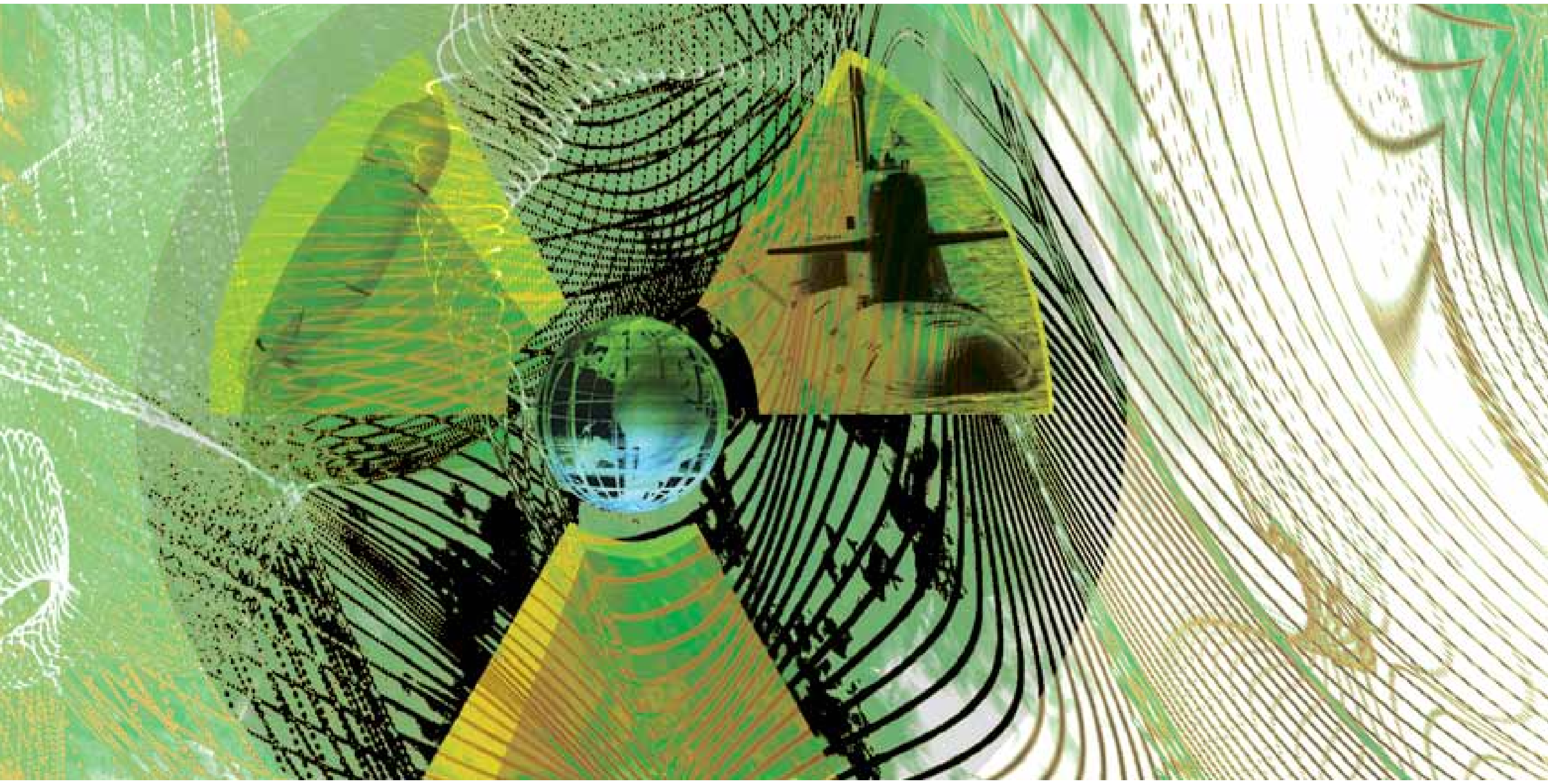
Technical Steps to Support Nuclear Arsenal Downsizing

A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS



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Executive Summary

There is a long history of US Presidents working to reduce the role and the spread of nuclear weapons. Most recently, President Obama voiced America's commitment "to seek a world without nuclear weapons," while clarifying that "as long as these weapons exist, the United States will maintain a safe, secure and effective arsenal."

Science and technology (S&T) will play a critical role in advancing the US plan to balance deterrence with downsizing the US nuclear arsenal. In particular, S&T are essential to enable three key goals associated with this plan:

1) verifying the process of downsizing and dismantling stockpiles;

2) sustaining the capability and expertise to ensure that the remaining arsenal is safe, secure, reliable and effective for as long as is necessary; and,

3) ensuring the peaceful use of fissile materials.

Consistent with that plan, we recommend the US take the following steps to allow S&T to more fully sustain and support nuclear arsenal downsizing and nonproliferation:

To support the goal of verifiable downsizing and dismantlement:

- **Declassify the total number of US nuclear weapons – deployed, reserve and retired – and encourage other nuclear armed countries to do the same.**
- **Establish international centers for verification research and validation to serve as test sites for assessing technologies and methodologies.**
- **Support R&D and demonstrations of "nuclear archeology" – a method for examining facilities to determine past material production – as a step to developing an internationally accepted capability to validate fissile materials declarations.**

To support the goal of sustaining the capability and expertise:

- **Refurbish elements of the US nuclear weapons infrastructure needed to sustain a smaller nuclear weapons stockpile.**
- **NNSA and its laboratories must adapt for the broader nuclear security mission that stockpile reduction will bring and for the national nuclear security roles that they will play.**

To support the goal of ensuring peaceful uses of fissile material:

- **Sustain federal investments in key programs including those to enhance safeguards, detect undeclared nuclear facilities, and address potential risks associated with global growth of nuclear expertise.**
- **Elevate the priority of non-proliferation in the NRC licensing process.**
- **Establish a program of information sharing among nuclear-related industries.**

Taken together, these steps will provide a strong S&T foundation for nuclear arms reduction proposals and nuclear nonproliferation goals.

Introduction

The current global effort to downsize nuclear arsenals is driven by several factors: the willingness of the Obama Administration to reengage the arms control process and to push for lower numbers as the START I Treaty expires; the anticipated pressures from non-nuclear weapons states before and during the 2010 Non-Proliferation Treaty (NPT) Review Conference; and the proposal by Schultz, Perry, Kissinger, and Nunn that setting a goal of zero nuclear weapons is both timely and credible.[1]

Nations acquired their nuclear weapons capabilities at great cost to address their most fundamental security concerns. Before reducing their arsenals these nuclear-armed nations must be assured that they will continue to be able to meet those critical security needs.

While individual nuclear-armed nations may undertake unilateral reductions or even the total elimination of their arsenals, it is more likely to assume reductions will come as a result of negotiated actions undertaken with some or all remaining nuclear-armed nations. The willingness to pursue and sustain arsenal reductions will ultimately depend upon how each nation envisions its ability to balance threats and opportunities against decreased nuclear capabilities.

Measured steps are essential to progress towards the eventual elimination of nuclear arsenals. Science and technology (S&T) will play a critical role in balancing deterrence with nuclear arsenal downsizing and in achieving nuclear nonproliferation objectives. In particular, S&T can help manage three key goals associated with this vision: 1) verifying the process of downsizing and dismantling of stockpiles, 2) sustaining nuclear weapons capability and expertise for as long as is necessary, and 3) removing the capabilities for reversals through various confidence-building measures, in particular by ensuring the peaceful use of fissile materials.[2]

These three goals have very particular embedded scientific challenges. For example, as the numbers of deployed strategic nuclear weapons in the US and Russian arsenals are reduced to the range of 1,000, agreement between the United States and the Russian Federation will be required to develop S&T requirements that include technologies and protocols to increase the transparency of nuclear weapon and component stockpiles. These include steps to:

- **Establish credible baselines for material and weapons accounting; and,**
- **Count warheads on launchers and verify weapons and warheads in storage and in various stages of dismantlement.**

While other nuclear states would not be necessary in discussions at this level, their involvement would be valuable in follow-on treaties to seek even further reductions in weapons stockpiles.

At reductions to a level of several hundred, technical requirements will have to expand to include, for example, technologies and protocols to:

- **Count all deployed and reserve weapons and warheads;**
- **Monitor warhead and delivery system production facilities;**
- **Track with quantitative measures the movement of weapons and materials, whether deployed, in dismantlement or in disposal;**
- **Assess the production capability of nuclear states; and**
- **Increase substantially the security and transparency of the nuclear fuel cycle.**

To reach much lower levels (e.g., below 100 per country), there will have to be an international regime established that eventually includes all nuclear-armed states and possibly latent nuclear states. The requirements, at a minimum, will include robust and proven technologies and protocols to:

- **Support rigorous multi-national inspection agreements for declared weapons and facilities;**
- **Regulate and monitor the infrastructure necessary to reconstitute a nuclear force;**
- **Conduct comprehensive searches for possible hidden weapons and weapons programs; and**
- **Ensure international transparency in relation to disarmament and control of all peaceful and non-explosive military uses of fissile material, including all aspects of the nuclear fuel cycle.**

At each stage, methods for building transparency and confidence between all involved nuclear states are critical. In addition, international agreements and sanctions must be in place to deal with violator states and rogue actors.

This report identifies several steps that can be taken to advance the S&T needed to support such nuclear arsenal downsizing. While we believe these are necessary steps, we recognize they will not be sufficient. Secure downsizing of global arsenals will also require diplomatic measures and protocols that are not the subject of this report. Ultimately, this effort may require a significant transformation of the international system.

Verifying Downsizing and Dismantlement

DISCLOSURE OF STOCKPILES

An essential component of robust future nuclear arms reduction agreements will be the declaration of existing stockpiles of weapons and fissile materials to establish baseline data against which to measure future reductions. Without a declaration that specifies how many and what kind of nuclear materials are where, it will be difficult - if not impossible - to verify whether a country is complying with the agreed limitations.

To establish a meaningful baseline for reductions, this declaration should include the number of each type of weapon that is deployed, is not deployed (whether in an active or inactive reserve), and in the inventory for dismantlement. The accounting should include all weapons, regardless of how they are identified (e.g. as strategic or tactical), plus all inventories of fissile material. Similar declarations of inventories were an essential initializing step for the Intermediate-Range Nuclear Forces and the Conventional Forces in Europe Treaties.

This declaration can provide the basis for building the confidence needed to make sizeable reductions and to analyze and plan the cooperative verification policies and technologies required to ensure that each country is abiding by the agreements. The U.S. could take a unilateral step in declassifying the number of each type of weapon in its nuclear stockpile while simultaneously working with Russia to reciprocate as a condition for future arms reductions. A Russian disclosure, even if made privately to US officials, would be a major breakthrough in transparency that could catalyze additional global activity on nuclear disarmament. Further public declarations could follow as confidence and transparency increase.

Official disclosure of stockpile numbers by the US and Russia is key to expanding agreements from bi-lateral to multi-lateral. Without such a step, it is unlikely that France and China will be willing to engage in arms reduction agreements. While the UK and France have been open to providing information on their deployed stockpiles, other nuclear-armed states have not. Engaging the nuclear-armed states that are not Parties to the Non-Proliferation Treaty (NPT) will be more complex and will likely only be achieved when progress among the P5 (US, UK, France, Russia and China) is tangible, if then. Information on stockpiles in each nuclear-armed state would allow each country to evaluate its own requirements for cooperative verification

RECOMMENDATION

To facilitate international monitoring and accounting, declassify and make public the total number of US nuclear weapons — active deployed, active and inactive reserves, and retired — together with all inventories of fissile material committed to nuclear weapons use, committed to non-explosive military use and to peaceful use, and encourage other nuclear-armed states to do the same — independently or as part of future arms agreements.

and monitoring as it calculates the impact of nuclear arms reductions on its national security.

The inventory (amounts, location, and form) of highly-enriched uranium and plutonium in all nuclear-armed countries should be included as another confidence-building measure because it provides an indication of a country's ability to re-arm in the future.[3] This is an important first step in producing a meaningful fissile material cutoff treaty, which constrains all stocks, not just newly produced material. As the numbers of weapons are reduced, similar attention must be paid to monitoring delivery systems, particularly those with dual capabilities.

VERIFICATION TECHNOLOGY

As the numbers of nuclear weapons decrease, any uncertainties in the arsenals of other states can become more destabilizing since the number of weapons needed by them to pose a significant military threat becomes correspondingly smaller. Simply stated, security at 1500 deployed weapons may be easier to realize than at 25. To accept a commitment to a reduction, each nuclear-armed state must be confident that its security will not be jeopardized. The verification technology needed to sustain progressive reductions will provide each state the evidence that all nuclear-armed states are fulfilling their commitments, giving each state added confidence that the threats of nuclear conflict are diminishing. Each nuclear-armed state must be confident that the verification methods applied within its territory are not used to acquire any information which is not clearly set forth in verification protocols, especially not any sensitive information (restricted data) relating to nuclear weapon design or manufacturing.

The verification challenges are many:

- **First: determine the requirements to verify inventories of special nuclear material, production capabilities, and numbers of weapons;**
- **Second: assess the state of technology necessary to meet those requirements;**
- **Third: develop any needed science and technology (S&T);**
- **Fourth: determine whether that S&T could reveal information that would compromise U.S. national security;**
- **And fifth: develop methods to protect the security of our assets.**

A further challenge is to make certain the verification happens in a manner that does not reveal weapons details to non-nuclear weapon states as proscribed by Article I of the Nuclear Non-Proliferation Treaty, or classified information reflecting national security interests and controlled through relevant U.S. laws and regulations.[4]

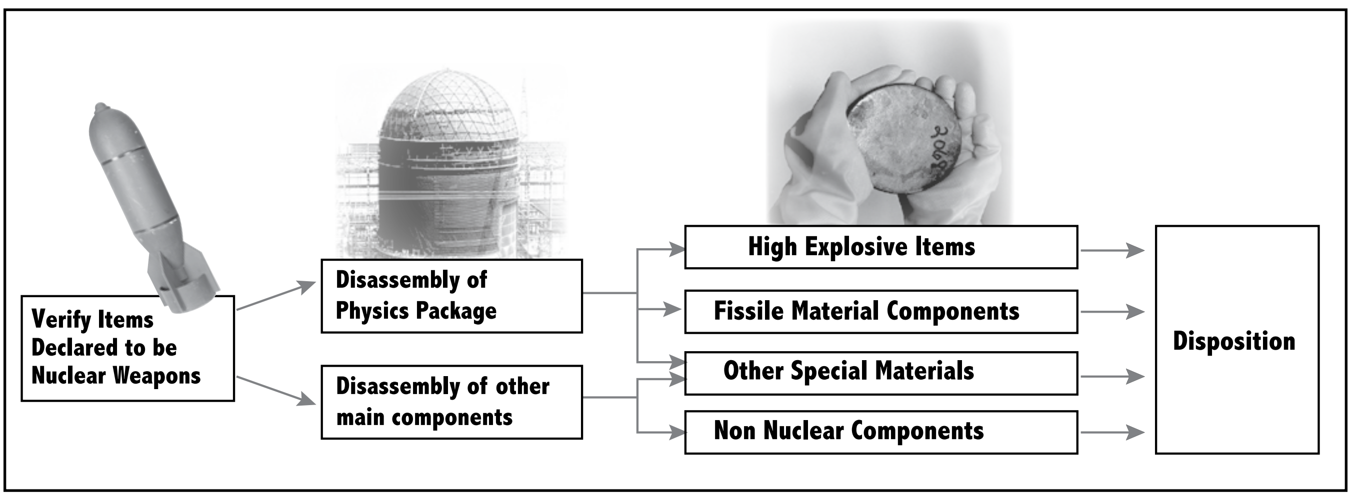
Recent monitoring and inspection practices affecting the United States and Russia focused on verifying the numbers and locations of launchers and delivery platforms (and hence deducing the maximum number of warheads that could be deployed on strategic delivery systems). Modest reductions in U.S. and Russian stockpile numbers (e.g., 1500) may rely primarily on these existing practices while more significant reductions in total stockpiles (1000 or fewer) will likely require the use of more intrusive techniques to verify numbers of warheads. If and when reductions in all nuclear arsenals are verified by multilateral agreements the techniques employed and the inspectors must guarantee international assurance of compliance.

Each reduction involving nuclear weapons offers possibilities for monitoring and verification that can confirm that the states are honoring their commitments. Verification will likely include two complementary efforts: confirming declared activities and detecting clandestine materials or operations. Science and Technology and Research and Development are needed to enable such steps.

In terms of the diagram below, the verification of declared disposition is straightforward, paralleling IAEA safeguards on *direct-use* fissile material in non-nuclear weapon States. Such verification will require the use of specialized methods and managed access.

FIGURE 1

Generic dismantlement verification process.



A number of storage and dismantlement verification technologies — focused primarily in the areas of radiation detection, remote monitoring, and tamper-indicating devices — were developed over the last 15 years to support a variety of negotiations and exercises. These technologies may be applicable to support verification throughout the dismantlement process, including monitoring and verification of weapons removed from operational deployment through various storage conditions and disassembly processes to the end states of disposed uranium and plutonium.

High-quality radiation measurements are central to determining that a weapon or material is – or is not - the item that it is declared to be. Because of the sensitive information that could be revealed by these measurements, information protection technologies, or "information barriers", are available to permit use of these higher-confidence techniques without divulging sensitive or classified information. The Department of Energy (DOE) and the Department of Defense (DoD) jointly sponsored a program of development at the national laboratories during the late 1990s that resulted in information barrier designs, their incorporation into advanced measurement systems for potential applications, and the initiation of cooperative development programs between U.S. and Russian Federation laboratories. Separately, the Trilateral Initiative between the International Atomic Energy Agency (IAEA), the U.S., and the Russian Federation made substantial progress in developing information barrier design concepts and a legal framework and deployment arrangement.

NNSA has continued to support development of second and third generation versions of these radiation detection and information barrier techniques over the last decade, including limited engagement with scientists from other countries. Additional development is needed to bring these technologies to a level of accuracy where they can be confidently deployed in treaty inspection protocols. In particular, these development efforts would focus on the required science and engineering for specific applications, authentication processes to ensure the information provided by these systems can continue to be trusted by all parties, and comprehensive adversarial analysis, commonly called "red teaming."

While current information barriers are not perfect, substantial progress has been made. In the near-term, the negotiation of specific treaties and agreements between the Russian Federation and the United States involving deep reductions in their stockpiles may require the inclusion of innovative methods and practices in which US and Russian scientists, security analysts, and negotiators have greater confidence as a result of this work. Additional work will be needed before security officials in the U.S. and Russia would grant approval for the IAEA to carry out any kind of monitoring and before the IAEA would accept the responsibility for monitoring weapons-related activities in the U.S. and Russia. Expanding this type of verification exercise to other nuclear-armed states would benefit the eventual application of universal measures.

As these techniques are considered for use in inspection protocols and transparency measures for warhead verification, dismantlement monitoring, and material storage, they must be critically reviewed by DoD, NNSA, the Department of State (DoS), the counter-intelligence community, and the National Security Agency (NSA). Indeed, each nuclear-armed state, as it enters into treaties and agreements that would rely on these methods, must determine the acceptability of obligations and verification measures according to its own national security apparatus. Each state, as well as the IAEA, would also have to evaluate and select authentication measures to ensure that the results are meaningful. These reviews will certainly result in design refinements and may reveal the need for new advances in information protection, radiation measurement techniques, and remote monitoring technologies.

As bilateral US-Russian nuclear stockpile reductions result in arsenals that no longer dwarf those of other nuclear-armed states, further reductions will require working with scientists and negotiators from a broader range of countries. At some point, it may be useful to monitor warhead dismantlement in such a way that the specific model (e.g., W88) can be determined. Template methods (matching a particular radiation signature) may be useful in addition to attribute measurements (ensuring that certain measured levels exceed defined limits in order to increase confidence in the contents) and may prove to be very attractive for some applications. A distinctive template would be created for each model and individual samples would then be compared to the templates on file to confirm (or reject) a declared item. The templates could include, for example, a combination of passive radiation signatures and/or radiation signatures caused by subjecting an item to a stream of neutrons and/or gamma rays.

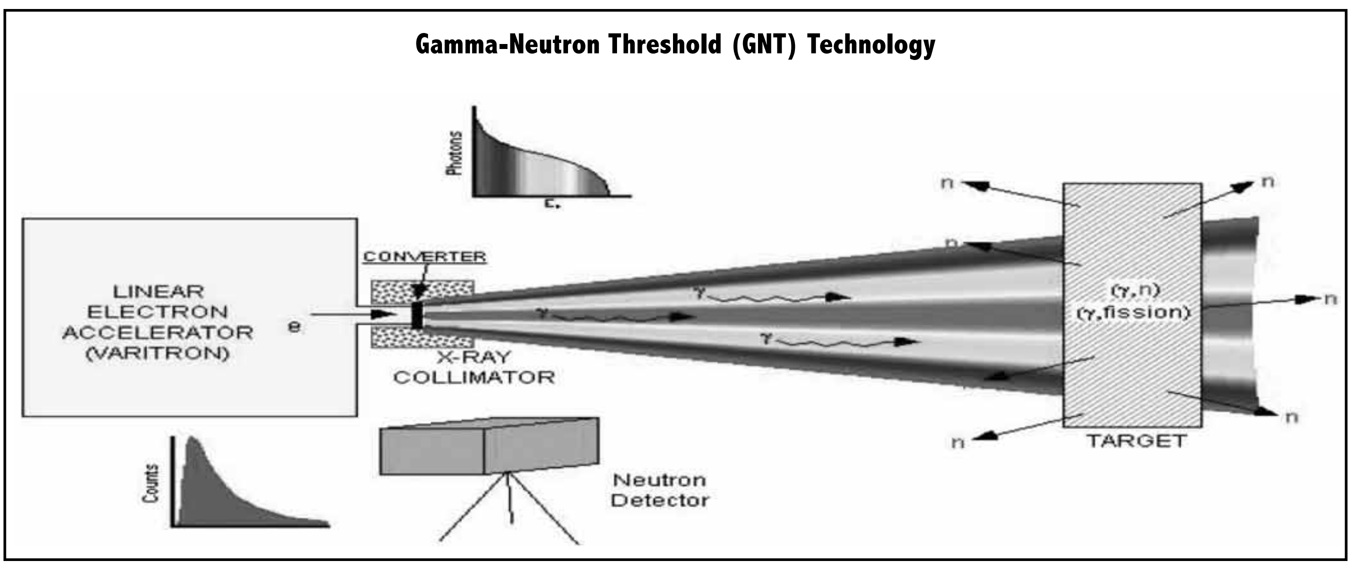
Passive detection techniques are excellent in many situations but they are inherently limited by the strength of the signal that reaches the detector from the measured item. For some materials or in cases of inadvertent or intentional shielding, active systems may be required.

In active detection systems (Fig. 2), a photon or neutron beam could be used to stimulate a response from an item that is predictable based on the

FIGURE 2

Depiction of Pulsed Photonuclear Assessment active measurement technique.

(image courtesy Idaho National Laboratory)



radioactive material within the item.[5] A transition from passive radiation measurement techniques to active measurement techniques could provide higher confidence in weapon and material identification but would require a challenging confidence building step for implementation. Additional materials control and accounting methods and remote monitoring techniques will also emerge as agreements are negotiated with more states and the expertise and creativity of the international arms control and nonproliferation technical community are engaged.

The techniques that have received the most attention for the purposes of warhead or material verification involve passive gamma and neutron measurements. Medium resolution gamma measurements (e.g., by sodium iodide (NaI) detectors) could be used to indicate the presence or absence of plutonium and to match weapon template signatures. High-resolution gamma measurements (e.g., high-purity Germanium detectors) provide, in addition, the ability to determine isotopic ratios indicative of weapons grade plutonium and americium content, thus revealing whether the plutonium is weapons grade, and the time since the last americium separation. In general, neutron measurement methods ranging from simple neutron counting to more complex coincidence and multiplicity techniques have been used to determine plutonium masses.

Measurements of some highly-enriched uranium (HEU) characteristics and material mass using specially-developed gamma measurement techniques have been shown to be possible under some carefully-controlled conditions. It is likely that high confidence measurements of HEU characteristics will require the use of active interrogation techniques. Experiments and demonstrations using a range of measurement systems – sodium iodide, high-purity germanium, and helium-3 detectors, as well as neutron multiplicity counters – have been performed to determine the feasibility and applicability of these techniques for potential verification measures.

Authentication of the equipment (ensuring that the measurements taken and answers given can be trusted when the equipment has been out of the inspector's immediate control for extended periods of time) also poses technical challenges. Research and experimentation have been actively ongoing for a wide variety of applications in this area over the last few decades. A number of promising methods exist for examining the equipment itself, the tamper-indicating measures that protect it, the software it employs, and the data that it provides. A strategy for employing these techniques and a venue for testing them in a range of scenarios are important next steps in getting these technologies to the field. Remote monitoring systems - integrating such elements as infrared and video cameras, radiation portal monitors, motion detectors, encrypted RF communications, advanced intrusion detection, innovative tag and tamper-indicating technologies, and change detection methods - have been developed and implemented to secure a variety of facilities and operations. These systems are key to the secure storage of sensitive materials and warhead systems of concern in this study.

In addition to these measuring and inventory technologies, the development of modeling and analytical capabilities to estimate the size of production complexes and assess production rates would be a useful complementary tool.

INTERNATIONAL CENTERS FOR VERIFICATION RESEARCH AND VALIDATION

Most, if not all, of the technologies described above as candidates for future arms control verification or confidence-building activities, will require some form of cooperative development before implementation. Each of these technologies needs to be tested by multiple parties to ensure robustness and that all parties are confident in the technology's operation and function.[6] One or more international verification centers would help foster the growth of a new generation of nonproliferation experts on an international level and contribute to the maturation process for new technologies to be used in future arms control activities.

The United States and Russia already have many years of experience in sharing verification technologies through the Warhead Safety and Security Exchange (WSSX) program and other initiatives. The establishment of international verification centers would allow for additional cooperative verification and transparency projects between the two countries in an environment that could stimulate broader multilateral education and involvement. This, in turn, could motivate the development and implementation of these systems in support of a wide variety of treaties and agreements.

Further, such verification centers offer the opportunity to develop a truly international approach to the design, testing, and implementation of these technologies, provide places to consider and address the varying concerns, capabilities, and perspectives of non-nuclear weapon states as well as nuclear weapon states beyond those actively involved in the past (i.e., Russia, the U.S., and the UK). Such centers could also provide a useful forum for interactions with the IAEA so that the considerable experience base developed by this agency in formulating multilateral technical solutions in the nuclear safeguards, nuclear security and civilian nuclear power arenas can be brought to bear around this new set of issues. In addition, these centers will provide a venue for university experimentation and partnerships so that key technological advances, innovative academic talent, and critical scholarly thinking can be integrated into the technology development process.

One technology area that would benefit from the establishment of verification centers is that of information barriers. As noted earlier, many of the basic concepts currently proposed were developed by U.S., Russian and IAEA teams, with first and second generation systems designed, built, tested, and evaluated in conceptual and prototype form in the 1990s. A number of U.S. and Russian laboratories have been involved in proposing and demonstrating a range of information protection techniques, with limited work currently ongoing on third generation systems. The designs developed would greatly benefit from both a reinvigorated review process within each country's framework as well as critical review by technologists from a range of other countries. These design approaches would also benefit from a serious evaluation of technological advances of the last decade for counterterrorism, financial security, and information management applications to see how they may be integrated with earlier concepts. It should be noted that application of information barrier principles to active interrogation systems (including imaging systems) and measurement systems that are not radiation-detection-based lags behind the development of approaches for passive radiation detection systems.

RECOMMENDATION

Establish international centers for verification research and validation to serve as test beds for developing and assessing technologies and methodologies and for building confidence between nuclear armed states.

Significant precedents exist that may serve as models for establishing these centers, including U.S. and Russian Federation transparency projects between design laboratories; Group of Scientific Experts experiments in support of CTBT technology development; IAEA monitoring of civilian nuclear operations; the Joint Verification Experiments (JVE) between the US and USSR for the Threshold Test Ban Treaty, and UK and Norway dismantlement transparency exercises.[7] The classified nature of the technologies, measurements, materials, and operations involved will require significant government oversight. Any centers established will need to balance the attributes of operational realism, classification sensitivities, technical expertise and required radioactive sources.

There are a number of facilities around the world that may meet the desired characteristics of such centers and build on the legacy of international cooperation mentioned above. The UK is working on a "disarmament laboratory." The U.S. has an extensive set of facilities at Kirtland Air Force Base in Albuquerque, New Mexico, that are specifically designed for arms control technology development and exercises including the DoD's Defense Threat Reduction Agency (DTRA) Technical On-Site Inspection facility (recently operated under the name Technical Evaluation Assessment Monitor Site), Sandia's Cooperative Monitoring Center, and specialized bunkers with facility-to- facility connections to simulated storage facilities in Russia. The Nevada Test Site (NTS) has several nuclear facilities, including the Radiological Nuclear Counter-Terrorism Evaluation Complex (RNCTEC) and the Device Assembly Facility that could be used for simulated exercises and real dismantlement activities, access to Category I radiation sources for demonstrations and testing, and a range of facilities that can be configured readily to simulate various portions of the deployment and disassembly cycles. NTS can also accommodate foreign visitors, as was witnessed by the Joint Verification Exercise in 1988. And, it is currently establishing a National Security Center that would be ideal for testing verification techniques. The Russian Federation has conducted a number of experiments and demonstrations as part of cooperative nonproliferation programs with the U.S. at various Rosatom and Ministry of Defense facilities. The European Commission Joint Research Centre at Ispra, Italy, hosted a Trilateral Initiative workshop and expressed interest in creating an international center for nuclear disarmament research under the auspices of the IAEA.

Such centers should be chosen with specific security missions and corresponding security arrangements in mind. International centers should be established with consideration of the ability to allow participation of experts from all nuclear-armed states. The work these centers provide will facilitate future treaties and agreements.

NUCLEAR ARCHEOLOGY

As noted above, for sustainable progress to be made towards the goal of ultimately eliminating nuclear weapons, nuclear arms treaties will require that states declare fissile material stockpiles. The accuracy of these declarations can be confirmed to some degree by examining the records states provide. When doubts arise as to the accuracy of the records states will apply various verification methods to test the veracity and to reduce willful cheating. One technique called "nuclear archeology" may offer new and promising tools to certifying completeness and accuracy.

In general, nuclear archeology is the study of nuclear facilities or fissile materials to determine historical information, to identify the source or morphology of specific material samples. Nuclear archeology employs a set of methods and tools that can be used to characterize past fissile material production activities. It does this by using measurements and samples at production and storage sites and direct measurements of samples of fissile materials or related feed and waste materials. While the technique cannot remove all uncertainty in a declaration, it can provide additional evidence of the overall operation of nuclear facilities and therefore identify amounts of plutonium and uranium production.

In one application, the isotopic composition of a reactor core and other components are measured with the goal of determining the reactor's operating history. Long-lived radionuclides produced by neutron absorption in naturally occurring nuclei will reside in the permanent components of a reactor core. By analyzing several samples of concentrations of the radionuclides in the reactor core and combining that with assumptions about the design and operation of the reactor, accurate upper limits can be determined of how much plutonium could have been produced by that reactor. That estimate can then be compared to the state's materials declaration and the operating records provided. While the technique cannot remove all uncertainty, it can provide additional evidence of how nuclear facilities have operated and therefore identify amounts of plutonium and uranium production.

U.S. experience shows that, even with full access and disclosure, it is often difficult to accurately account for all materials produced. This fact will need to be taken into account to ensure that a procedure designed to increase confidence does not inadvertently reduce it. One goal might be to have various states provide national data in order to establish an acceptable international range for "Material Unaccounted For."

RECOMMENDATION

Support nuclear archeology R&D and demonstrations as a step to developing an internationally accepted capability to validate fissile materials declarations.

Analyzing specific samples of fissile material may allow for the determination of the date and site of production and the facility-specific process characteristics to be identified. Verifying plutonium declarations is easier than verifying uranium declarations. Uranium characteristics can be determined through the measurement of the minor isotopes (esp. ^{232}U and ^{234}U, ^{236}U after irradiation) and protactinium in-growth, thus providing additional data to verify the accuracy of the uranium enrichment records.

The fundamental techniques of nuclear archeology, while well established,[8] have not, to date, been applied rigorously to the validation of materials declarations. It is our opinion that an R&D effort connected to demonstration projects with U.S. and Russian reactors and enrichment facilities can provide the necessary foundation for incorporating this technique into future reduction initiatives.

Sustaining Capability and Expertise

THE NUCLEAR WEAPONS INFRASTRUCTURE

Each nuclear-armed state will require that its national security not be undermined as progress is made towards downsizing nuclear arsenals. Obviously, the threats posed and the functional capabilities of a state will change over time, with or without arsenal reductions. Each state is more likely to accept new commitments to increasing reductions if it is proceeding from a position of strength, confident in its capabilities. Nuclear disarmament is likely to require a number of incremental reductions over time to carry out the associated changes and to adjust to the new realities.

At every point in this process, regardless of the size of the U.S. stockpile, it will be necessary to maintain the technical skills and special facilities to guarantee that remaining weapons will function if they are ever required to do so, and to verify they will remain safe against accidents and secure against unintended use. This can only be accomplished if steps are taken to maintain the nuclear design, engineering and manufacturing expertise to certify the safety, security, reliability, and effectiveness of all remaining weapons, and to maintain the capability to re-arm if other nuclear-armed states threaten U.S. national security. The Stockpile Stewardship Program has been remarkably successful in accomplishing this mission without nuclear testing for the past 15 years, but its continued success requires the support of the expertise and capabilities of the weapons labs, the Nevada Test Site, and U.S. production plants. Many of these skills and facilities cannot be found in universities, other government laboratories, or in U.S. industry today.

This nuclear weapons infrastructure is no longer directly proportional to the size of the stockpile because the number of skilled workers and facilities does not scale with the number of weapons. While such proportionality existed when the U.S. was designing, testing, and building a large number of weapons and types, today there exists a floor below which the size of the complex cannot go if it is to maintain *any* competence in nuclear weapons-related activities. Both the Obama Administration and Congress will need to recognize this fact, size the complex accordingly, and provide the funding to sustain it. As an example, reducing the number of weapons by 50 percent does not mean the number of plutonium experts can be similarly reduced since plutonium expertise is required to maintain all nuclear weapons and not just a particular system. In a similar argument, if the weapons program requires a nuclear facility to build or to examine plutonium pits, the equipment in the facility to handle 10 plutonium pits/year might be the same as handling 50/year or more.

Many recent high-level reviews of the current state of the U.S. nuclear weapons infrastructure have concluded that the U.S. must address the decaying infrastructure and the aging expertise to competently continue the mission of managing the stockpile through certifiable changes in the enterprise.

A group within the NNSA complex is studying and implementing ways to integrate the various capabilities across nuclear sites to reduce and remove redundancies. This group, the National Security Enterprise Integration Committee, includes senior representatives from the laboratories, the Nevada Test Site, and production facilities. It will be necessary to continually review downsizing and consolidation efforts to ensure the remaining skills and facilities are adequate to carry out the mission. However, the nuclear infrastructure requires a level of recapitalization that must be consistent with the projected needs of the stockpile for the next 20-30 years. This is estimated to be an expensive undertaking, but the alternative of operating outdated facilities could be more expensive, due to an inability to maintain the stockpile in these facilities (at any size) in a cost-effective and secure manner.

RECOMMENDATION

Refurbish elements of the US nuclear weapons infrastructure needed to sustain a safe, secure and smaller stockpile for as long as is needed.

For the stockpile stewardship program, the expertise must cover the theoretical and experimental base of the nuclear designs in our stockpile. This expertise covers a broad set of technical fields including nuclear physics and systems engineering, materials science, chemistry, computer science, and conventional high explosives. Some of these fields, e.g. actinide chemistry, have not been in great demand outside the nuclear weapons program and therefore it may be necessary, in certain disciplines, to subsidize university research and Ph.D. programs to provide the expertise needed to maintain the stockpile.

The expertise needed in the production complex to manufacture necessary replacement parts will also require attention because of significant retirements over the last decade. This challenge parallels the problems at the labs since production expertise results partially from the hands-on experience that is acquired by building or modifying actual weapons. A close collaboration between labs responsible for certification and plants responsible for production has always been important. As the weapons age, and materials or replacement parts are required, this collaboration will be critical to ensure the proper skills, tools, and processes are available to certify the weapons after production and prior to re-entering the stockpile.

SUSTAINING CAPABILITIES AT THE NUCLEAR WEAPONS LABORATORIES

As mentioned in the previous section, the human resources and expertise and the technical capabilities needed to maintain the nuclear weapons, non-proliferation, nuclear counter-terrorism and treaty verification programs of the United States do not scale in any simple way with the number of weapons in the stockpile. Both the National Nuclear Security Administration and the nuclear weapons laboratories must embrace the larger role of the nuclear security mission as the resources devoted to the stockpile mission itself are reduced over the long term. Within their nuclear security mission, the tools of the traditional nuclear weapons program are required to solve issues such as nuclear weapons control, inventory and dismantlement under treaty regimes, nuclear forensics and nuclear archaeology, identification and defeat of improvised nuclear devices, and intelligence studies. Additionally, the DOE/NNSA laboratories have contributed significantly to non-nuclear weapons programs and security programs outside the DOE, most notably to those of the DoD, the intelligence and law enforcement communities, and the Department of Homeland Security.

To sustain their capabilities over the long term, the nuclear weapons laboratories and NNSA must thoughtfully recast themselves for the larger national nuclear security mission, understanding that within their specific nuclear mission they must think as multi-program laboratories, not just as weapons design laboratories. Each of the nuclear weapons laboratories has specific successes of such behavior in individual isolated technical or disciplinary areas. There is opportunity for entrepreneurial behavior to become more generalized and thus enable attracting personnel and investment that will further the state-of-the-art intellectual and infrastructure capital capabilities needed to maintain the nuclear weapons, non-proliferation, nuclear counter-terrorism and treaty verification programs of the United States. The challenge to NNSA and its laboratories is one of both attitudes and practices.

RECOMMENDATION

NNSA and its laboratories must adapt for the broader nuclear security mission that stockpile reduction will bring and for the national nuclear security roles that they will play.

Ensuring Peaceful Uses of Fissile Material

As nuclear arsenals are substantially reduced, there will be an even greater need to manage fissile material and the growth of nuclear expertise. High confidence in the security mechanism to prevent nuclear terrorism and to insure the peaceful uses of fissile materials will be essential to significant downsizing. A strong nonproliferation regime and robust security at nuclear facilities that addresses the challenges of rogue states and terrorists, and limits the spread of sensitive nuclear technologies are central components for a world with fewer nuclear weapons. The resurgence in interest in nuclear power only increases the urgency and importance of taking steps now.

The U.S. has created important partnerships, such as the Cooperative Threat Reduction program, the Global Initiative to Combat Nuclear Terrorism, and the Proliferation Security Initiative to address many concerns associated with nuclear terrorism. While R&D is important to their success, these efforts generally do not support new R&D efforts to improve capability and are not relevant to this discussion.

FEDERAL PROGRAMS

There are numerous, well-established activities and programs set up to manage the security and peaceful uses of fissile material. This section identifies a few of these critical S&T-based federal programs. It is intended to illustrate the key role that S&T plays in achieving stable reductions.

Safeguards are essential to providing confidence in the peaceful uses of nuclear energy, and are implemented in various ways. The IAEA provides international safeguards; Euratom and the Argentine-Brazilian Agency for Accounting and Control of Fissile Materials provide regional safeguards; and various nuclear supply agreements provide bilateral safeguards.

Effective and efficient safeguards depend on technology and technical expertise. These technologies include methods to detect and measure quantities of fissile materials, information management and environmental sample collection and analysis systems, overhead imagery acquisition and analysis, and unattended and remote monitoring systems. Safeguards expertise requires an understanding of the complete nuclear fuel cycle, nuclear weapons proliferation pathways, the capabilities and limitations of safeguards technologies, and safeguards concepts and approaches.

Safeguards technology and expertise are also critical to monitoring the downsizing of nuclear arsenals, including a fissile material cutoff treaty, fissile materials disposition, and some aspects of overall weapons dismantlement. In addition, this technological expertise is used for nuclear security in a variety of ways to protect against terrorist threats to fissile materials and facilities.

In late 2008, NNSA began the Next Generation Safeguards Initiative (NGSI) in part to reverse a steady decline in safeguards R&D and technical expertise.[10] The NGSI focuses on five main areas: safeguards policy and outreach, safeguards concepts, technology, human resources, and infrastructure development. Strong fiscal support for NGSI is critical to ensure its appropriate integration with related programs within DOE/NNSA and other agencies. It is particularly important to further develop and improve methods to detect undeclared fissile materials and activities, and human resource development.

RECOMMENDATION

Sustain federal investments in key supporting activities including the Next Generation Safeguards Initiative, R&D on technologies to detect undeclared fissile materials facilities, and the Nuclear Security Assistance Program to address potential risks associated with global growth of nuclear experts.

For the past several years, the U.S. Department of State (DOS) has run a successful program to improve bioethics and biosafety among life scientists in Southeast Asia. In late 2008, DOS created the Nuclear Security Assistance Program (NSAP) program to work with nuclear scientists. Currently active in Morocco and Algeria, this program is expected to expand to eight more countries in the Middle East/North Africa region by 2011. This program focuses on smaller, fledgling nuclear programs in countries that do not yet have substantial existing facilities.

At present, the program addresses technical issues relating to civilian nuclear power and other topics requiring civilian nuclear expertise. Program activities include:

- **Providing training and community building to develop effective, low-cost educational opportunities for scientists and engineers to lead to the development and implementation of best practices in nuclear security and safety; and**
- **Funding design and construction of regional nuclear medicine facilities.**

One indication of program success for DOS would be the willingness of international partners and/or host states to bear a greater proportion of long-term costs and responsibility for the instigation of and sustainability of these training programs.

DOS initiated the program in the Middle East/North Africa region—where several countries expressed interest in nuclear power— due to existing area DOE programs. DOS plans to expand this program to other countries, but will require additional funding and resources. While working with Libya, Syria, Pakistan, North Korea and Iran would likely be productive, legal and political challenges remain. A small program to create a regional nuclear medicine center based in Libya was stalled in early 2008. DOS requires White House guidance for working with Syria; under the last Administration the DOS was not authorized to work with Syria. The current political climate makes it nearly impossible for DOS to engage with both DPRK and Iran.

Experts from non-governmental organizations, such as the World Institute for Nuclear Security, are working with DOS to identify in-country personnel needed for partnerships as well as how to assist in training. This program could be expanded to include other non-government organizations to help run training programs or regional workshops.

LICENSING

RECOMMENDATION

NRC should adequately address the non-proliferation threats of new technologies in their licensing process.

Nuclear arsenal downsizing is most likely to occur if the U.S. and others believe the problem of proliferation is addressed through all practicable means. The role of the licensing and regulatory communities in nonproliferation is often overlooked. To ensure appropriate regulatory and licensing framework, and, in particular, to ensure there is appropriate development and understanding of S&T within the regulatory and licensing cultures, nonproliferation considerations must be an integral part of the calculus in decision-making.

Over the next several years, the Nuclear Regulatory Commission will be reviewing license applications for new technologies that could carry substantial proliferation risks. As arsenals are downsized, high confidence must be maintained in the peaceful uses of fissile material and NRC assessments will thereby take on even greater significance.

The NRC's 2004-2009 strategic plan (NUREG-1614) details how the NRC will prevent any "instances where [NRC] licensed radioactive materials are used domestically in a manner hostile to the security of the United States."[11] The strategic plan also notes that the NRC will:

> *… coordinate with Federal and international counterparts to provide appropriate security and control to prevent the proliferation of special fissile materials and nuclear technology and to reduce the potential for harmful use of high-risk radioactive material.*[12]

The NRC has three nonproliferation-related roles and has responsibility to:[13]

- **Enforce US treaty and agreement obligations at domestic nuclear facilities;**
- **Enforce physical security and all other safeguards at domestic nuclear facilities; and**
- **To enforce export-import licensing regulations for specific lists of nuclear-related items.**

In addition, the NRC provides considerable consultation and training support for a wide variety of domestic and international nonproliferation activities.

Each of these requirements must be addressed during the licensing process. Prospective licensees must include specific details about how they intend to comply with physical protection and material accounting standards mandated by agreements such as the US-IAEA Safeguards Agreement and the Additional Protocol to that agreement. The NRC also issues import licenses for certain imported nuclear-related items.

While the NRC has laid out a compelling strategic plan that appears to include nonproliferation at the proper level of importance, it is critical that the NRC make nonproliferation a priority, in fact and in practice. At this time, based on publicly available NRC documents, nonproliferation is not an obvious part of the license evaluation.[14] The U.S. Congress should consider appropriate legislation to ensure adequate attention to nonproliferation over the long term.

RECOMMENDATION

Establish a program of information sharing among relevant nuclear-related industries.

INDUSTRY ROLE

Broadening industry involvement in nonproliferation could provide significant new capabilities to prevent the spread or diversion of nuclear, radiological, or dual-use material or technology. As a complement to existing government efforts industry can also be an important first line of defense in detecting and thwarting proliferation, such as illicit trade networks or insider theft. While the Nuclear Suppliers group is a valuable non-proliferation mechanism, the current level of information-sharing should be strengthened.[15] Such sharing will only be successful if it is sensitive to issues of proprietary information and marketplace competitiveness.

Independent analysis of this problem has considered how establishing effective information sharing can be a good business decision in addition to being a good national security decision.[16] The authors of this independent analysis surveyed dozens of companies to determine responsible and practical first steps and concluded:

> *"Because industry is closest to users of the goods and technology that could be illicitly diverted throughout the supply chain, industry information can potentially be more timely and accurate than other sources of information. Industry is in an ideal position to help ensure that such illicit activities are detected. This role could be performed more effectively if companies worked together within a particular industry to promote nonproliferation by implementing an industry-wide governance/self-regulation program."*

Performance measures would be used to ensure that materials and technologies are secure throughout supply chains and that customers are legitimately using and maintaining oversight of these items. This approach is broader than internal compliance programs (ICPs) implemented by individual companies. While an ICP focuses narrowly on a system a particular company has developed to ensure and promote compliance with existing regulations, broader industry self-governance is required to contribute to global nonproliferation.

The PNNL report determined that several companies are already engaging in information sharing and self-regulation. While their recommendation for more extensive voluntary information-sharing requires further assessment by policy makers, the need for action is well documented.

Conclusion: Looking to the Future

This report identifies near-term technical steps to support the goal of substantial reduction in the global numbers of nuclear weapons.

The standard military assessment of a problem is that the solution lies in the trade space between technology, doctrine and operations. We find that although technology is a common thread through all our recommendations these recommendations must be supported by these other two other components for a solution. As physicists, these other components lie outside the scope of our report, as do the political and diplomatic aspects of the issues.

Three critical science and technology challenges must be addressed;

1) **verifying and monitoring arms control treaties, including dismantlement efforts;**
2) **sustaining nuclear weapons expertise as long as it is necessary, not just to support the deployed stockpile, but also to support nuclear counter terrorism, nuclear forensics and archeology, and materials control and monitoring programs as required;**
3) **insuring that the nuclear power enterprise is appropriately monitored and regulated to ensure peaceful use of fissile materials.**

Even as the number of nuclear weapons decreases there remains a significant challenge to monitoring and assuring mutual security. The near-term steps we identify may be funded and staffed as an extrapolation of past expenditures. However, longer term steps will require new partners and broader engagement in the development, assessment and use of monitoring tools. The costs and staffing associated with these longer term steps may rival the investments currently needed to keep the deployed stockpile credible, safe and secure.

We are confident that the development of the technology needed for a safe and secure downsizing program for global nuclear arsenals is within our reach if it is adequately supported. The associated operational and doctrinal measures will require major investments as well. The technology steps are clear; the structure of the overall program requires careful assessment and ongoing support.

ENDNOTES

1 George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, *A World Free of Nuclear Weapons*, The Wall Street Journal, January 4, 2007. Since then, similarly distinguished individuals in, for example, the UK, Germany, France, Italy, Norway and Australia have joined in calling for global nuclear disarmament.

2 "Fissile material" as used in this report includes radionuclides that are or could be used in nuclear weapons without further isotopic enhancement. Fissile material includes plutonium containing appreciable percentages of ^{239}Pu, ^{241}Pu; uranium containing in excess of 20% ^{235}U, 12% ^{233}U, and neptunium or americium.

3 This may also require the declaration of the historical data relative to stockpile sizes and compositions by weapon types.

4 http://www.un.org/events/npt2005/npttreaty.html.

5 It is important to note that such systems can be designed to different levels of certainty, bearing in mind that increasing the dimensions of a template to include geometric factors, for example, raises the requirements on security approvals for its use. Such methods can only be expected to be adopted if they are developed by and demonstrated to all parties involved.

6 These tests must be carried out without revealing classified information to inspectors or to third parties.

7 http://www.vertic.org/assets/Events/UK-Norway%20Initiative-FINAL.pdf

8 *Nuclear Archaeology: Verifying Declarations of Fissile-Material Production*, Steve Fetter, Science and Global Security, 1993, Volume 3, Issue 3, page 237–259.

9 These issues were dealt with in *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States*, Chapter 6 and in The Henry L. Stimson Center, *Leveraging Science for Security: A Strategy for the Nuclear Weapons Laboratories in the 21st Century*, March 2009.

10 *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk*, Nuclear Energy Study Group of APS, May 2005: http://www.aps.org/policy/reports/popa-reports/proliferation-resistance/upload/proliferation.pdf

11 http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1614/v4/strategic-plan-at-a-glance.pdf

12 Ibid.

13 Ibid.

14 http://www.nrc.gov/materials/fuel-cycle-fac/ge-laser-license-process.pdf

15 G. Hund, A. Seward, *Broadening Industry Governance to Include Nonproliferation*, PNWCGS Publication, PNNL-17521.

16 Ibid.

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