Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities[1]

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Introduction

Previous studies by the National Academy of Sciences' Committee on International Security and Arms Control (CISAC) emphasized the key role of transparency, monitoring and verification, both for the future of arms limitations among the nuclear-weapon states and for keeping nuclear-explosive materials (NEM)[4] away from proliferation-prone states and terrorists. In 2000, the U.S. Department of Energy requested that CISAC study the potential for a more comprehensive approach to nuclear-arms control. *The report, Monitoring Nuclear Warheads and Nuclear Explosive Materials,* explores the extent to which current and foreseeable approaches to transparency and monitoring can support verification for all categories of nuclear weapons – strategic and non-strategic, deployed and nondeployed – as well as for the nuclear explosive components and materials that are their essential ingredients. Increasing the categories of items subject to transparency and monitoring would be valuable – and may ultimately be essential – as the United States and the world attempt to address the urgent and interrelated goals of reducing the dangers from existing nuclear arsenals, minimizing the spread of nuclear weaponry to additional states, and preventing the acquisition of nuclear weapons by terrorists.

In addition to understanding the transparency and monitoring possibilities and requirements for more ambitious arms control regimes, the study also focuses on potential applications to the continuing challenges of keeping nuclear weapons out of the hands of proliferant states and terrorists. To give one prominent example, the United States has emphasized the need for verification as part of an agreement to eliminate North Korea's nuclear weapons program. Likewise, as the United States continues to work with Russia to ensure that nuclear materials are adequately protected and accounted for, the partners will continue to require transparency measures to facilitate the process.

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[1] The paper is adapted from the Executive Summary of *Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities*, Committee on International Security and Arms Control (2005). Available at: http://www.nap.edu/catalog/11265.html.

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[4] A "nuclear-explosive material" is a mixture of fissionable nuclides in which the proportions of these are such as to support an explosively growing fission chain reaction when the material is present in suitable quantity, density, configuration, and chemical form and purity. Uranium containing more than 20 percent U-235 or more than 12 percent U-233 (or an equivalent combination of proportions of these two nuclides) is considered NEM, as are all mixtures of plutonium isotopes containing less than 80 percent Pu-238.

The study addresses the technical and institutional approaches and capabilities in transparency and monitoring that could be applied to declared stocks of nuclear weapons, nuclear weapons components, and nuclear-explosive materials. The study also evaluates methods that could be used to detect clandestine stocks or covert production of nuclear weapons or NEM. Although the study does not make recommendations about U.S. arms control and nonproliferation policies, such policy choices will continue to shape the context within which monitoring approaches and capabilities might be applied.

The Magnitude of the Monitoring Challenge

More than 30,000 nuclear weapons remain in the world. The United States and Russia possess about 95 percent of existing nuclear weapons, with the remainder held by the United Kingdom, France, China, Israel, India, Pakistan, and possibly North Korea. In addition, stocks of NEM—high-enriched uranium (HEU) and separated plutonium—sufficient to make more than 100,000 additional nuclear weapons exist in military and civil nuclear facilities worldwide. HEU and plutonium are difficult to produce. Access to these materials is the primary technical barrier to the acquisition of nuclear weapons. These stockpiles of NEM, in addition to presenting a ready resource for further production of weapons by the states holding them, also constitute a potential source for the fabrication of nuclear weapons by non-nuclear weapon states and even terrorist groups.[5] Any assessment of the potential future availability of NEM, moreover, must include not only military stocks of these materials but also the NEM in research reactors and the growing quantities of it in civilian nuclear power programs.

Table 1. World Stocks of NEM (metric tons)[7]

	Military	Civil	Total
HEU	1840	60	1900
Plutonium (unirradiated)	260	230	490

The International Atomic Energy Agency (IAEA) definition of a "Significant Quantity" (SQ) – enough for a weapon – is 25 kilograms of HEU or 8 kilograms of Plutonium. Global NEM stocks are greater than 100,000 SQ.

The monitoring challenge is further compounded by the physical characteristics of nuclear weapons and NEM (e.g., radioactivity, toxicity, etc.), and by the tension that exists between sharing stockpile information and maintaining the security of these stockpiles against attack, sabotage, and theft.

[5] Other concerns include the increasing number of weapons in nuclear-weapon states, the acquisition of nuclear weapons by states that don't yet have nuclear weapons but do have NEM (so-called "latent" nuclear states); and the illicit transfer to or theft by other states or sub-national groups intending to make nuclear weapons.

[7] Adapted from: David Albright and Kimberly Kramer, "Fissile Material Stockpiles Still Growing," *Bulletin of the Atomic Scientists*, November/December 2004, pp 14-16. See also the underlying analysis on the website of the Institute for Science and International Security, available as of August 20, 2004 at: http://www.isis-online.org.

The extent to which transparency and monitoring measures should be enshrined in formal agreements remains a point of contention. The 2002 Treaty of Moscow commits the United States and Russia to reduce operationally deployed strategic offensive nuclear weapons to 1700-2200 each by end of 2012. The Treaty does not cover nonstrategic weapons or non-deployed strategic weapons, and it includes no transparency or monitoring provisions. In addition, the declarations and monitoring mandated under START I expire in December of 2009. Negotiation of agreements with formal transparency and monitoring measures may be difficult and protracted, but may be needed for the most stringent measures and for assurance of sustainability.

Nuclear Weapons and Nuclear Weapons Components

A comprehensive weapons monitoring regime would have many elements. The necessary technical tools are either available today, or could be available with some additional development, to support significantly enhanced transparency and monitoring for declared stocks at declared sites throughout the nuclear weapon life cycle.

- Developments in cryptography now widely used in banking and other commercial transactions offer a way to exchange and grant selective access to sensitive information about nuclear weapons that countries would not be willing to share more openly and comprehensively because of security concerns.
- Methods are available to examine from a short distance the radiation from a nuclear weapon or to interrogate a declared weapon container with an external radiation source. The radiation signature can be matched against templates of actual nuclear weapon signatures, or some portion of the radiation signatures can be singled out to identify attributes that confirm that the object is indeed a weapon. These techniques permit identification without revealing sensitive weapon design information. For example, table 2 gives data from a demonstration of the Trusted Radiation Identification System (TRIS). A comparison of the radiation signature of a weapon with a template taken from a weapon of the same type consistently produces a score (reduced chi-square) of about one, indicating a match, while the signatures of other types of weapon or weapon component clearly do not match.
- A wide array of tags and seals, ranging from bar codes and tamper-indicating tape to electronic chips, can be applied to weapons containers and storage rooms. Some such systems can be interrogated remotely to check their status.
- Monitored perimeter-portal systems, which exploit radiation and other distinctive signatures, can be confirm that what enters and leaves any given facility is consistent with declared activities.
- Facilities and areas within facilities can be equipped with appropriate sensors and accountability systems to monitor declared activity and detect undeclared activity, the recordings from which can either be examined during periodic inspections or uploaded via the Internet or satellites for transmission to a monitoring center.

This array of tools makes it possible to contemplate a set of transparency and monitoring measures that would give a high level of confidence in the accuracy of declarations of weapon stocks. These measures could be undertaken unilaterally or through formal agreements. In general, tools and measures that provide a higher degree of confidence come at the cost of greater intrusiveness and potential impact on normal operations and require more effort to protect sensitive weapon design information.

Even a modest subset of the measures outlined here could provide a degree of openness concerning weapon stockpiles and a framework for access to weapon sites that would greatly ease the difficulties of cooperation to improve security of nuclear weapons everywhere against theft or unauthorized use. For the more demanding purpose of monitoring agreements to control or reduce the stocks of nuclear weapons held by nuclear weapon states, the more intrusive measures would also be required.

Nuclear-Explosive Materials

Nuclear-explosive materials are readily convertible by nuclear weapon states (or other states or groups that have knowledge of nuclear weapon technology) into the components of actual weapons. The size of the NEM stock determines, to a reasonable approximation, how many weapons of particular types could be made. The difficulty of producing such materials means, moreover, that their acquisition is and will remain a limiting factor for states or subnational groups aspiring to make such weapons.

The basic structure of transparency and monitoring for NEM is parallel to that for nuclear weapons and nuclear weapons components. A NEM monitoring system could include comprehensive declarations of fissile material quantities and locations that include information on chemical forms and isotopic composition, NEM surplus to military and civilian needs, and provisions for inspection of all declared facilities as well as of any undeclared suspicious activities.

Transparency and monitoring can be made easier by reducing stocks and flows of NEM throughout the fuel cycle. This can be accomplished through the accelerated down-blending of excess HEU for use as reactor fuel, replacing HEU fuels in research reactors and the disposition of excess plutonium by conversion to mixed-oxide fuel for civil reactors or immobilization with radioactive waste. An international cutoff of NEM production for weapons and designing nuclear fuel cycles for civil reactors that minimize or eliminate the vulnerability of NEM would greatly reduce the risk of NEM loss, as would the centralization under international control of all facilities capable of enriching uranium or separating plutonium.

Related measures that would assist international efforts to increase transparency and monitoring for NEM include the continued substantial improvements in national systems of Material Protection Control and Accounting (MPC&A) and strengthening the IAEA safeguards regime, including the universal application of the Additional Protocol and increasing the IAEA's manpower and funding.

Improved management and decreased inventories of NEM would become increasingly crucial if lower limits were agreed on total warhead stocks. The lower such limits became, moreover, the greater would be the need for reduced NEM stockpiles and high confidence in monitoring the remaining stocks. While technologies exist to achieve greatly improved monitoring for NEM, a strengthened international consensus on the value of doing this will be needed to solve associated problems cooperatively.

Clandestine Stocks and Covert Production

As noted above, methods are available to verify with high confidence declarations of nuclear weapons and NEM stocks. But undeclared weapon stocks could exist, either through the clandestine retention of existing nuclear weapons, or through the clandestine production of nuclear weapons from hidden stocks of NEM. In addition, NEM for weapons might be produced clandestinely or diverted covertly from peaceful nuclear power programs. Tools for detecting clandestine stocks include National Technical Means (NTM), human sources, audits of records, and other physical evidence ("nuclear archaeology"). A state might confidently hide enough NEM for tens (China) to hundreds (Russia) of weapons. The potential for clandestine activities in these categories poses the largest challenges to efforts to strengthen transparency and monitoring for nuclear weapons, components, and materials on a comprehensive basis.

Production of NEM is difficult to hide. The ability of U.S. intelligence agencies to identify the emergence and evolution of nuclear weapon programs is one indication of the likelihood of future success in detecting covert production. Historically, U.S. intelligence has become aware of programs to develop nuclear weapons relatively early and well in advance of the production a weapon. U.S. intelligence has detected every program and identified production facilities, before significant quantities of NEM were produced in the Soviet Union, China, Israel, India, Pakistan, South Africa, Iraq, North Korea, and Iran. Estimates of the date of the initial fabrication of an actual nuclear device and future inventories of materials and weapons have often underestimated or overstated actual capabilities, however. Methods for detecting and evaluating clandestine efforts—in particular, NTM and environmental sampling—have improved over time and should continue to do so.

Given the already extensive knowledge of existing nuclear programs, the additional information that would result from the process of verifying declarations, the new inspection capabilities provided by the IAEA Additional Protocol, and the demonstrated capabilities of NTM, it is unlikely that any state could develop or reconstitute a complete and covert nuclear weapon production program that would not be discovered over time. If, however, undeclared stocks of NEM exist or can be diverted without detection from civilian stocks or production facilities, then it is much more likely that the assembly of new weapons could escape detection. Where concerns about compliance exist, the synergistic effect of multiple technical and management measures, supported by increased transparency and robust national technical means of intelligence collection, could reduce the risk that significant clandestine activities would go undetected and over time could build confidence that verification was effective.

Conclusion

Current and foreseeable technological capabilities exist to support verification at declared sites, based on transparency and monitoring, for declared stocks of all categories of nuclear weapons—strategic and nonstrategic, deployed and nondeployed—as well as for the nuclear-explosive components and materials that are their essential ingredients. Many of these capabilities could be applied under existing bilateral and international arrangements without the need for additional agreements beyond those currently in force.

Table 2. Trusted Radiation Identification System (TRIS) Template Identification Demonstration

	Template for Weapon Type				
Object	**A**	**B**	**C**	**D**	**E**
Weapon Type A, #1	0.8*	92	32	7.7	42
Weapon Type A, #2	0.9	90	31	8.2	45
Weapon Type A, #3	0.8	91	32	8.5	45
Weapon Type B	496	0.8	140	336	491
Weapon Type C	63	43	0.9	34	128
Weapon Type D	11	102	26	0.6	46
Weapon Type E	55	174	86	31	1.0
Pit, Type A	558	91	319	547	794
Pit, Type E	858	203	566	821	1071
CSA, Type A	52	118	88	64	66
CSA, Type E	27	156	77	22	6.4

* The "reduced chi-square" is a measure of the goodness-of-fit between the object's spectrum and the template. The gamma-ray spectrum between 80 and 2,750 keV was divided into 16 groups (two of which are discarded) and the number of counts in each group for the object and the template was computed; the reduced chi-square is the sum over all groups of the squared difference in the number of counts for the object and template divided by the variance, divided by the number of degrees of freedom.

SOURCE: D.J. Mitchell and K.M. Tolk, "Trusted Radiation Attribute Demonstration System," *Proceedings of the 41st Annual Meeting of the Institute of Nuclear Materials Management* (Northbrook, IL: Institute of Nuclear Materials Management, 2000).