled. Since repeated measurement increases monitor confidence and there are technical advantages to both measurement times, a combination of pre-dismantlement and post-dismantlement measurement will lead to the highest overall confidence. The relative importance of the two types of measurement is directly dependent on the specifics of the treaty under discussion.

Keywords: nuclear; disarmament; attribute; template; dismantlement

1. Nuclear Arms Reduction Treaties

Most treaty monitoring scenarios can be reduced to two requirements, one for the host party and one for the monitoring party:

- The owner of nuclear material or a device (the host party) makes a declaration concerning that item (the treaty-limited item or TLI) and/or its disposition to another entity (the monitoring party).
- The monitoring party must confirm this declaration without observing any sensitive information. By sensitive information, we mean classified information that the two parties do not intend to share.

The crux of the treaty-monitoring measurement challenge lies with the phrase “without observing any sensitive information.” Traditional nondestructive assay (NDA) techniques (based on gamma-ray detection, neutron detection, or calorimetry) are widely and successfully used in numerous scenarios (e.g., waste assay and spent fuel monitoring) that do not involve classified information (unlike treaty monitoring). [1]

Nuclear arms reduction treaties in force today are generally based on the number of delivery vehicles. [2] The use of radiation detection in verification of these treaties is limited to confirming that items are not weapons—lack of radiation levels above background is taken as evidence that an item is not a nuclear weapon. However, it is possible that future monitoring regimes will include warhead confirmation and/or monitored dismantlement. In both cases, it is necessary to confirm that a declared TLI is indeed a warhead. In the remainder of this paper, we address some of the issues surrounding warhead confirmation in a monitored dismantlement scenario.

The host party is responsible for certification of the measurement system and monitoring regime. This certification will include **information certification** (that sensitive information will not be divulged), **facility certification** (that all facility safety and security regulations have been met), and **nuclear explosive safety certification** (that the measurement system and process are acceptable for use on the host's declared TLIs). The certification challenges associated with allowing a monitor to confirm that an item is a warhead are much more complex than those associated with confirming that an item is not a warhead. In particular, warhead confirmation involves radiation measurements on sensitive nuclear items, and identifying defining characteristics of these items--both of which could reveal sensitive information.

Similarly, the monitoring party is responsible for all steps required to build monitoring party confidence in the measurement system and its use within the monitoring regime; a process generally termed authentication. Regime authentication will include consideration of **measurement system authentication** (that the measurement system is making the agreed upon measurements) and **protocol and procedures authentication** (that the treaty protocol and procedures allow for independent confirmation of the host's declaration). Other authentication concerns include the **context and environment** in which the system will be operated (discussed briefly below in section 2.1), and maintaining knowledge of location (termed chain of custody or **CoC**) of the TLI, measurement system, and calibration sources. The additional limitations on the monitoring regime that are prompted by the host's certification of warhead measurements make it more difficult for the monitoring party to maintain confidence in the monitoring regime and its results.

Arms reduction treaties are often reciprocal and each party must verify each other's declarations. Thus, each country will play the role of both host and monitor during the course of the treaty. In particular, each authentication or certification technique proposed for a given host/monitor pairing must be evaluated by both countries for its impact when the roles are reversed.

Although many of the specific examples in the remainder of this paper refer to the monitored dismantlement scenario, the concepts, and in particular the measurement concepts, apply more generally to treaties involving warhead (as opposed to delivery vehicle) confirmation. In sections 2 and 3, we will review dismantlement and measurement concepts while in section 4 we move on to a discussion of the timing of confirmation measurements.

2. Dismantlement Treaty Verification

As noted above, treaty verification generally involves confirmation of a TLI declaration or confirmation of a disposition declaration. Within a monitored warhead dismantlement treaty, these become warhead confirmation and dismantlement confirmation.

For the purposes of this discussion, we will define dismantlement of a nuclear weapon as the separation of fissile material (FM) from high explosive (HE). Given this definition, dismantlement confirmation can be achieved by demonstrating FM presence and HE absence in the declared FM container along with confirming that there is no FM in other containers or remaining in the dismantlement area. If HE were tracked, similar confidence could be achieved by confirming presence of HE and absence of FM in the declared HE container and no HE elsewhere—however, "no HE elsewhere" is very difficult to confirm practically. It is easier to detect and track undeclared FM in containers and large areas. Dismantlement confirmation, regardless of method, obviously must occur "post-dismantlement."

As described above, a combination of presence and absence measurements can be used to confirm that a nuclear item has been dismantled. Confirming that that a declared item is a nuclear warhead is the more difficult to the two problems. As shown in Figure 1, there are four points at which confirmation measurements might be performed on a declared warhead: (1) upon entering the monitoring regime, (2) somewhere within the CoC regime, (3) immediately prior to dismantlement, and (4) immediately after dismantlement. We will discuss the options for when to perform warhead confirmation measurements and the influence of other aspects of the monitoring regime (such as CoC) on these timing choices (and *vice-versa*). Warhead confirmation measurements are important not only to confirm that the item being monitored is indeed a warhead, but also that the item that is dismantled was indeed a warhead.

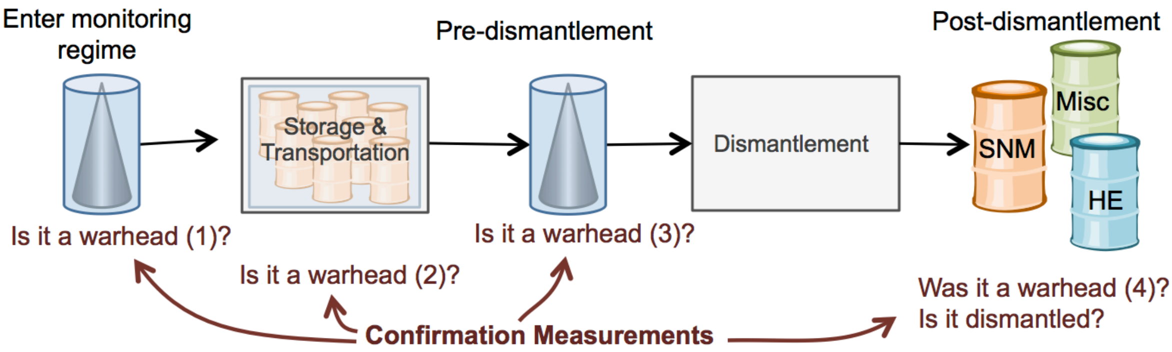

Figure 1. Schematic representation of a possible dismantlement regime identifying potential confirmation measurements. The dismantlement process is shown as a black box as it is anticipated that the host country will consider the details of this process sensitive.

3. Confirmatory Measurements

We have identified three primary methods to warhead confirmation. These are:

• **Attribute Measurements**: Are specified item properties consistent with it being a warhead?
• **Template comparison**: Is the item consistent with other items known or believed to be warheads?
• **Provenance**: Has the item undergone movements or come from a location consistent with being a warhead?

The first two methods are measurement-based and are described in detail below. The third approach is to use the provenance of the item as evidence that it is a warhead, and to maintain continuity of knowledge on the item through the remainder of the monitoring regime. Even if any one of these methods produces relatively low assurance, all three can be used in combination to increase monitor confidence. The host's definition of "sensitive information" limits all three techniques, but each is limited in a different way.

In this paper, we focus on measurement methods (both attribute and template) and mention provenance only in passing, even though provenance may be an important source of confidence and can be used in conjunction with the warhead confirmation measurements discussed here. [3]

3.1. Information Barriers

Confirmatory measurements often involve the collection of sensitive data. The measurement system must report the non-sensitive results, while simultaneously protecting any intermediate data required for the measurements. A key component of confirmation measurement systems is the information barrier (IB). [4] The IB is a series of controls that ensures that no sensitive information is released during a measurement and, simultaneously, that the monitoring party is able to independently confirm the host's declaration concerning the measured TLI.

A conceptual drawing of a generic measurement system incorporating an IB is shown in Figure 2. In practice, an IB would not be the single shell shown below—a practical IB includes layers of hardware, software, and procedural protection to provide a barrier system that, as a whole, are fault resistant and the components of which are fault tolerant.

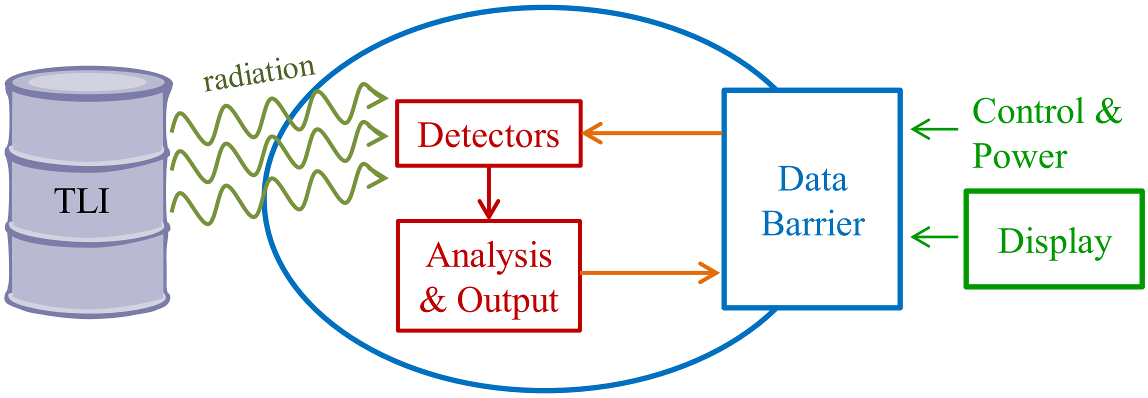

Figure 2. Schematic representation of an information barrier (IB) for a generic measurement system. All potentially sensitive information (contained in parts of the system shown in red) is contained within the IB (blue) while the monitors (green) are outside of the IB. In an attribute measurement system the IB prevents the release of any information other than the attribute results. In a template comparison system, the IB prevents the release of any information other than positive or negative results of a successful comparison.

Unfortunately, the same IB system that excels at protecting the host party's classified information also excels at "protecting" the monitoring party from any information that could be used to confirm the host party's declaration. Attribute measurement (discussed in section 3.2) and template comparison (discussed in section 3.3) are both ways of presenting useful non-sensitive results based on sensitive data.

3.2. Attribute Measurement

One approach to confirming that an item is consistent with a warhead with a carefully controlled release of information about the TLI is to use an attribute measurement system (AMS). Attributes, as defined here, are unclassified indicators of potentially sensitive measurement results. Potentially sensitive information can be made into an attribute by comparing the information with a threshold, e.g., the attribute is "quantity above threshold." Some potential attributes are:

- the presence of nuclear material,
- having a nuclear material mass above a threshold,
- having a plutonium isotopic ratio below a threshold, or
- having a uranium enrichment above a threshold.

In any fielded implementation of an AMS, the host and monitoring parties would agree on the attributes to be measured (as well as the details of the AMS itself). The confidence generated by an AMS is only as high as the confidence that the chosen attributes uniquely define a warhead. The choice of attributes is very important—not only must the attribute display be non-sensitive, but the reason for choosing that attribute must also be non-sensitive. Thus, negotiated attributes are often bounded by sensitivity concerns and may not be capable of providing a high level of confidence in warhead identity.

A number of AMSs have been built and demonstrated for international audiences in the last 15 years. Three significant examples are:

- *Trilateral Initiative Demonstration system* - designed and built in the U.S., measured 3 attributes, demonstrated for IAEA and Russian representatives, focus on information barrier capability. [5]
- *Fissile Material Transparency Technology Demonstration* (FMTTD) – designed and built in the U.S., measured six attributes; demonstrated to Russian and U.S. government representatives, focus on certification and information security. This is the only AMS where a classified weapon component was measured in front of an uncleared audience. [6]
- *Attribute Verification system for Neutrons and Gammas* (AVNG) - trilaterally designed (VNIIEF, IAEA, LANL/LLNL), jointly developed (VNIIEF, LANL/LLNL) and built in Russia, measured three attributes, demonstrated for a U.S. audience, focus was on certification. [7]

An AMS performs independent measurements on each item. Thus, the confirmation (or lack thereof) of each declared item is completely independent of measurements on other items. Since each measurement stands alone, no long-term storage of classified information is required. As long as the same attributes are declared, the measurement system can be used with several types of TLI or the same TLI in different containers. Finally, there can be a good match between the declared characteristics of the TLI and what is actually measured.

3.3. Template Comparison

Another approach to the challenge of generating monitor confidence is to use template matching. In this case, a potentially sensitive signature (most often a radiation signature) from one declared TLI is compared with a similar signature from an item known to be a TLI. This comparison can generate a high level of confidence that two items are identical or that a given item is unchanged. Since the template and individual results are not shown to the monitoring party, the template itself can contain sensitive information.

Several template-matching demonstrations occurred over the same 15-year time frame as the AMS development discussed above. Of note are:

- *Trusted Radiation Identification System* (TRIS) that was a U.S. developed system designed to provide a means to use low-resolution gamma-ray spectral measurements from sodium iodide (NaI) detectors to confirm the identities of declared material. TRIS compares the radiation signature of an inspected item with a known standard for a weapon or component of the same type. [8]
- A *template-matching demonstration* with classified canned subassemblies in containers was held in the U.S. in 1999. In this demonstration reference signatures were acquired for two containers with different items with the Russian delegation present. The signature was obtained for a third item in the third container and it was shown to match one of the reference signatures. This comparison was displayed on the computer screen for viewing by a Russian delegation with the ordinate scrambled.
- A similar *template-matching demonstration* was performed with three classified plutonium metal parts in containers at VNIIEF for a US delegation with the same display of the ratio of signatures with the ordinate scrambled.

In a template comparison, two items can be compared without ever releasing the template itself. The major advantage of this is that a template can incorporate a broad range of potentially sensitive radiation signatures (or other item features) and can result in high confidence that two items are nominally identical. However, template comparisons require long-term jointly controlled storage of sensitive information. The information barrier in this scenario must include a robust methodology for storing and comparing sensitive information without unintended release.

Since templates can result in high confidence that two items are nominally identical, templates have a large potential role in maintaining CoC. [9] However, for the purpose of warhead confirmation, confidence in a template comparison is only as high as confidence that the comparison copy is legitimate. In addition, whereas attribute measurements result in independent confidence levels for each warhead, template comparisons result in correlated confidence levels for each item. Confidence (or lack thereof) in the legitimacy of the comparison copy automatically transfers to the level of confidence in the accuracy of warhead confirmation for an entire series of items.

4. Timing of Warhead Confirmation Measurements

As illustrated in Figure 1, warhead confirmatory measurement can be performed at four different times within the dismantlement process. As described below, each of these times has specific advantages and disadvantages. The different approaches to warhead confirmation (templates, attributes, provenancing or a combination thereof) offer different levels of confidence at different times; thus, the details of a warhead confirmation measurement will influence optimum timing of that measurement.

The timing of a confirmation measurement can also result in a trade-off between measurement complexity and CoC complexity. The availability of CoC tools and item provenance must be taken into account when determining the optimum times to perform warhead confirmation measurements. CoC can be maintained during storage and transportation using a combination of visual observation and tags and seals. Maintaining CoC through the dismantlement process requires more elaborate measures such as the “room within a room” discussed in another paper at this conference. [10]

4.1. Pre-dismantlement – Entry into Monitoring Regime

We define entry into the monitoring regime as the time when the monitoring party has the option to begin maintaining CoC on the item. We do not assume that warhead confirmation measurements are necessary to “initialize” an item into the monitoring regime but that this entry time is one potential time to perform confirmation measurements. Confirmation measurements could be based on attribute measurement or template comparison or both.

Performing confirmation measurements upon entry into the monitoring regime provides the monitor with immediate confidence that an item is as declared. Otherwise, an item may be present (and potentially tracked) within the monitoring regime for many years before achieving confidence that it is a TLI. In addition, if the item has a known useful provenance (in this case, useful means that the provenance provides evidence that the item is a warhead), then immediate warhead confirmation measurements together with the provenance may be the best way to provide strong confidence that the item is as declared.

The timing of the warhead confirmation measurements has ramifications for the importance of maintaining CoC. If confirmation upon entry into the monitoring regime is the only warhead confirmation measurement prior to dismantlement, then CoC between entry into the regime and dismantlement is extremely important. If, on the other hand, the item does not have a useful provenance and if the movements within the regime are not useful for confirming that the item is a warhead, then it may not be important to perform warhead confirmation measurements at entry into the monitoring regime; in this case, the importance of CoC at any time prior to the first warhead confirmation measurements is minimized.

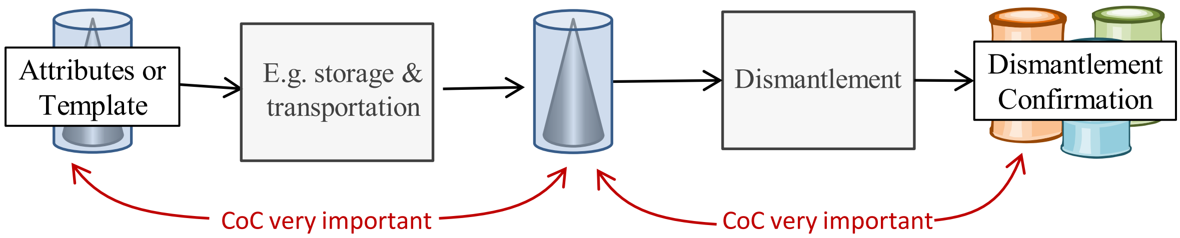

Figure 3. Ramification on CoC for performing warhead confirmation measurements upon entry into the monitoring regime. If there is only one set of warhead confirmation measurements, CoC between those measurements and dismantlement confirmation is extremely important. If the confirmation measurements are performed upon entry into the monitoring regime, there may be a relatively long amount of time (up to years) between the measurements and the dismantlement.

Confirmation made upon entry into the regime has the strongest tie to warhead provenance but requires long-term CoC within the regime to connect the confirmation with eventual dismantlement, which may occur many years later. In addition, confirmation at this time involves the relatively difficult technical challenge of measuring assembled weapons where nuclear signatures may be shielded by explosive material and/or the casing of the weapon itself. Information security concerns may also be heightened for measurements of an assembled weapon.

4.2. Pre-dismantlement – Immediately Pre-dismantlement

Another potential time for warhead confirmation measurements is immediately prior to dismantlement. Such a measurement may or may not represent the first set of confirmation measurements made on the declared TLI. Confirmation measurements made immediately prior to dismantlement provide added confidence that the item entering the dismantlement process is truly a warhead. The more time that elapses between the most recent warhead confirmation measurement and the dismantlement process, the more difficult it will be to maintain CoC.

If the confirmation measurements are only performed immediately pre-dismantlement, then maintaining CoC prior to this first set of measurements is only valuable if using provenance and/or movement of the item is a source of confidence in item legitimacy.

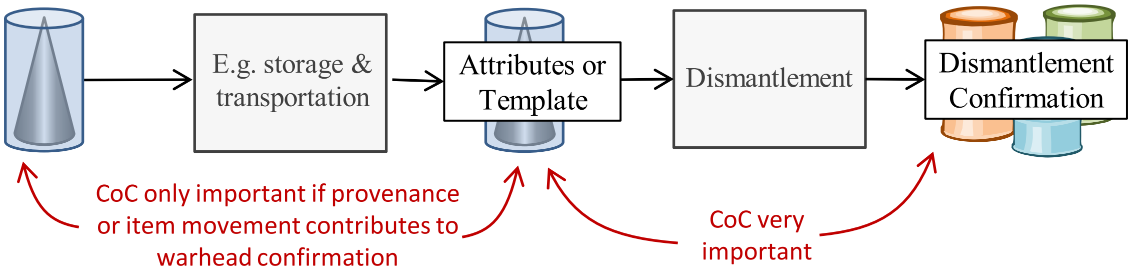

Figure 3. Ramifications on CoC for attribute measurements pre-dismantlement only. If the provenance or item movement is a source of confidence, then CoC prior to the first warhead measurement is very important. If provenance and item movement do not provide confidence, then the value of maintaining CoC prior to confirmation measurements is questionable.

If confirmation is made immediately prior to dismantlement, the tie to dismantlement is much stronger, but the link to the original declaration, and entry into the regime, requires extensive CoC. As the warhead is still assembled at this point in time, the measurement challenge is probably no different than in section 4.1.

4.3. Pre-dismantlement – During transportation and storage

Warhead confirmation could also occur at any time during the pre-dismantlement storage and transportation. For the most part, the strengths and trade-offs inherent in this measurement time fall on a sliding scale between the “Entry into Regime” described in section 4.1 and the “Immediately Pre-dismantlement” described in section 4.2. However, the one significant exception is that a robust CoC connection is now required for linking to both end points—the direct tie to either provenance or dismantlement has been lost with no specific compensating gain. For this reason, all else being equal, we would advocate making the primary confirmation measurements at one end or the other, and not at an intermediate position.

However, all else is seldom equal. If the CoC regime can begin on the delivery vehicle itself, practical and access limitations may prevent the confirmation measurement from being made simultaneously. In this case, performing a confirmation measurement as soon as possible following entry into the CoC regime may increase monitor confidence.

In addition, random “challenge” measurements during transportation and storage can increase the monitoring party’s confidence that the TLI remains as declared throughout the process. These intermediate measurements would not replace the confirmation measurements, but would increase confidence that the item being tracked is a TLI. Even if attribute measurements and/or provenance are used for initial confirmation, a template comparison may be the most effective way to perform these challenge measurements.

Another use of “intermediate” confirmation measurements is to re-establish CoC on an item if CoC has been lost at some point during the transportation and storage operations. It is never the intention to lose CoC, but it is important to have a recovery mechanism, such as re-confirmation, in case such a loss occurs. In addition, the access constraints discussed further in section 4.5 may have a significant impact on confirmation timing.

4.4. Post-dismantlement

There are two potential types of confirmation measurement that may take place post-dismantlement. The first, and most obvious, is to confirm that an item is dismantled, i.e., that the HE and the FM are separate. Although the dismantlement confirmation itself presents challenges (as touched upon in section 2), the timing of dismantlement confirmation is not in doubt.

Following dismantlement, the TLI confirmation measurement is significantly changed and may be simplified. However, some of the critical characteristics that "make a weapon a weapon" may be lost in the dismantlement process:

- The shielding effects of HE may be reduced or eliminated in a post-dismantlement measurement. In addition, since the FM is no longer part of a warhead, the storage and packaging requirements will be changed. If the relevant characteristics are primarily nuclear, like the attribute examples given above, then the reduction in shielding may make nuclear measurements faster, more effective, and more discriminating.
- However, if other characteristics, such as relative FM and HE geometry, are important in the definition of a warhead, then post-dismantlement confirmation adds little or no confidence to an attribute measurement. The effectiveness of this type of warhead confirmation depends explicitly of the declared characteristics of the warhead and the mix of attribute measurement, template comparison and provenance used to make this confirmation.

The CoC requirements for confirmation that a declared item has been dismantled are essentially non-existent as warhead confirmation and dismantlement confirmation are occurring simultaneously (or nearly so). Conversely the CoC requirements for tying the dismantled TLI to the originally declared TLI become more extreme—in particular, the link now passes though the dismantlement "black box."

4.5. Comparisons and Analysis

All four potential times for performing warhead confirmation measurements illustrated in Figure 1 have advantages and disadvantages—some of which have been discussed above. The determination of which confirmation timing is most suitable will depend directly on the details of the particular treaty being confirmed. Two limiting examples can illustrate this concept:

- If a treaty is purely concerned with item dismantlement, then post-dismantlement confirmation provides the strongest link between the item and the dismantlement process. In this extreme, CoC prior to dismantlement becomes less important as the link to regime entry is not a major goal.
- Conversely, if a treaty is purely concerned with keeping track of warheads within a monitoring regime, then confirmation upon entry into the regime provides the strongest, and most timely, tie to the warheads themselves.

In practice, it seems unlikely that a monitored dismantlement treaty would fall into either of these extreme cases. Some of the factors used in determining the most effective times to perform warhead confirmation measurements are: (1) the treaty importance of accepting warheads into the regime, (2) whether a useful provenance of the warhead is available, (3) whether the movements of the item through the monitoring regime provide additional confidence that the item is a warhead, (4) the relative confidence in CoC during different stages of the monitoring regime, (5) the planned types of warhead confirmation measurements (templates or attributes), (6) practical considerations such as the measurement difficulty due to amount of shielding around the item at different points in the monitoring regime, (7) the degree of host sensitivity concerning the container details and/or geometry of the item at different points in the monitoring regime, (8) safety requirements for measuring the item at different points in the monitoring regime, and (9) accessibility of the item, measurement equipment and/or radiation test sources at different points in the monitoring regime.

As *regime acceptance (1)* becomes more important in treaty verification, warhead confirmation at entry into the monitoring regime also becomes more favoured. If *item provenance (2)* is used as a source of confidence that the dismantled item was indeed a warhead, then it is necessary to maintain CoC continuously from entry into the monitoring regime to post dismantlement regardless of when warhead confirmation measurements are performed. Similarly, if *item movements (3)* through the monitoring regime add confidence in item legitimacy, then CoC must be maintained continuously starting before the movements until after dismantlement. The optimum timing of confirmation measurements may still be influenced by confidence in CoC (as discussed below) but may be dominated by considerations of measurement ability, safety and security.

If item provenance and movements provide only limited confidence and must be supplemented with confirmation measurements, then the timing of warhead confirmation greatly influences (and is influenced by) the *type of CoC (4)* required during different phases of the monitoring regime. The availability of CoC tools influences the optimum timing of warhead confirmation measurements, and maintaining CoC during dismantlement is relatively more difficult than maintaining CoC during storage and transportation.

A good example of a trade-off between CoC and confirmation timing results from the differences of performing confirmation measurements either before or after dismantlement. Regardless of timing, maintaining CoC between the most recent warhead confirmation measurements and post-dismantlement is necessary in order to confirm that the item that is dismantled does (or did) meet warhead confirmation criteria. If the warhead confirmation measurements can be performed prior to dismantlement, then CoC must be maintained through the dismantlement process. Performing warhead confirmation measurements post-dismantlement avoids the relatively difficult task of maintaining CoC during dismantlement.

There is interplay between the timing of different *types of warhead confirmation measurements (5)*. In particular, a template comparison may be best performed prior to dismantlement due to the changes in radiation signatures that accompany dismantlement. Although the attribute examples given in this paper can be measured either before or after dismantlement, some other potential attributes, such as ones based on relative geometry of FM and HE, could only be performed prior to dismantlement. Attributes that must, by their nature, be performed prior to dismantlement may provide a stronger indication that an item is a warhead. However, such attributes could also be more sensitive and have not been used in measurement systems to date.

There are *practical (6)* and *security (7)* ramifications of measuring assembled weapons pre-dismantlement or components post-dismantlement. Prior to dismantlement, the assembled item may have more shielding, thus complicating the technical ability to make the measurement and the geometry of the assembled weapon may be more sensitive than the geometry of the disassembled components increasing security concerns. The *safety (8)* ramifications depend on the item and the facility. An assembled weapon is usually in a highly stable (and safe) state and it may be easier to perform confirmation measurements on an assembled weapon than on a disassembled component containing HE. On the other hand, confirmation measurements on a disassembled FM component may have fewer safety considerations than measurements on an assembled system containing HE. Safety considerations will influence access (and in particular standoff distance) to the item for the measurement equipment.

The *(9) accessibility* of an item through the various stages of monitored dismantlement can have a very direct influence on the optimum confirmation timing. Measurements such as neutron multiplicity counting and image generation can require large detectors, which are physically incompatible with some locations. As another example, dedicated facilities may have fewer sensitive characteristics, making it easier for monitors to move around the facility and perform necessary measurements.

Perhaps the best combination (from a monitoring point of view) of measurement strengths, CoC strengths, and efficiency would be achieved by doing warhead confirmation upon entry into the regime (or as early as practical), immediately pre-dismantlement, and post-dismantlement, with a monitoring party option to perform confirmation measurements at various points during the storage and transportation phases. Steps back from this ideal would be made after considering the nine factors described above. One possible way to decrease the measurement burden while maintaining monitor confidence would be to give the monitoring party the option of performing measurements at any of these times while still requiring that the confirmation measurements be performed a certain percentage of the time.

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