The Challenge of Nuclear Warhead Verification For Arms Control and Disarmament: A Review of Attribute and Template Systems

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Abstract

Currently, verification of nuclear arms control refers to the verification of delivery vehicles. Warheads are counted indirectly via the delivery vehicles they are associated with. As states move to lower numbers of nuclear weapons, verification will likely pose some fundamentally new complex challenges in future nuclear arms control agreements. Most importantly, next-generation nuclear disarmament treaties may place limits on the total number of nuclear weapons in the arsenals. Such agreements would then require inspections of individual nuclear weapons without revealing secret information. Authentication of nuclear warheads and perhaps also of warhead components is at the center of the verification challenge for future reductions in the nuclear arsenals. This talk provides an overview of the development of verification systems, and highlights the challenges and the opportunities for research in this area.

Background

Existing nuclear arms-control agreements between the United States and Russia place limits on the number of deployed strategic nuclear weapons. Verification of these agreements takes advantage of the fact that deployed weapons are associated with unique and easily accountable delivery platforms (that is, missile silos, submarines, and strategic bombers) to which agreed numbers of warheads are attributed. The next round of nuclear arms-control agreements, however, may place limits on the total number of nuclear weapons and warheads in the arsenals. This would include tactical weapons as well as deployed and non-deployed weapons.

Deciding that a warhead offered for reduction is what a State Party declares it to be, will be one of the most critical aspects of any such treaty. Agreements would require new verification approaches, including inspections of individual nuclear warheads in storage and warheads entering the dismantlement queue. Warhead authentication, establishing the provenance of a warhead, and maintaining an appropriate dismantlement chain-of-custody are considered to be three of the most technically challenging verification processes in this context.[1] Authentication in particular is considered a qualitatively new challenge because the design of nuclear weapons is highly classified information and cannot be exposed to international inspectors.

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[1] Comley, C, et al. *Confidence, Security & Verification: The Challenge of Global Nuclear Weapons Arms Control* http://www.fissilematerials.org/library/awe00.pdf (Atomic Weapons Establishment, Aldermaston, UK, 2000). p12-21.

Basic concepts: Attributes, Templates, and Information barriers

A viable verification approach has to resolve the tension between reliably verifying that the inspected warhead is authentic while avoiding disclosure of information about its design.[2,3] Two fundamentally different approaches have been proposed to address this problem: the "template" approach and the "attribute" approach. U.S. and Russian nuclear weapon laboratories have done considerable collaborative work to develop both approaches for arms control purposes and have produced several prototype systems to identify both nuclear weapons and weapon components.

Template approach

Template measurements do not seek to determine absolute or relative values of properties that characterize the item (such as plutonium mass or isotopics); instead, the template approach seeks to generate a unique "fingerprint" or "radiation passport" of the item and compares this signature against a recorded template previously generated with the reference item that is known or believed to be authentic. The fingerprint often consists of a set of characteristics of a warhead or warhead component, including various combinations of a weapon's mechanical, thermal, electrical, acoustical, and nuclear properties, but most concepts have relied entirely on gamma-ray radiation emission.[4]

There are two kinds of template systems: passive and active. Passive template systems are based on intrinsic gamma-ray emissions from plutonium and uranium isotopes contained in the nuclear warhead or warhead components that emit high-energy gamma rays, which are highly penetrating, cannot easily be shielded, and are therefore readily detectable. There are several challenges for warhead authentication using a template approach. The most fundamental challenge is establishing the authenticity of the reference item itself, i.e., ensuring that the template was produced using an authentic weapon or weapon component. The reference item for specific types, also called the "golden warhead," can be obtained by using random selections from a population of these warheads from the declared deployed nuclear weapons on missiles or in the arsenal. Another special challenge is protecting the sensitive weapon design information contained in the template and protecting the template or reference item between measurements. In order to solve the first problem, information barriers are required during the template measurement and analysis to protect sensitive data. Important inspection systems based on the template approach are summarized in Table 1.

In 1988, Brookhaven National Laboratory (BNL) proposed the concept of Controlled Intrusiveness Verification Technology (CIVET) with the capability of acquiring sensitive

[2] Anderson, B. et al. *Verification of Nuclear Weapon Dismantlement: Peer Review of the UK MoD Programme* (British Pugwash Group, London, 2012).

[3] Spears, D. (ed.) *Technology R&D for Arms Control* http://www.fissilematerials.org/library/doe01b.pdf (US Department of Energy, Office of Nonproliferation Research and Engineering, Washington DC, 2001).

[4] Committee on International Security and Arms Control, National Research Council, 2005, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities*, Washington, DC, National Academies Press, BOX2-4A, p99

information while preserving its confidentiality in a bilateral environment.[5] During the 1990s, under the auspices of the U.S. Department of Energy (DOE) and the Department of Defense (DOD), the CIVET system was tested in field trials and successfully implemented to verify warheads and warhead components during various exercises and demonstrations.[6] From 1999 to 2001, Sandia National Laboratories (SNL) modified CIVET for use with Radiation Identification System to produce the Trusted Radiation Identification System (TRIS).[7] TRIS included a physical and software security architecture that enabled TRIS to securely confirm the identities of potential Treaty Accountable Items (TAIs). Tests conducted at the Pantex plant demonstrated that TRIS could reliably identify various types of weapons and weapon components, such as pits and canned subassemblies (CSAs).[8] Based on TRIS, Sandia developed the Next Generation Trusted Radiation Identification System (NG-TRIS)[9] for secure joint monitoring and verification of sensitive items. All of the sensitive information and operating software of NG-TRIS are protected within a secure, inspectable, tamper-indicating enclosure (TIE). Additional means of authenticating its physical integrity and identity have been incorporated using a reflective particle tag (RPT), the application of which provides both a unique identifier and tamper indication when applied to a weld or other connection point of an object.

Since the low-energy gamma rays emitted by uranium-235 are readily absorbed by other weapon materials or easily shielded, the gamma-ray emissions from such weapons may be too weak to provide a useful template. In this condition, active template systems have been proposed to provide robust signatures. These systems use an external radiation source to stimulate fission events in the weapon's plutonium and uranium. One important example is the Nuclear Material Identification System (NMIS),[10] which has been under development at Oak Ridge National Laboratory (ORNL) since 1984 and uses active and/or passive neutron and gamma interrogation to determine the characteristics of containers or devices containing fissile material.[11] Its usefulness for template identification was demonstrated in a blind experiment, in which the instrument correctly distinguished between 16 different types of weapons and weapon components. Recent developments of the NMIS system include a fast-neutron imaging capability and a fieldable version of the instrument (FNMIS). NMIS

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[5] Cesar Sastre, *CIVET a Controlled Intrusiveness Verification Technology*, December 1988, BNL-90156-1988

[6] Peter B. Zuhoski, et al., *Building a Dedicated Information Barrier System for Warhead and Sensitive Item Verification,* BNL-66214, http://www.bnl.gov/isd/documents/19942.pdf. Peter E. Vanier, et al., *Study of CIVET Design of a Trusted Processor for Non-intrusive Measurements. 2001*, INMM

[7] K.D. Seager, et al., *Trusted Radiation Identification System*, Proceedings of the 42nd Annual INNM Meeting, Indian Wells, CA, 2001.

[8] Committee on International Security and Arms Control, National Research Council, 2005, *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities*, Washington, DC, National Academies Press, BOX 2-4A, p102

[9] Peter B. Merkle, et al., *Next Generation Trusted Radiation Identification System*, INMM Meeting, 2010. Highlight: February 2011, Next Generation Trusted Radiation Identification System (NG-TRIS), Office of Nonproliferation and International Security (NIS).

[10] L. G. Chiang, el al., *Nuclear Materials Identification System Operations Manual*, ORNL/TM-2001/65, Rev. 2

[11] In the active interrogation mode, the signatures for fissile material used for reference template can be accurately characterized and protected by using time-dependent coincidence and correlation techniques with information barrier.

appears well suited for detection of shielded highly enriched uranium (HEU) and plutonium, but it has apparently not been combined with an information barrier concept to date.

Table 1. The development of verification system based on template approach

Time	System	Designer	Radiation Measurement	Information Barrier
1988-1991	CIVET: Controlled Intrusiveness Verification Technology	Brookhaven National Laboratories	Passive gamma ray (high-resolution gamma spectrometer)	YES
1999-2001	TRIS: Trusted Radiation Identification System	Sandia National Laboratories	Passive gamma ray (low-resolution gamma spectrometer)	YES
2007-	NG-TRIS: Next Generation Trusted Radiation Identification System	Sandia National Laboratories	Passive gamma ray (low-resolution gamma spectrometer)	YES
1984-	(F)NMIS: (Fieldable) Nuclear Material Identification System	Oak Ridge National Laboratory	Active and/or neutron and gamma ray	(NO)

Attribute approach

The attribute approach seeks to confirm intrinsic characteristics of nuclear weapons and their components. A range of attributes has been suggested by the United States, often in cooperation with Russia, to characterize a nuclear warhead with high confidence. For robust authentication, the attributes should be chosen such that they are easy to measure and make cheating difficult and costly; ideally, items that are not warheads or warhead components will not simultaneously meet all attributes. To the best of our knowledge, nuclear weapons contain kilogram-quantities of fissile material, i.e., plutonium and/or highly enriched uranium.[12] The presence of fissile material can therefore serve as a basic attribute for a warhead or warhead component. Under the attribute approach, parties must also agree on one or more threshold values that characterize the inspected item (e.g. "more than 2 kg of plutonium"). In order to be authenticated, an inspected item may have to pass a number of attribute tests and an information barrier also must be used to protect the sensitive information contained in the radiation measurements. The advantages and limitations of attribute measurement techniques for warhead authentication were reviewed and discussed before.[13] This article only briefly summarizes the development of the attribute measurement systems.

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[12] The United States has classified the fact "that all U.S. weapon pits that contain plutonium have at least 500 grams of plutonium" (RDD-8). It has also declassified the fact that, "hypothetically, a mass of 4 kilograms of plutonium or uranium-233 is sufficient for one nuclear explosive device."

[13] Malte Göttsche and Gerald Kirchner, *Measurement Techniques for warhead Authentication with Attributes: Advantages and Limitations*, Science & Global Security, 2014, 22:83-110

In the 1990s, because of the need to agree on transparency measures to verify the weapon-origin of plutonium to be placed in the Mayak storage facility in Russia and the unresolved sensitivity issues related to templates,[14] most research and development efforts have shifted away from template-based methods towards a focus on attribute measurements. Several attribute measurement systems using both passive or active techniques have been developed and demonstrated, even though most work has slowed down since the late 1990s. A list of the proposed attributes and relevant attribute systems is summarized in Table 2.

Table 2. A list of the proposed attributes and the relevant attribute systems

Attributes	Attribute Systems						
	TRADS (US)	AVNG (Russia)	AMS/IB (US)	NG-AMS (US)	3G-AMS (US)	UKNI* (UK-Norway)	INPC (China)
presence of plutonium	(✓)	✓	✓	(✓)	✓	✓	✓
plutonium Isotopics	✓	✓	✓	✓	✓	✓	✓
plutonium mass	✓	✓	✓	✓	✓		✓
plutonium age			✓	✓			✓
absence of oxide			✓				✓
symmetry			✓				✓
presence of U-235					✓		
uranium enrichment					✓		
U-235 mass					✓		
presence of high explosive					✓		
* As described in the text, only gamma ray sources were used in the research phase to date.							

Sandia National Laboratory (SNL) developed a typical passive system, the Trusted Radiation Attribute Demonstration System (TRADS)[15], which confirms attributes of weapon-grade plutonium and highly enriched uranium (HEU) in nuclear warheads or warhead components using only a high-purity germanium detector. A "trusted processor" was first adopted to acquire and analyze data and to address the potential needs of an arms control regime in which nuclear weapons must be inspected with a portable system.

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[14] Nicholas Zarimpas (editor), *Transparency in Nuclear Warhead and Materials: the political and technical dimensions,* SIPRI 2003, Appendix 8A, p166. However, at last, Russia decided to only store plutonium "pits" converted into non-classified forms at Mayak. It is not possible to verify if the material originated in warheads or not. The attributes measurement were not implemented for the verification of warhead component.

[15] Dean J. Mitchell and Keith M. Tolk, *Trusted Radiation Attribute Demonstration System*, 2000, Sandia National Laboratories.

Under the Trilateral Initiative (1996–2002), an attribute verification system (AVNG)[16] with information barriers for mass and isotopic measurements was designed and developed by scientists at the Russian Federal Nuclear Center-VNIIEF, with support of Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL). With the use of a neutron multiplicity counter and a gamma-ray spectrometric system, three attributes of "presence of plutonium", "plutonium mass >2 kg", and "plutonium isotopic ratio (Pu-240:Pu-239<0.1)" were implemented.[17] Fabrication, certification, and demonstration of the AVNG had not been fully completed at the end of the Trilateral Initiative. Upon consideration within each government, the United States-Russian Federation Warhead Safety and Security Exchange (WSSX) Agreement approved the work to complete the project. In June 2009, the AVNG demonstration was held at Sarov, Russia, for a joint U.S./Russian audience. The demonstration included testing both the secure mode and the open mode of AVNG operation using a set of multi-kilogram plutonium reference materials.[18]

Another important precedent was the Fissile Materials Transparency Technology Demonstration (FMTTD) conducted in August 2000 at the Los Alamos National Laboratory (LANL). U.S. technical experts presented an Attribute Measurement System with Information Barrier (AMS/IB)[19] to a delegation of Russian officials. The system was designed and developed by a multi-laboratory team including Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and Pacific Northwest National Laboratory (PNNL). By combining information barriers and a simple yes/no display, six plutonium attributes (as shown in Table 2) were confirmed to have the declared characteristics.[19]

Between 2005 and 2008, the Next Generation Attribute Measurement System (NG-AMS)[20] was designed and built with Commercial Off-The-Shelf (COTS) hardware and software using blind-buying and random selection for the purpose of increasing the trust of the system. The NG-AMS determines three attributes: plutonium isotopics, mass, and age.[21] On

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[16] Sergey Razinkov, et al., *AVNG system objectives and concept*, 2010, INMM, http://www.inmm.org/source/proceedings/files/2010/258.pdf

[17] Alexander Modenov, et al., *AVNG system software — attribute verification system with information barriers for mass and isotopics measurements*. 2005, INMM, http://www.inmm.org/source/proceedings/files/2005/pdffiles/papers/235%20162.pdf.

[18] Sergey Kondratov, et al., *AVNG System Demonstration*, 2010, LA-UR-10-02620

[19] Technical Overview of Fissile Material Transparency Technology Demonstration – Executive Summary, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/exec_sum.pdf. Diana G. Langner, *Attribute Verification Systems with Information Barriers for classified forms of Plutonium in the Trilateral Initiative*.

[20] Jason Shergur, et al., *An overview of the design of a Next Generation Attribution Measurement System*, 2005, INMM, http://www.inmm.org/source/proceedings/files/2005/pdffiles/papers/026%20145.pdf

[21] Furthermore, two significant advances were successfully demonstrated in the system. One improvement was the use of two weak gamma sources with very different half lives (one long-lived and one short lived), which were mounted to the HPGe detector to substitute for a battery powered real-time clock. The other improvement was the inclusion of a much simpler (in complexity) computational block that any previous AMS developed by U.S. laboratories.

this basis, the Third Generation Attribute Measurement System (3G-AMS)[22] was further developed by the funding of the Office of Nuclear Verification (ONV) in the National Nuclear Security Administration. Compared to previous attribute measurement systems, the 3G-AMS not only measures properties related to plutonium, but also takes into account the possible presence of uranium and explosives.

Under UK-Norway Initiative (UKNI), a Gamma Ray Attribute Measurement System with an integrated Information Barrier was jointly designed by researchers from the United Kingdom and Norway. The initiative focuses on the development of Managed Access procedures and Information Barriers s.[23] The measurement system uses commercially available HPGe detectors to obtain the gamma ray attribute and determines the presence of plutonium and compares the isotopic composition against a declared threshold. For ease of conducting trials on the Information Barrier system, and to address the technical questions without risk of discussion around sensitive material characteristics, a mock-up Odin "nuclear bomb", using two gamma ray sources ^{60}Co and ^{22}Na to simulate the plutonium was designed to implement the verification task.

During last two decades, China continued to carry out independent researches on nuclear arms control verification technologies, such as the authentication technology of nuclear warheads and components, information barrier technology, and technologies of monitoring the dismantling process. In 2011, a Pu-subassembly Attributes and Measurement System with Information Barrier was designed and completed by the Institute of Nuclear Physics and Chemistry (INPC) in China Academy of Engineering Physics (CAEP).[24] The system is functionally similar to the AMS/IB. It was specifically designed to implement the authentication of Pu-subassembly, possessing the capabilities of verification for six plutonium attributes. In addition, an auto-adjustment subsystem for the tested items and a passive gamma radiation measurement for symmetry attribute were supplemented to strengthen the robustness and adaptability under different verification scenarios.

Template versus Attributes

Both the template approach and the attribute approach have characteristic strengths and weaknesses. For example, both the template and attribute approaches require measurements of an agreed set of characteristics. Although the attribute approach has the ability to authenticate the measurement system using an unclassified standard without the need to store sensitive data for later comparisons, it cannot identify the particular type of nuclear

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[22] Jonathan Thron, *Designing a 3rd Generation, Authentication Attribute Measurement System*, 2009, LA-UR-09-03569. Dan Archer, *Third Generation Attribution Measurement System,* 2012, INMM. http://www.inmm.org/source/proceedings/files/2012/a393_1.pdf. Glen Warren, et al., *Concepts for the Measurements Subsystems of the Third Generation Attributes Measurements System*, 2012, PNNL-SA-89171.

[23] David M Chambers, et al., *UK-Norway Initiative: Research into Information Barriers to allow warhead attribute verification without release of sensitive or proliferative information*. 2010.

[24] http://www.caep.ac.cn/kxjsnew/yjjz/wlx/13392.shtml and http://vip.dglib.cn:8080/FK_ArticelSearch.aspx?ID=41664840# (in Chinese)

weapons or components. A comparison between template approach and attribute approach for the application on nuclear warhead authentication is listed in Table 3.[25]

In general, there is a broad consensus that template approaches would be appropriate in a monitoring regime that involved the measurement of numerous items of the same type, while attribute approaches would be most appropriate if the regime involved items not of the same type but with similar features. The template approach is generally considered to be more robust against cheating than the attribute approach, while the attribute approach may be best applied to nuclear weapons as a complement to templates in order to provide further confidence that inspected items are genuine.

Table 3. Comparison of attribute and template approaches[25]

Attribute	Templates
Characteristics of a single item evaluated	Comparison with a reference item
Information barrier required	Information barrier required
No storage of reference data	Storage of reference data required
Requires quantitative value and acceptable deviation	Quantitative value is unknown; parameter comparison is more precise

Information Barriers

In practical nuclear warhead verification scenarios, none of the radiation measurements based on template or attribute approaches would be accepted unless sensitive classified information is reliably protected. Practitioners and policy makers have been well aware of this conundrum, and prior work by national laboratories in the United States, Russia, and the United Kingdom addressed it by using "Information Barriers" (IB). For an integrated radiation signature-information barrier inspection system, the fundamental functional requirements and construction have been thoroughly discussed in the past.[26] These systems relied heavily on a combination of hardware, software, controls, and procedures to assure that information has been determined to be sensitive by a host Party from an inspecting Party is protected, while also providing the inspecting Party with certain agreed upon, nonsensitive information. Information barriers generally consist of sophisticated automated systems that process highly classified information measured during an inspection, but only display results in a yes/no manner.[27]

[25] Nicholas Zarimpas (editor), *Transparency in Nuclear Warhead and Materials: the political and technical dimensions*, Appendix 8A. SIPRI 2003.

[26] JL Fuller, *The functional Requirements and Design Basis for Information Barriers*, 1999, PNNL-13285. Duncan W. MacArthur and Rena Whiteson, *Comparison of Hardware and Software Approaches to Information Barrier Construction*, Nucl. Mater. Manage. July 2000. Duncan W. MacArthur, el al., *Functional Description of an Information Barrier to Protect Classified Information*, Nucl. Mater. Manage. July 1999.

[27] Richard Williams, *Advances in Information Barrier Design*, LANL, 2005, LA-UR-05-4149.

From the perspective of the host party, the overriding information barrier requirement is that sensitive information must be highly secure, i.e., the system cannot accidentally release such information or leak it through an unknown “side channel.” From the perspective of the monitoring party, the key requirement is to obtain enough information to gain reasonable confidence in the host-party declaration. This confidence can be built and increased through the authentication of each hardware and software component of the information barrier system to make sure that there are no hidden backdoors or Trojans. It is an inherent challenge to require both parties to trust that they have no ‘trapdoors’ hidden from the inspector, which could be used to cause a system to declare invalid objects as authentic, nor side channels unknown to the host, which could leak classified information to the inspector or others. These concerns are serious obstacles to adopting such systems.

An alternative approach

In order to avoid the authentication problem of the information barrier system, a fundamentally different approach, so called zero-knowledge protocol was proposed by researchers at Princeton University.[28] Rather than trying to acquire and then analyze classified data behind an engineered information barrier, this new approach uses the cryptographic notion of zero-knowledge proofs to ensure that sensitive data are never measured in the first place and so does not need to be hidden. The proposed zero-knowledge protocol inspection system combines active high-energy neutron measurement techniques with non-electronic detectors using a template-matching approach.[29] In essence, the proposed system is based on neutron transmission through the contained warhead and gives a null result if the item is what the host says that it is.

This approach is still in the proof of principle stage. The proposed inspection system relies on active interrogation of a test object with 14-MeV neutrons, including both tomographic transmission measurements that are sensitive to warhead configuration, and scattering/ fission measurements that are sensitive to material properties. The calculations for scenarios in which material is diverted from a test object show that a high degree of discrimination can be achieved while revealing zero information. Recently, a two-color neutron setting was also proposed.[30] By combing a high energy 14-MeV D-T neutron source and a lower energy p-Li neutron source, the system can better discriminate isotopics, for example, of different uranium and plutonium compositions.

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[28] Alex Glaser, et al., *A zero-knowledge protocol for nuclear warhead verification*, Nature, 2014, vol 510: 497–502.

[29] Simply say, counting neutrons transmitted through the warhead will produce a neutron radiograph (call this T as reference), to avoid seeing this radiograph, and hence obtaining proliferative information, the inspector uses detectors that are preloaded by the host with the negative of the contained warhead’s radiograph ($-T$). So, if the item is genuine the inspector will see a null signal: $-T+T=0$. Then the inspector can confirm that the item is as declared, but is no wiser about its detailed properties.

[30] Yan Jie, “Two-color Neutron Setting for Nuclear Warhead Verification in Zero-knowledge Protocol”, working paper, in preparation. See also Robert J. Goldston, et al., *Zero Knowledge Warhead Verification: System Requirements and Detector Technologies*, INMM, 2014.

Outlook: What's next?

U.S. President Obama's 2009 Prague speech, in which he outlined his vision to "seek the peace and security of a world without nuclear weapons,"[31] reenergized the nuclear disarmament debate worldwide. Other weapon states have reaffirmed the commitment to nuclear disarmament also. As a permanent member of the United Nations Security Council and a nuclear-weapon state under NPT, China advocates and promotes the complete prohibition and thorough destruction of nuclear weapons.[32] On this road to a world free of nuclear weapons, the challenge for any significant arms reductions could be the accurate verification of warhead inventories, i.e., to confirm both the correctness and completeness of declarations made by weapon states about their arsenals. There will always be a fundamental tension between intrusive verification activities and stringent physical security, information security, and safety requirements. Authenticating nuclear warheads without revealing classified information represents a qualitatively new challenge for international arms-control inspection.

To facilitate and promote confidence-building for a new round of bilateral and perhaps multilateral arms-control negotiations seeking deeper reductions in the nuclear arsenals, a network of laboratories with international participation, including nuclear weapon states and non-nuclear weapon states, should be established as soon as possible. Such an international cooperation could work on specific areas that need further work, including:[33]

- *Establishing a Universal Test Object (UTO):* For the development of inspection systems that could be used for bilateral or multilateral treaty verification, all partners have to agree on performance requirements for such systems. In order to demonstrate the capabilities of a proposed system, a widely accepted reference item would be extremely helpful. With such a "Universal Test Object" (UTO), the advantages and disadvantages of different verification systems could be examined and compared comprehensively, which is pivotal for making design choices and strengthening mutual confidence in the process.

- *Determining a set of Agreed Minimal Attributes (AMAs):* As noted in the concept section, several Nuclear Weapon States (NWS) have already designed and developed one or more attribute-based inspection systems. It is therefore likely that the first jointly developed systems would also be based on the attribute approach. There is broad agreement on some basic warhead attributes, such as the presence of plutonium (or highly enriched uranium), but there is no consensus on the exact threshold value for basic attributes; and there is no broad agreement on some other attributes, for example, relating to geometry or configuration. Joint international research is the only way to ultimately determine a set of agreed AMAs.

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31 http://www.whitehouse.gov/the_press_office/Remarks-By-President-Barack-Obama-In-Prague-As-Delivered

32 Preparatory Committee for the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, Implementation of the Treaty on the Non-Proliferation of Nuclear Weapons, Submitted by the People's Republic of China, 2014,http://www.un.org/ga/search/view_doc.asp?symbol=NPT/CONF.2015/PC.III/13

33 The Nuclear Threat Initiative (NTI) has recently proposed a complementary list of recommendations for future work in this area. *Verifying Baseline Declarations of Nuclear Warheads and Materials*, pp. 7–8, 42–43.

- *Designing an Authenticatable Information Barriers (AIBs):* For a standard nuclear warhead verification system, an information barrier (IB) must be added to the system to conceal classified information. Although the primary purpose of the IB is protection of sensitive information, as noted earlier there are concerns associated with the authentication of IB hardware and software. While almost every NWS has already accumulated abundant experience with the design of an IB, there is no unified framework for the design of an IB or agreement on common standards. A joint effort to develop an Authenticatable Information Barriers (AIBs) could help relieve some current concerns.