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Tagging and Fissile Material Verification Concepts for Nuclear Warhead Dismantlement

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ABSTRACT

Arms control treaties that reduce the number of deployable nuclear-warhead delivery systems might also lead to provisions for the verified dismantlement of nuclear weapons. Based on public information and very simple conceptual models of nuclear warheads, one can visualize a set of procedural and technological requirements to account for warheads removed from deployed sites and ultimately dismantled. To accomplish the accounting function, verification-quality tags and/or seals might be needed in order that the warheads taken out of storage can be tracked to the dismantlement site. These tags/seals would represent an overlay on the existing chain of custody. The verified dismantlement of the warheads poses special problems in confirming their identity and in avoiding the loss of sensitive information. A central factor is the publicly recognized need for some minimum quantity of fissile material to constitute a nuclear warhead. A measurement system that could make such a determination without giving away unnecessary information would be desired. Some approaches based on existing fissile assay methods are discussed.

INTRODUCTION

Arms control treaties currently signed, being negotiated, or under consideration are resulting in a reduction in the number of deployed nuclear-warhead delivery systems. As a result of the military, political, economic, and social changes taking place in Europe, both the United States and the Soviet Union will probably have some types of nuclear warheads in excess of requirements. National security would be enhanced if both superpowers could be assured that the other party is dismantling their surplus warheads. Treaties that require verification are the established means of institutionalizing arms reductions. For the purposes of this paper, it is assumed that a bilateral U.S./U.S.S.R treaty would be negotiated for cooperative verification of dismantlement of an agreed number of nuclear weapons.

How could nuclear-warhead dismantlement be verified with high confidence -- but without revealing sensitive information? Based on public information and very simple conceptual models of nuclear warheads, one can visualize a set of procedural and technological requirements to account for warheads removed from deployed sites and to verify their ultimate disassembly.

First, one must be certain that real nuclear warheads are in fact returned for destruction. Second, there must be agreement on the definition of dismantlement, destruction, or demilitarization of the warheads. Third, the information derived in the process of verification must be protected. And fourth, an understanding must be reached on the ultimate disposition of the warhead materials. Each of these tasks will be considered conceptually in this paper, with emphasis on tagging and fissile-material detection techniques.

DEFINING A NUCLEAR WARHEAD

Aside from commonality in application of basic physical principles and practices, neither side in a treaty is likely to have much detailed knowledge of each others nuclear warhead design, and if they did they're not likely to admit it. Perhaps some information could be disclosed in bilateral confidence, but the underlying uncertainty about the design and materials of the nuclear weapons is likely to persist. Even unrestricted access to the dismantlement process and to the separated parts might not be sufficient. Only nuclear explosive tests are likely to be convincing. Even though such tests could be carried out through a sampling process, they would probably be in disfavor because of increasing environmental and testing controls.

A strategic nuclear warhead could be defined in part or even sufficiently by virtue of its deployment -- on a missile or other strategic carrier. Theater nuclear weapons, on the other hand, in some cases have the same external configuration as non-nuclear warheads.

By tracking the nuclear warheads from the point of deployment or storage via the custodial chain to a dismantlement facility, this major aspect of identity verification is attainable. Further confidence could be gained by making in the field some physical measurements of the devices that are declared to be nuclear weapons and by allowing verification of non-declared items which are not nuclear armed.

To accomplish the accounting function, verification-quality tags and/or seals might be needed in order that the warheads taken out of storage can be tracked without continuous monitoring to the dismantlement site. These tags/seals would represent a verification-imposed overlay on the existing chain of custody and national safeguards.

Before getting into details, it is necessary to complete the picture of an overall verification framework. It is assumed that seals will be checked at the portal of a dismantlement facility and also that certain physical measurements will be allowed at that point (see Fig. 1). A seal will be examined by both parties when presented at the dismantlement portal and, if secure, the shipment will be passed through the portal. The seal can be broken by the warhead owner within the facility after the device has passed inspection.

It is likely that warheads shipped to a receiving facility will be held in temporary (but possibly lengthy) storage, depending on the throughput of the dismantlement facility. The facility designated for dismantlement might be one that is an enclosed and monitored part of an existing facility which can handle nuclear weapons. Between dismantlement campaigns, an inspection of the dismantlement facility might be expected to ensure that no parts are stockpiled.

FISSILE MATERIAL MEASUREMENTS

Because the verified dismantlement of the warheads poses special problems in confirming their identity and in avoiding the loss of sensitive information, I will assume that radiation measurements will be carried out at the portal in the following fashion.

Each side will declare in a confidential memorandum the minimum quantity of fissile material characteristic of each type of nuclear weapon. This minimum quantity would not be the actual quantity, but some lesser value, perhaps roughly 50 or 75 percent of the actual fissile content. A radiation detection system would be used at the portal that is capable of measuring fissile materials in complex geometries with an accuracy sufficient to determine the threshold value but insufficient to determine the exact fissile content. The fast-neutron hodoscope is capable of being adapted to this task [1]. Twenty-five years of experience in measurements of kilogram quantities of fissile and fertile materials within thick surrounding and containers have been acquired at the TREAT reactor in Idaho and the CABRI reactor in France.

Once inside the portal, the warhead would be dismantled by the owner without being witnessed by the monitoring party. The warhead parts would be sorted in to distinguishable containers or possibly placed into bins within the original shipping container to be exited through the portal.

At exit several observations would take place under controlled conditions. Although the seal to the container would have been broken after passage through the portal, the tag on the warhead would be made accessible for post-dismantlement inspection. Also, by virtue of the physical separation of warhead parts into different bins or containers, it would be visually or otherwise evident that the warhead had been dismantled into constituent parts. In particular, the fissile material would be found to be in a separated bin, cage, or container and to have a fissile quantity similar to that which was present upon entry to the portal. In other words, the key requirement for the radiation system is to measure a relative quantity rather than absolute quantity of fissile material, comparing input to output. Of course, the output should also be above the original threshold of fissile content. The treaty might also require additional destruction or melting of components as part of the arms elimination process, which might entail other verification measures. Safety and environmental concerns for special nuclear materials, high-explosives, and other toxic items will have to be taken into account.

The actual measurement of the fissile content is probably best carried out by injecting penetrating neutrons that induce measurable fission. This is a process that goes to the heart of the nuclear weapon trigger and which does not require assumptions regarding the fissionable isotope. Passive measurements are not expected to provide sufficient information on the quantity of fissile material, especially for uranium. A neutron-reaction hodoscope can carry out this task with tailored mass resolution; an external source would induce fissions that are characteristic of the fissile material. Calibration can take place by using standards that are periodically circulated through the verification portal by the monitoring party.

In order to protect sensitive information, various methods of masking the data could be used. There is no need for the specific measurement results to be available to either party: only the verification of the integral conclusion that the same quantity of fissile material that entered in the form of an intact warhead exited as a disassembled device and that the fissile content was above the declared threshold. The data could be fully contained, in encrypted fashion, within a dual-access-key computing system having volatile memory. Moreover, the actual instrument parameters could be varied randomly in such a manner as to defy human access to absolute values but be internally decodable for the relative measurement. Absolute values are difficult to compute anyway to better than 25 or 35 percent because of the reconfigured fissile geometry, self-absorption of neutrons, and the presence of moderating materials.

The transfer of the fissile materials to storage or other disposition is governed by other treaty arrangements, and that topic will not be discussed here.

SEALS AND TAGS

One can assume that nuclear weapons are normally transported under a national custodial system that emphasizes physical security, safety, and other domestic requirements. Negotiated nuclear arms reductions will add an additional cooperative verification overlay that should not diminish the chain of custody. The additional aspect might simply consist of a tagged nuclear warhead being transported with an additional verification seal on the container.

The seal would be designed to assure the verifying party that during transit to the portal the container could not be opened without revealing that the seal had been decoupled. Such a seal might have a standard of verification quality that exceeds that which is normally associated with domestic or international safeguards for two reasons. First, the resources for defeating the seal available to a national party generally exceed those that are available to adversaries considered in design of a domestic safeguards seal. Second, weapons of mass destruction require a much higher level of assurance than normally associated within international safeguards on fissile materials.

Seals that might be improved to meet the more stringent arms-control verification standards include two particular types: fiber-optic seals (VACOSS) that include light-transmitting cables which can be wrapped around a container and brittle-ceramic seals that include ultrasound-conducting cables which can be interrogated by acoustic methods. The fiber-optic seals have been developed by Sandia National Laboratory and the Euratom Joint Research Center; the ultrasonic seal is under development at Argonne National Laboratory.

When a deployed or stored warhead is identified by the owning party and confirmed on site by the inspecting party, the outer casing could be tagged. Such a tag will significantly increase confidence in the continuity of the custodial chain through the process of destruction, particularly if it is non-transferable from an integral part of the visible casing of the warhead.

Although various attached tags have undergone considerable development, they might have difficulty meeting the non-transferability requirement with high confidence. Electronic tags such as those developed at Lawrence Livermore and Los Alamos national laboratories provide a built-in indicator of detachment and might be able to meet a stringent tamper-revealing requirement. In this application, they would not have some of the liabilities that are considered present for electronic tags with deployed systems: vulnerability to targetting and lack of durability in an exposed environment. In a protected environment characteristic of systems to be dismantled, these are not barriers to their use; and having a tag that could be interrogated at a distance or even through a non-metallic container would be helpful. However, there would still be a problem in dealing with unattributable failures: other tags would leave visible evidence of induced damage, but electronic circuits can be caused to malfunction without attributable failure evidence.

Intrinsic tags do not have these difficulties. A tag that consists of a unique signature of the surface or subsurface of the warhead casing (or re-entry vehicle) would leave visible evidence of tampering. Moreover, a section of the casing cut out or separated could be given after dismantlement as proof of disassembly. Pacific Northwest Laboratory has been working on a subsurface signature tag authenticated by ultrasonic scanning.

An intrinsic-surface-roughness tag has been under development at Argonne National Laboratory. Any machined surface has unique microscopic topology. A faithful plastic-casting "fingerprint" can be made of a small surface area, with copies for each treaty party. The casting is returned to the laboratory, where the microtopography can be scanned and digitized by an electron microscope, one of the most powerful scientific imaging instruments. One square centimeter of surface area will give in the order of a billion bits of unique information. When the disassembled nuclear warhead is exited from the dismantlement facility, verification of its demilitarization can take place by providing the inspectors with an opportunity to take another casting of the designated surface on the separated weapon case. This would later be compared in each verification laboratory with the original casting.

The plastic casting can be likened better to a "footprint" than a "fingerprint" because when magnified by the scanning electron microscope, it presents an irregular and unique three-dimensional topography that defies counterfeiting or detachment (see Fig. 2). It is one thing to make a faithful casting of a surface; it turns out to be a formidable challenge to reproduce the "foot" hat created the "print" by means that would escape the micron-level three-dimensional resolution of the electron microscope.

SUMMARY

In scoping the verification process possible for nuclear warhead dismantlement, a series of coupled steps appear capable of providing the confidence needed for verifiable dismantlement and the protection needed for sensitive data. Tagging warheads at their point of deployment or original storage and applying verification-quality seals to their containers are essential initial steps. A dedicated dismantlement facility that is within a portal/perimeter monitoring system is the ultimate destination of the warheads. Upon receipt at the portal, the warhead in its container could be checked to ensure that it has a minimum threshold quantity of fissile material by radiation interrogation means that do not reveal sensitive information. By comparing the relative quantity of fissile material in the shipping container before and after dismantlement, the remaining assurances can be obtained. The tag, which could be based on intrinsic-surface-roughness, can be checked again after dismantlement as further evidence of the demilitarization process.

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REFERENCE

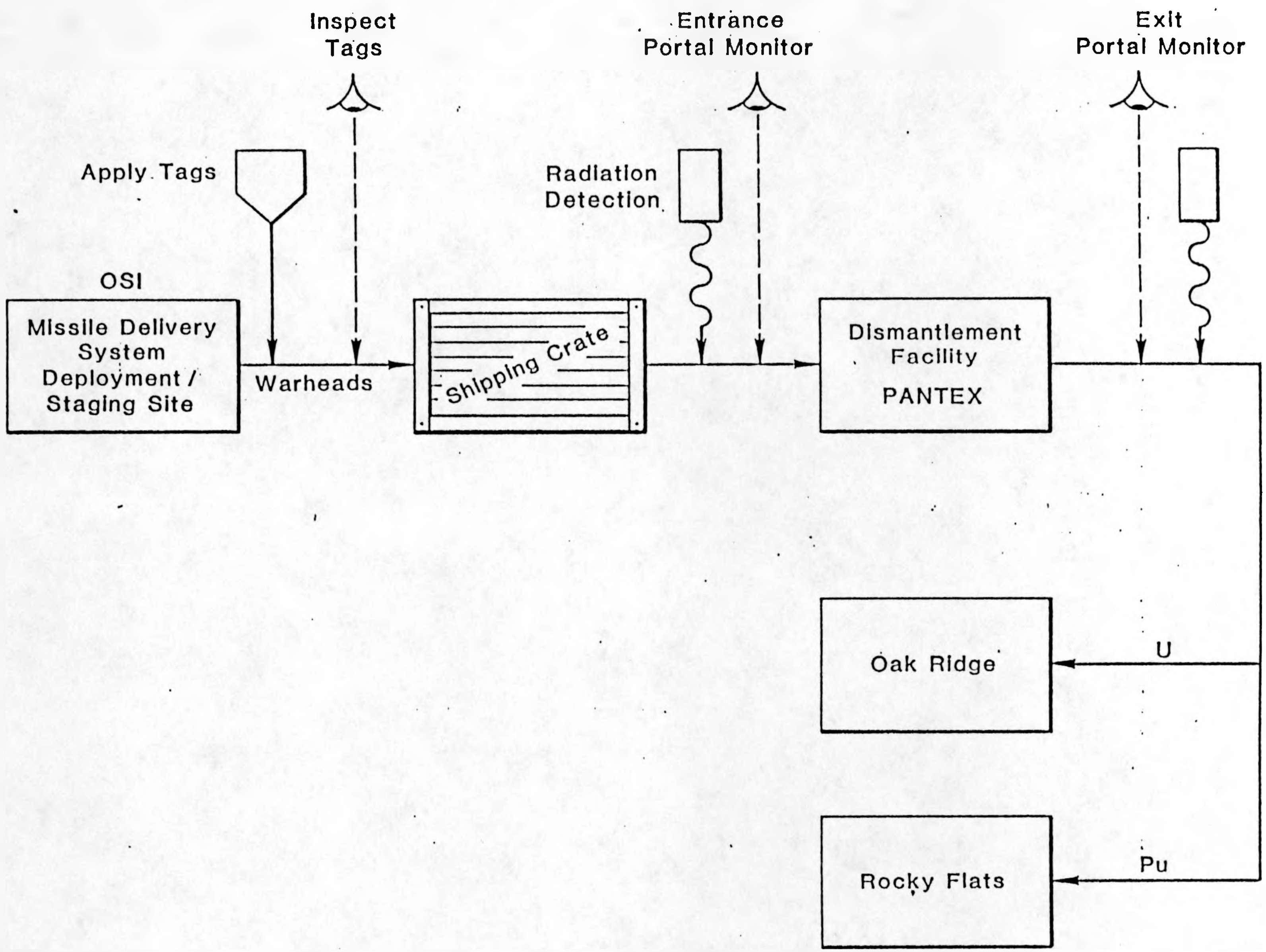
1. A. DeVolpi, "Applications of Cineradiography to Nuclear-Reactor Safety Studies", Rev. Sci. Instrum. 55(8):1197 (1984).

Figure captions

1. Flow chart indicating major steps in materials flow and verification of dismantlement.

2. An two-dimensional example of the intricate three-dimensional topography of a surface that can be magnified by a scanning electron microscope.

VERIFIED DISMANTLEMENT OF WARHEADS



AUTHENTICABLE INTRINSIC TAG INSCRIBED INTO TLI SURFACE AND INVENTORIED BY A BAR CODE