Essential Capabilities for Nuclear Security:

A National Program for Nonproliferation and Verification Technology Development

Dr. James Doyle

and Nuclear Watch New Mexico

January 2015

Essential Capabilities for Nuclear Security:
A National Program for Nonproliferation and Verification Technology Development

Dr. James Doyle and Nuclear Watch New Mexico

Executive Summary and Recommendations

Achieving nuclear security in the 21st century and beyond requires a far more diverse set of national capabilities than during the Cold War. Today's nuclear threats are more geographically dispersed, varied and nuanced. New actors who are not deterred by the threat of nuclear retaliation seek dangerous nuclear materials and must be denied. As America reduces its reliance on nuclear weapons and decreases the size of arsenal it needs new tools and capabilities to keep weapons and materials secure and verify that other nations are complying with similar obligations.

Nuclear weapons, which are receiving sufficient funding and attention, cannot counter the full spectrum of nuclear security challenges facing the nation and the world in the decades ahead. Nor can they counter or deter the most likely nuclear threats to the nation. The technical and human capabilities for nonproliferation, verification and monitoring are being neglected with perilous potential consequences. These capabilities are essential to verify compliance with current and anticipated nuclear arms agreements and to move safely towards a world without nuclear weapons.

However, almost five years after the 2010 Nuclear Posture Review called for a national program on "*expanded work on verification technologies and the development of transparency measures,"* there has been no substantial follow-up. As a consequence, the technical and human capabilities needed to reduce the most likely nuclear threats to the nation are being neglected with perilous consequences.

The missions of nonproliferation and arms verification have for too long been considered part of the "soft power" tools of the diplomatic and arms control communities. Responsibility for them has been scattered across mid- to low level departments within several different agencies, without strong national champions in the interagency bureaucracy or Congress. The transformed nuclear security environment requires that we now consider these capabilities as vital elements of our national security infrastructure. They are potent "smart power" tools offering unique advantages in a rapidly evolving nuclear security environment.

To develop new verification technologies over the next decade, a new program with annual funding on the order of $125 million to $150 million should be initiated now. This amounts to far less than 1 percent of the $185-200 billion identified for nuclear weapons and infrastructure spending over the next decade. To put this modest funding requirement in perspective, the estimated $1.5 billion cost for the tail-kit of the proposed B61 Mod12 nuclear bomb would be enough to fund a dedicated nonproliferation and verification technology program for a decade. Such a program is affordable at a fraction of the cost of other nuclear infrastructure modernization tasks, and is needed to maintain nuclear security in an evolving security environment. This modest investment, which could pay back immense dividends, should be made now, even in the pending FY 2016 appropriations process.

Consistent with their nuclear security mission, that should give greater emphasis and funding to nonproliferation programs, the national labs can contribute to the formulation of a national verification and monitoring program. They have the skills and experience to successfully develop the needed technology and procedures and should be assigned a leading role in program implementation. Indeed, the labs have a number of existing or newly developed verification and monitoring technologies that have yet to be widely deployed for the benefit of the nation (see a detailed list in our full report).

Recommendations:

- A new, integrated multiagency program to develop nonproliferation, verification and monitoring technologies for nuclear security should be initiated without delay. The program structure should ensure a common understanding among agency leads for defining the challenges and implementing a national program framework, including policy, diplomacy, operations, and research, development, test and evaluation.

- The program should be funded as a core aspect of the nation's nuclear infrastructure modernization plan, and thus implemented and funded jointly by the National Nuclear Security Administration and the Department of Defense, with guidance from the State Department, intelligence community and National Academy of Sciences.

- Responsibility for these missions should be assigned to high-level officials who have budget and program authority across the nuclear weapons and nonproliferation programs within the Departments of Defense and NNSA. The State Department should assign a senior task force leader to coordinate with the DoD and NNSA program directors.

- The program should maximize international collaboration. Program plans and activities should be a central element of the P-5 dialogue on verification. Other non-nuclear weapons states that support verification and monitoring R&D should also be involved.

- The need for this program was formally codified as an objective in the 2010 Nuclear Posture Review, and has been repeatedly articulated by both the U.S. government and independent assessments. That need should be met now. Failure in the form of a nuclear detonation on American soil (or anywhere) is not an option.

Our full report, *Essential Capabilities for Nuclear Security: A National Program for Nonproliferation and Verification Technology Development*, can be downloaded at http://nukewatch.org/importantdocs/resources/Doyle-EssentialNuclearSecurityReport.pdf

Contact information: Nuclear Watch New Mexico, 903 W. Alameda #325, Santa Fe, NM 87501
Voice and fax: 505.989.7342 • info@nukewatch.org • www.nukewatch.org
http://www.nukewatch.org/watchblog/ • http://www.facebook.com/NukeWatch.NM

Essential Capabilities for Nuclear Security

Table of Contents

Introduction: Nuclear Security in the 21st Century 1

Identifying Needed Capabilities 3
Future Bilateral and Multilateral Nuclear Arms Reductions
Verification and Monitoring for a Fissile Material Cut-off Treaty
Technologies for Nuclear Safeguards
CTBT Verification
Verifying the Disposition of Fissile Materials
Verification Supporting U.S. National Space Policy

Summary of Existing Programs 8
NNSA Office of Nonproliferation Research and Development
NNSA Office of Nonproliferation and International Security Policy
State Dept. Office of Verification and Transparency Technologies
DTRA Treaty Verification and Technology Office
Other Interagency Technical Organizations

Sampling of Emerging Technologies 12
Confirming the Elimination of Nuclear Warheads
Next Generation Attribute Measurement System
The Trusted Radiation Attributes Demonstration System
Template Matching
Chain of Custody Verification and Monitoring
Verifying a Cut-Off of Fissile Material Production
New and Novel Technologies for Nonproliferation Verification and Monitoring

Priorities for a National Program 20
Funding
Problem Definition

Comprehensive Strategy 22
National and International Testing Capabilities
Innovative Implementation

Conclusions and Recommendations 24

Key Reference Documents 25

Author's Biography 28

Contact Information 28

Essential Capabilities for Nuclear Security:

A National Program for Nonproliferation and Verification Technology Development

Dr. James Doyle and Nuclear Watch New Mexico

Introduction: Nuclear Security in the 21st Century

Maintaining nuclear security in the 21st century and beyond requires a far more diverse set of national capabilities than during the Cold War. Previously it was believed that the threat of unleashing the destructive kinetic energy of nuclear weapons would deter our most likely adversaries from challenging America and its allies. Today a far more geographically dispersed, varied and nuanced spectrum of threats can lead to nuclear catastrophe. New actors who are not deterred by the threat of nuclear retaliation seek dangerous nuclear materials and must be denied. As America reduces its reliance on nuclear weapons and decreases the size of arsenal it needs new tools and new capabilities to keep weapons and materials secure and verify that other nations are complying with similar obligations. Equally important is to prevent additional states from acquiring nuclear weapons.

Unfortunately, the United States and its international partners do not have sufficient technological and procedural capabilities to achieve these objectives when political and diplomatic opportunities arise. In recent years this strategic shortcoming has been consistently identified in multiple interagency defense studies and nongovernmental reports, including the 2010 Nuclear Posture Review.[1] The recommendations of these reports for robust and sustained investment in nonproliferation, verification and

[1] See for example: 2010 Nuclear Posture Review Report.
http://www.defense.gov/npr/docs/2010%20Nuclear%20Posture%20Review%20Study.pdf;
Defense Science Board - Assessment of Nuclear Treaty Monitoring and Verification Technologies, January 2014. http://www.acq.osd.mil/dsb/reports/NuclearMonitoringAndVerificationTechnologies.pdf;
Secretary of Energy Advisory Board -Interim Report of the Task Force on Nuclear Nonproliferation August 1, 2014.
http://energy.gov/sites/prod/files/2014/08/f18/SEAB%20TFNN%20Interim%20Report_August%201%202014%20with%20appendices.pdf;
White House Office of Science and Technology Policy, National Science and Technology Council, "Nuclear Defense Research and Development Roadmap, Fiscal Years 2013 – 2017," April 2012.
The Nuclear Threat Initiative, "Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks: Verifying Baseline Declarations of Nuclear Warheads and Materials, July 2014.
http://www.nti.org/media/pdfs/WG1_Verifying_Baseline_Declarations_FINAL.pdf?_=1405443895
Committee on International Security and Arms Control. *U.S. National Academy of Sciences, Monitoring Nuclear Weapons and Nuclear-Explosive Materials.* Washington, DC: National Academy Press, 2005;
Office of Nonproliferation Research and Engineering, Arms Control & Nonproliferation Technologies Project. *Technology R&D for Arms Control*. Washington, DC: U.S. Department of Energy, 2001;

monitoring capabilities and for creation of a strong, dedicated interagency program to execute this mission have gone unheeded.

Five years after the 2010 Nuclear Posture review called for a national program on "*expanded work on verification technologies and the development of transparency measures"* there has been no substantial follow-up. No U.S. government agency or team of agencies has been assigned responsibility for creation or implementation of a sufficiently broad and dedicated program. As a consequence, the technical and human capabilities needed to reduce the most likely nuclear threats to the nation are being neglected.

Instead, the Obama Administration and the larger U.S. strategic community appear overwhelmingly focused on replicating a massive triad of offensive nuclear weapons that were conceived and built for a previous nuclear era while reducing investment in nonproliferation and verification technology.[2] This choice raises the risk that America's nuclear security capabilities will lack the breath and balance needed to meet the full range of 21st century nuclear threats.

Eighty-five percent of global nuclear materials that could be used in a nuclear attack exist in military nuclear programs without international verification and monitoring mechanisms in place to confirm their security from theft or misuse.[3] America lacks the means to confirm how many total nuclear warheads or how much weapons-grade nuclear materials other nations possess – this is critical to establishing a baseline both for the purposes of assessing the capabilities of potential nuclear adversaries and verifying nuclear reductions. As a final example, we still cannot confirm that a nation claiming to cease or limit production of nuclear warheads or fissile materials has done so.

This report makes the case that a new, integrated multiagency program to develop nonproliferation, verification and monitoring technologies for nuclear security should be initiated without delay.[4] These capabilities are essential to verify compliance with current and anticipated nuclear arms agreements, prevent nuclear terrorism and nuclear proliferation and to move safely towards a world without nuclear weapons. The program should be funded as a core aspect of the nation's nuclear infrastructure modernization plan, and thus implemented jointly by the National Nuclear Security Administration and the Department of Defense, with guidance from the State Department, intelligence community and National Academy of Sciences. Such a program is affordable at a fraction of

---

[2] Fiscal Year 2015 Omnibus Bill Analysis Defense and Energy Department Segments, Center for Arms Control and Nonproliferation. http://armscontrolcenter.org/issues/securityspending/fy_2015_omnibus_analysis/

[3] This shortcoming will be addressed at the 2016 Nuclear Security Summit see: http://www.fmwg.org/calendar.cfm?action=detail&Id=9C6C1064-FA4D-3A8F-174D-F66D9394C7AA&PagePopup=1

[4] George P. Shultz, William J. Perry, Henry A. Kissinger and Sam Nunn have called for this initiative. See "Next Steps in Reducing Nuclear Risks: The Pace of Nonproliferation Work Today Doesn't Match the Urgency of the Threat," The Wall Street Journal, March 6, 2013. The authors recommend, "The U.S. launch a "verification initiative" that involves the U.S. nuclear weapons laboratories and global scientific experts in developing essential technologies and innovations for reducing and controlling nuclear weapons and materials." http://www.nuclearsecurityproject.org/publications/next-steps-in-reducing-nuclear-risks-the-pace-of-nonproliferation-work-today-doesnt-match-the-urgency-of-the-threat

the cost of other nuclear infrastructure modernization tasks, and is needed to maintain nuclear security in an evolving security environment.

Identifying Needed Capabilities

The needs for nonproliferation, verification and monitoring technologies to support nuclear security objectives are remarkably broad. Such capabilities are becoming more critical to maintaining stable deterrent relationships with Russia and China as their nuclear forces evolve. They are also essential for transparently demonstrating that U.S. and allied nuclear forces are appropriately sized and defensive in nature, and that nonproliferation obligations are being met - conditions that help reduce the motivation of other states to seek nuclear arms.

Nonproliferation, verification and monitoring capabilities are equally vital to confirming that Russia and China and other nuclear weapon states are adhering to arms control agreements. These capabilities are also needed to provide confidence in the security of nuclear weapons and materials and confirming reduced chances that terrorists could acquire the means to conduct a nuclear attack. A final example is that these tools are required to confirm that states are not hiding a cache of nuclear warheads or materials or conducting illicit activities at secret locations.

These are only a sampling of the nuclear security needs for improved verification and monitoring capabilities. Some of these are described in greater detail below and additional gaps in capability and specific needs are identified. The proposed national program should be broad enough to address the full spectrum of needs across the nuclear security and weapons of mass destruction domain.

<u>Future Bilateral and Multilateral Nuclear Arms Reductions</u>

In April 2009, the President outlined a long-term goal of a world free of nuclear arms. To achieve this world, future negotiations to reduce nuclear weapons will need to move away from the traditional focus on strategic delivery systems and towards limits on nuclear warheads themselves, including non-deployed and non-strategic warheads in addition to deployed systems (i.e. warheads mated to their delivery vehicles). Verification of treaties that directly address nuclear warheads will require new approaches that balance the need to protect sensitive information with the inherent difficulty of confirming the presence of nuclear devices (warheads).

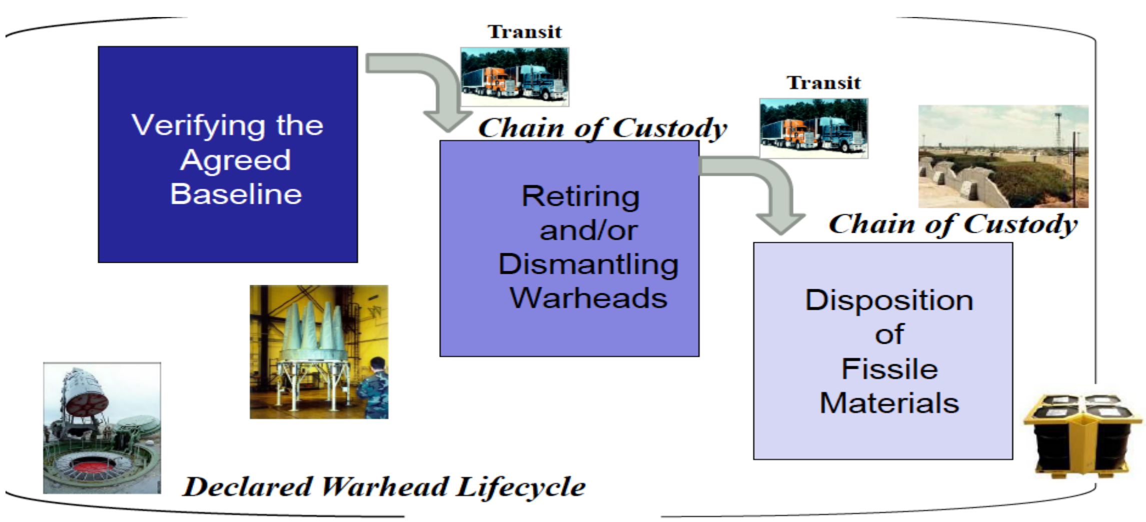
Future treaties will require technologies for verifying the presence or absence of nuclear warheads. These methods and technologies will need to intrinsically protect classified information but yet provide enough information to confirm the identity of items declared to be a warhead or nuclear weapon component. In addition to new technology, this requires a better understanding of the information the United States and other potential treaty partners are willing to share or not share in the context of future treaties or agreements.

Technologies and procedures needed to support future nuclear arms reduction treaties include:

- Tools to assure chain of custody (COC) for a nuclear device once it has been authenticated. Specifically, once an item has been inspected and catalogued, we want to be sure that it cannot be diverted or tampered with.
- Tools and processes for authenticating chain of custody for equipment used to verify non-nuclear objects and weapons.
- Tools to uniquely identify each declared warhead or weapons component so that it is never counted twice or substituted with a fake, and allow it to be tracked within a high-security environment.
- Tools to provide continuity of knowledge throughout the disposition process so that items can be monitored until they are removed from a state's inventory and have gone through final and irreversible dismantlement.
- Means to detect warheads in transit and storage that are trusted and sharable between treaty partners.
- Means for verifying dismantlement or storage of individual warheads.
- Tools for distinguishing between strategic versus non-strategic and between actively deployed versus retired warheads while protecting nuclear weapons design information.

Ideally, the research and development institutions of prospective treaty partners would develop the technologies and procedures to meet these needs collectively. This allows for more efficient use of resources. It also recognizes the fact that many countries are more willing to trust information derived from jointly developed verification technology than they would trust data from technology developed exclusively by the United States.

One of the most difficult verification challenges will be to confirm the retirement or dismantlement of individual nuclear warheads. There are three major stages to this challenge, as illustrated here.



If this process were to begin at locations where nuclear warheads are deployed on missiles, or
in storage shelters near airfields, technologies and procedures would be needed to monitor the de-mating of the warhead from the missile or removal from storage, and their verifiable transfer to shipping containers for transport to final disposition.

From this crucial point, the following capabilities will likely be needed:

- Application of trusted tags and seals to containers to uniquely identify the warheads and detect any tampering with the containers.
- Monitoring of transportation of warhead containers to storage facilities.
- Recertification that the Treaty Limited Item (TLI) presented for storage is the TLI it is purported to be by the host country.
- Monitoring of warheads in storage facilities to prevent unauthorized entry or removal of warheads.
- Monitoring of transfer of warheads from storage location to dismantlement facility.
- Confirmation of irreversible dismantlement.

While these challenges have been recognized for decades, most of the technologies and procedures proposed for accomplishing these tasks have not been brought to maturity, much less fully tested in the field. Additional time and resources are needed to have confidence that these nuclear operations could be effectively verified in a future treaty in cooperation with international treaty partners. This is a key reason why a well-structured and funded long-term national program is critically needed.

Verification and Monitoring for a Fissile Material Cut-off Treaty (FMCT)

A verification model for a future FMCT has yet to be established. Based on experience from International Atomic Energy Agency (IAEA) safeguards, however, an effective regime can be expected to comprise three basic elements: routine verification activities for declared facilities and material; verification activities aimed at detection of possible undeclared fissile material production; and complementary measures aimed at transparency and confidence building. Technologies for determining that uranium enrichment plants and plutonium reprocessing plants are not producing and diverting fissile materials for weapons purposes exist today.[5] They are in widespread use by the IAEA in its nuclear safeguards agreements with nonnuclear weapon states that operate full nuclear fuel cycles. However, major nonproliferation and verification challenges related to a future FMCT remain, including:

- Technologies to detect, localize, and characterize undeclared plutonium production processes, including reprocessing, separation, and metal production.
- Technologies to detect, identify, collect and analyze samples that provide increased confidence in characterizing uranium conversion and enrichment processes.

---

[5] John Carlson, Can a Fissile Material Cutoff Treaty Be Effectively Verified? *Arms Control Today, http://www.armscontrol.org/act/2005_01-02/Carlson*

- Verification means to confirm that highly enriched uranium (HEU) designated for naval reactor use is not being used to produce warheads, and eventually is phased out in favor of low enriched uranium for naval reactor purposes.

Technologies for Nuclear Safeguards

Nuclear nonproliferation capabilities must continue to be improved in support of the NonProliferation Treaty (NPT) and international safeguards verifying that material for nuclear energy uses are not diverted to make nuclear weapons or other nuclear explosive devices. As cases of NPT violations in Iraq, Libya and Syria indicate, such capabilities are needed to provide policy makers with actionable information and early warning of the activities of nations or groups interested in developing clandestine nuclear weapons capabilities. Specifically, some of the following tools are needed:

- Effective seals and tags that can be widely dispersed and monitored remotely by inspectors that are trusted by both the hosting and inspecting parties.
- Sensors to detect, characterize and quantify fissionable materials at various locations within nuclear facilities.
- Sensors to detect tampering and provide integrity assurance of monitored equipment.
- Devices providing real-time data from multiple sources for inspectors to use during their evaluation of declared nuclear inventories and operations and to detect any undeclared activities.

One interesting nonproliferation and verification technology challenge is to assess the applicability of existing IAEA safeguards technologies for warhead environments for verifying compliance with potential future nuclear arms reduction treaties. Currently, the IAEA employs a wide variety of safeguards tools and techniques, including tags, seals, remote monitoring, and environmental sampling. An international team of experts could explore whether or not these technologies would be useful as verification methods in high security environments where nuclear weapons operations are taking place.

CTBT Verification

Today there is a high probability that a militarily significant nuclear test anywhere on the planet will be detected by the CTBT verification system that is already deployed. The capabilities of this system will further increase as more and more monitoring stations join the global network of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the international entity mandated to establish the verification regime so that it is operational when the treaty enters into force.[6] However, potential verification challenges remain, including defeating ever-improving foreign denial and deception capabilities designed to impair data collection. The capability to detect yields within the power range of conventional explosions and distinguish them from nuclear explosions is also required. Therefore, research still needs to be performed to enhance understanding of test site environments and develop new collection instrument,

[6] See Overview of the Verification Regime, CTBTO Preparatory Commission at http://www.ctbto.org/verification-regime/

and methods to exploit new signatures associated with nuclear testing.

The following capabilities will be needed:

- Smaller, more rugged seismic and acoustic sensors with improved capability for identification and characterization of underground explosions.
- Tools and technologies to provide data and detailed post-event analyses of incidents of verification concern; and to detect and identify possible nuclear tests conducted underwater, in the atmosphere, and in outer space.
- Improved capability to rapidly determine whether an explosion is nuclear or conventional.
- Improved tracking of air volumes for estimating the location of sources of radionuclide particulates and noble gases detected at International Monitoring System (IMS) stations. In order to precisely identify radionuclides and/or radioactive noble gases as originating from a nuclear explosion, it is vital to increase the knowledge of "background" through atmospheric transport modeling.

Verifying the Disposition of Fissile Materials Removed from Military Programs

The United States and Russia pledged to eliminate excess weapons-grade plutonium in order to prevent theft or diversion for illegal nuclear programs. Both states also wanted to ensure neither was able to reincorporate this material into its weapons arsenal. In 1998 the United States and Russia each declared 50 metric tons of plutonium to be surplus to their security needs. This was followed by the September 2000 Plutonium Management and Disposition Agreement (PMDA) in which both countries agreed to transform 34 mt of excess military plutonium into a proliferation-resistant form.

In order to achieve this target, Russia intends to irradiate all 34 mt of its plutonium in fast-neutron reactors, thereby utilizing the mixed-oxide (MOX) fuel option. The United States originally planned a dual-track approach in which it would irradiate the majority of its surplus plutonium as MOX fuel, as well as immobilizing a smaller quantity with highly radioactive wastes. The U.S. MOX program is deeply troubled, primarily because of huge cost overruns, and its future is very much in doubt. Pertinent to this report, the verification arrangements for the PMDA or any potential future agreements declaring additional quantities as excess fissile materials have yet to be determined, and may require:

- Inspection of sites designated for disposition of excess fissile materials, possibly including weapons components. Sites designated for disposition may include long and short-term storage facilities, down blending of weapons grade plutonium, and MOX feedstock processing and fuel fabrication.
- Monitoring of transportation of components and fissile materials to disposition sites.
- Ensuring chain of custody during transport or movement.
- Monitoring of types and quantities of weapons components and excess fissile materials at disposition sites.
- Monitoring of short-term storage, prior to removal to disposition site.
- Use of radiation detection equipment to certify that fissile materials have been transformed into mixed oxide fuel for use in civilian and naval reactors.

Verification Supporting U.S. National Space Policy

The National Space Policy released in June 2010 says that the United States will consider space-related arms control concepts and proposals that are equitable, effectively verifiable, and enhance the national security of the U.S. and its allies. The Administration is also expanding its efforts in international cooperation in space activities and conducting expedited reviews of key issues, such as long-term sustainability of space activities and orbital debris mitigation that will require improved space situational awareness. In addition, there is an ongoing need to further develop measures to verify the ban on weapons of mass destruction (WMD) in space, and the prohibitions on interference with National Technical Means. Needed capabilities include:

- New surveillance technologies to improve our ability to assess and monitor possible violations of the Outer Space Treaty.
- Expanded means and methods to detect violations of treaty obligations and indicators of intent to violate the obligations, including the development, testing and deployment of anti-satellite weapons.
- Transparency and confidence building measures to promote safe, responsible, and peaceful behavior in space.
- Development of a "Code of Conduct for Outer Space Activities."
- Improved space object situation awareness and capabilities to detect and attribute a wide range of prohibited behavior by possibly very small satellites of unknown provenance at various orbits.

Summary of Existing Programs

The National Nuclear Security Administration's (NNSA's) Office of Defense Nuclear Nonproliferation implements the majority of the U.S. nuclear nonproliferation and verification R&D activities, principally through its Research and Development Program and its Office of Nonproliferation and International Security Policy. Historically, an additional program run by the Basic and Applied Sciences Directorate of DoD's Defense Threat Reduction Agency supports research to counter the threat of weapons of mass destruction. As some counterproliferation capabilities are applicable to the nonproliferation mission, this program's research supports nonproliferation technology as well. The Office of Verification and Transparency Technologies (VTT) under the State Department's Bureau of Arms Control, Verification and Compliance also participates in the interagency community that seeks to identify technological solutions for verification and compliance issues relevant to current and future arms control and nonproliferation challenges. These three agencies, NNSA, DTRA and State VTT, co-chair the Nonproliferation and Arms Control Technology Working Group, an interagency coordinating body that guides the research and development of new verification and transparency technologies and assets. Additional detail on the nuclear nonproliferation, verification and monitoring activities of each of these organizations is provided below.

NNSA Office of Nonproliferation Research and Development

This office has the responsibility of developing technology for both cooperative purposes, such as the verification of arms control treaties and international nuclear safeguards; and unilateral purposes, including the monitoring and assessment of foreign nuclear activities. The Office has two major sub-programs. The Office of Proliferation Detection develops technologies to detect foreign nuclear weapons programs. While doing that, it supports nuclear arms control treaty verification and monitoring for compliance, and supports national nuclear security.[7] This includes the development of novel, crosscutting technologies such as simulations, algorithms and modeling applicable to multiple NNSA and interagency missions. Nuclear safeguards support the International Atomic Energy Agency's mission to monitor the Nuclear Nonproliferation Treaty and the commitments of signatory countries to refrain from developing new nuclear weapons.

The Proliferation Detection (PD) subprogram also executes NNSA's part of the Integrated University Program, which is a Congressionally mandated three-way effort between the Nuclear Regulatory Commission, DOE, and NNSA to enable development of the next generation of nuclear engineers and scientific researchers. For example, in March 2014 the PD subprogram announced the award of a $25 million grant to a University of Michigan-led consortium for research and development in nuclear arms control verification technologies, including nuclear safeguards effectiveness. Another major project of the PD subprogram directly related to this report is the creation of a test bed at the former Nevada Test Site to support U.S. capabilities to monitor future international treaties and cooperative agreements, especially those that might limit actual nuclear warheads. An integrated demonstration of technical approaches to confirm nuclear warhead dismantlements under a hypothetical treaty is planned at the Nevada Center for Nuclear Science in 2016.

NNSA Office of Nonproliferation and International Security Policy

The Office of Nuclear Verification within NNSA's Office of Nonproliferation and International Security Policy develops and deploys measures to ensure verifiable compliance with treaties and other international agreements. This includes implementing current arms reduction and nonproliferation transparency treaties and agreements; developing technologies to support U.S. monitoring capabilities for future nonproliferation and arms control treaties and agreements; and developing technologies to detect potential clandestine weapons programs or diversion of nuclear material. The Office of Nuclear Verification also assists in implementing nuclear material elimination agreements and regimes.

These NNSA activities include a particular focus on future treaties that might require nuclear warhead verification. For example, NNSA has been implementing a Warhead Dismantlement Transparency Program for many years in collaboration with the U.K. Atomic Weapons Establishment. This bilateral effort is designed to assist technical experts in developing, evaluating, and gaining experience with technologies, monitoring

[7] See http://nnsa.energy.gov/aboutus/ourprograms/dnn/rd/pd

procedures and verification in actual nuclear warhead environments. A key objective is to demonstrate radiation measurements on warheads and their components that confirm their declared identities in a hypothetical future treaty. To be as realistic as possible, the joint experiments are performed in an operational nuclear facility with representative quantities of fissile material and simulated high explosives.

State Department Office of Verification and Transparency Technologies (VTT)

The Department of State VTT Office manages the Key Verification Assets Fund (V Fund), which supports innovative research proposals addressing nuclear verification and monitoring requirements and preserves critical verification assets. The V Fund also promotes the development of new technologies and improvements to analytical tools, models, data and metrics applicable in the science and policy decision-making process. The Fund supports projects from across industry, academia and the national laboratories ranging from the basic science level to assistance for the operation of a fully developed capability.

The V Fund has traditionally been used as seed money to survey the technical opportunities and challenges associated with new verification regimes under consideration by the policy community. It awards modest initial funding to projects that display potential for advancing capability in nuclear explosive detection; seismology sensors; nuclear proliferation detection; and exploring the promise and peril of digital era tools such as social media to explore the utility of societal verification. Many of these projects, after passing the proof of concept phase, are then funded at higher levels by the NNSA or DTRA.

DTRA Treaty Verification and Technology Office and Nuclear Arms Control and Technology Research Development, Testing and Evaluation Program

The DoD has long played a significant role in developing advanced nuclear detection and monitoring technologies to support the combatant commands, services and other interagency customers. In recent decades a focus has been on increasing the range of fixed and mobile nuclear material detection systems from several yards to standoff distances in order to locate, track or interdict nuclear weapons and materials in the hands of adversaries. DTRA maintains relationships with many interagency partners on nuclear detection, including NNSA and the Department of Homeland Security's Domestic Nuclear Detection Office, in order to achieve a multi-layered defense strategy to protect the U.S. from nuclear or radiological attack.

DoD-specific missions often require mobile and transportable nuclear detection systems, some mounted on military vehicles, and employed in fluid and potentially hostile environments. To create a fully integrated nuclear defense capability, the DoD not only partners with U.S. government agencies but also seeks international partnerships to build capacity in countering weapons of mass destruction. This includes maritime demonstrations of radiation detection, international partnerships in technology development for detection and forensics, and regional academic workshops on WMD technologies.

Until recently DTRA had extensive collaborative projects with the Russian Ministry of Defense to expand and update automated nuclear asset inventory controls, fund training programs for personnel, and enhance security while transporting nuclear warheads. For example, DTRA teams traveled throughout the Russian Federation to verify the operability of security enhancements for nuclear weapons and materials. Many such sites are now better protected against the threat of nuclear terrorism or theft of weapons-usable nuclear materials. A key objective was to establish a joint standard for physical protection systems to address potential threats. These activities have been scaled back in recent years due to declining U.S.-Russian nuclear cooperation.

DTRA also has technical programs for improving the verification and reliability capability of the waveform and radionuclide nuclear detonation detection stations comprising the U.S. portion of the International Monitoring System (IMS) for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The Nuclear Arms Control and Technology (NACT) Program is the operational organization that installs, operates, maintains, and sustains the waveform and radionuclide IMS stations in the U.S.

Other Interagency Technical Organizations

In addition to the offices within the Departments of Energy, State and Defense described above, several other technical organizations participate in the development of nonproliferation, verification and monitoring technologies. These include the Defense Advanced Research Projects Agency (DARPA) that pursues high-risk, high payoff concepts for sensing nuclear materials and high explosives and managing information regarding global nuclear activities. The Remote Sensing Laboratory (RSL) is another facility operated by the NNSA. The RSL has its primary facility on Nellis Air Force Base near Las Vegas, Nevada, with a satellite facility at Andrews Air Force Base just outside of Washington, D.C. The Remote Sensing Laboratory is focused on the creation and fielding of technologies to perform measurements from a distance in support of radiological emergency response, non-proliferation and counterterrorism.

NNSA's network of national laboratories also plays a significant role in the development of nonproliferation and verification technologies. The three nuclear weapons laboratories, Los Alamos, Lawrence Livermore and Sandia, along with the nuclear weapon facilities at Pantex in Texas and the Y-12 plant in Tennessee, have been working on the challenges of proliferation detection and the verified elimination of nuclear weapons and materials for decades. U.S. universities are used by several government agencies to conduct basic and applied research on these challenges as well.

Two international organizations that play major roles in the development and use of nonproliferation and verification technology are the Comprehensive Test Ban Treaty Organization (CTBTO) and the International Atomic Energy Agency (IAEA). The CTBTO has the responsibility for verifying the CTBT once it enters into force. To this end the CTBTO coordinates the construction of the International Monitoring System (IMS) that includes monitoring stations in 89 countries, the International Data Centre and the Global Communications Infrastructure.

The IMS uses four complementary verification methods. Seismic, hydroacoustic and infrasound stations monitor the underground, the large oceans and the atmosphere respectively. The fourth method employs radionuclide stations that detect radioactive debris from atmospheric explosions or vented by underground or underwater nuclear explosions. Radionuclide laboratories assist radionuclide stations in identifying these radioactive substances.

The IAEA develops international safeguards technologies to verify states' compliance with their obligation not to use their civil nuclear technologies or materials for nuclear weapons purposes. IAEA monitoring technologies are installed in nuclear facilities worldwide, often continuously providing data remotely to the IAEA or designed to be analyzed during on-site inspections. The IAEA relies on partnerships with member states for new technology development, balancing between low-risk options that can help achieve efficiency improvements over currently deployed systems and higher-risk "game changers" that have the potential to significantly improve future safeguards implementation.

Sampling of Emerging Technologies

This section describes a selection of technologies essential for meeting some of the critical nonproliferation, verification and monitoring challenges of a world without nuclear weapons. For example, candidate technologies for confirming a nuclear test ban, the elimination of nuclear warheads, the cessation of the production of fissile materials for weapons purposes and detecting clandestine nuclear activities are briefly described. This sampling is far from comprehensive and does not include discussion of the equally challenging task of developing agreed-upon procedures for utilizing these technologies to provide mutual confidence to national governments that may lack trust.

Confirming the Elimination of Nuclear Warheads

Nuclear warheads are complex devices with diverse life cycles comprising design, construction, deployment, maintenance, retirement, dismantlement and disposition. All states with nuclear weapons must conduct a range of similar operations, including the secure transportation and storage of nuclear warheads and their components during their life cycle. In any hypothetical treaty to eliminate a designated set of nuclear warheads, parties will have to identify the warheads they are willing to eliminate. This could occur at bases where the nuclear warheads are on missiles or in storage facilities. The first challenge is to authenticate that an item that has been presented as a nuclear warhead is a nuclear warhead.

Nuclear warheads emit passively detectable neutrons and gamma rays, even when they are placed inside a missile or transportation container. Therefore a portable or fixed radiation detector could theoretically be used to authenticate nuclear warheads.

However, it is very complicated to authenticate a specific type of nuclear warhead for several reasons:

- Many factors determine the detectable radioactive emissions from nuclear warheads, such as the mass, density, geometry, and isotopic and chemical composition of the fissile core and the materials surrounding it.
- Many factors affect nuclear warhead detection capabilities, including shielding containers, distance from warheads, size and efficiency of nuclear detectors, background radiation, settings of measurement devices, and data analysis methods.
- The radiation signal from nuclear warheads can be actively induced and strengthened by irradiating the warhead itself, but this may create safety concerns in several environments.

Two primary passive approaches have been developed for warhead authentication, attribute matching and template matching.

Attribute Matching: establishes authenticity of an inspected item by demonstrating that the item possesses the intrinsic and unclassified characteristics of a nuclear weapon. Sample attributes include:

- Presence of weapon-grade plutonium
- Presence of a threshold mass of plutonium
- Age of plutonium
- Presence of weapons-grade HEU
- Presence of a threshold mass of HEU
- Presence of high explosive

Some examples of warhead authentication technologies that use the attribute approach include:

<u>Next Generation Attribute Measurement System (NG-AMS)</u>
The NG-AMS was developed at Los Alamos National Laboratory to allow an inspecting party to verify declarations concerning sealed containers of Pu. The NG-AMS determines the Pu isotopic composition, mass, and age of these potentially sensitive items and displays attributes, which have been agreed upon between the two parties as non-sensitive, derived from these measurements. The NG-AMS is composed of neutron and gamma ray measurement systems, which measure and calculate the properties of the Pu, surrounded by an information barrier, which assures that only the agreed upon information is available to the inspector. The NG-AMS could be modified to authenticate nuclear warheads.[8]

[8] Greg White, "Review of Prior U.S. Attribute Measurement Systems," Lawrence Livermore National Laboratory, July 2012. https://e-reports-ext.llnl.gov/pdf/626735.pdf
See also "The Design and Implementation of the AVNG Measurement System," S. Razinkov, et.al., Proceedings of the 51st INMM Annual Meeting, Baltimore, MD, July 2010, and "AVNG Authentication Features," J. Thron, D. MacArthur, G. White, S. Razinkov, A. Livke, LA-UR-10-03606, http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-10-03606

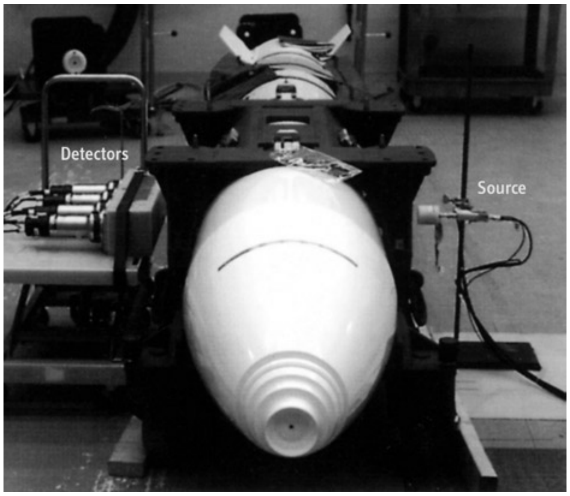
Next Generation Attribute Measurement System
All photographs are courtesy of either the U.S. government or James Doyle.

The Trusted Radiation Attributes Demonstration System (TRADS)
TRADS, developed at Sandia National Laboratory, uses a high-purity germanium detector to confirm attributes of the inspected item, which is a W84 warhead in the photograph below. The detector is mounted inside the cart and the “trusted” processor and electronic components are on top of the cart. The trusted processor employs a divided architecture and software design that protects sensitive information. Several features, including easily inspected components, a tamper-indicating enclosure, and a secure hash algorithm for software authentication, address the needs of the inspecting party. Measurements are completed after a 10-minute counting time. There is no size limit for the inspected items. The analysis algorithm is sufficiently robust to accommodate the effects of intervening materials, so items ranging from small components to complete weapons can be inspected.

Trusted Radiation Attributes Demonstration System

Template Matching
The fissile materials in nuclear weapons emit gamma rays with spectral distributions characteristic of the isotopes contained in the weapon materials. Because gamma rays are scattered and absorbed by intervening materials (casing, containers, etc.), the distribution of gamma rays is also affected by non-emitting materials. The resulting spectra are sufficiently distinctive to identify items by comparing a measured spectrum with the

template for the declared type. Measuring one or more items certified to be authentic creates the template. In the case of an arms control agreement, the template could be certified by attribute measurements or by random selection from deployed nuclear warheads.



Nuclear Weapons Identification System

An example of a template matching systems is the Nuclear Weapons Identification System pictured above. This is an active system developed at the Oak Ridge National Laboratory. To the right of the nuclear bomb is a Californium-252 source that sprays the bomb with penetrating neutrons. When neutrons strike fissile material, they induce fissions. To the left are four scintillation counters that measure the numbers and timing of the secondary gamma rays and neutrons from the induced fissions. The counting pattern from a certified "template" warhead may therefore be compared with that from a warhead declared to be identical to see whether or not there are differences.[9]

Chain of Custody (CoC) Verification and Monitoring

The process of monitoring and maintaining the status, security and authenticity of an accountable item throughout a defined lifecycle is Chain of Custody. In the case of a future agreement limiting nuclear warheads, CoC technologies and procedures would ensure that a declared warhead, once identified, is continually accounted for and tracked from deployment to dismantlement. CoC technologies must be able to:

- Uniquely identify items
- Provide evidence of tampering
- Track items during intra/inter-site movements and shipments
- Monitor the status of items placed in storage

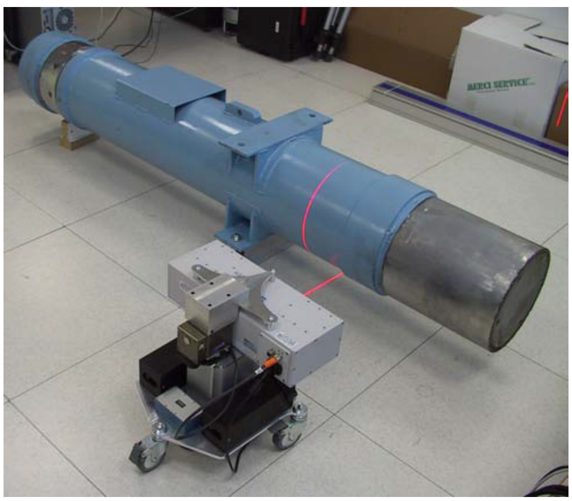
Some candidate technologies for fulfilling part of the CoC objective include:

- Tamper Indicating Devices/Enclosures (TID/TIE): Passive/active, Self-protecting seals.
- Physical Security/Surveillance Sensors: Cameras, motion detectors, portal monitors, etc.

[9] Global Fissile Material Report 2009: A Path to Nuclear Disarmament, p. 74. www.fissilematerials.org

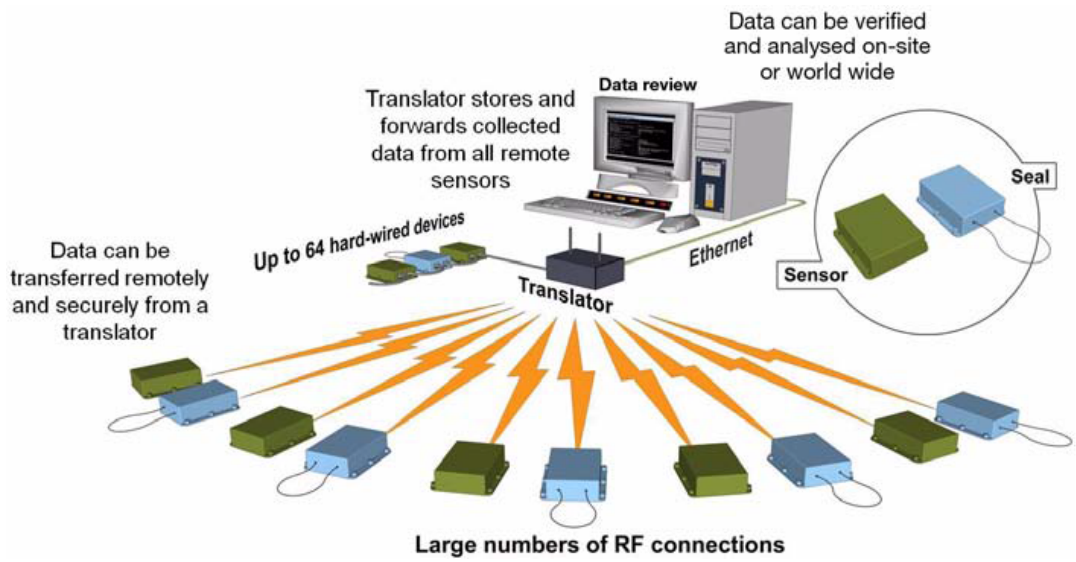
Containment verification techniques play an important role in IAEA safeguards approaches to maintain CoC of material stored in a specific container. Comprehensive containment verification needs to include not only the sealing systems but also the integrity of the entire surface of the container or enclosure, such as the welded joints, to ensure that there have been no penetrations that could go undetected by the sealing system. The IAEA has implemented a laser mapping system for containment verification (LMCV) and a laser item identification system.

The laser mapping system for containment verification works by laser scanning over some part of the surface of a container. Calculations are made using interferometry, thereby generating a quantitative, 3-D image, which accurately maps unique variations such as cracks, pits, corrosion and dents. The results are compared with a reference image in order to provide a high degree of confidence that the inspected containment is authentic and has not been tampered with (for example, cut and re-welded).



Laser surface mapping of a shipping container.

As is the case now for sealed items in a civil nuclear facility the IAEA monitors dozens of individual containers. One approach being considered for future application is a remotely monitored seals array (RMSA). The RMSA consists of electronic optical seals and a data translator using a radio frequency communication link for data acquisition from seals (see schematic below). Any tampering with the seals or unauthorized movement of the containers would be reported to a central data system in near real time. Timely knowledge of any attempt to open or divert containers would be essential for a future treaty limiting nuclear warheads, so a system similar to the RMSA could potentially meet this challenge.

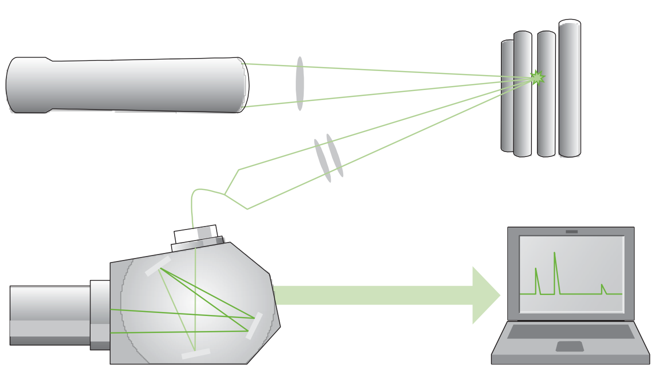


Remotely monitored seals array (RMSA). Remote sensors store and forward collected data to the local translator via radio frequency or hardwire.

Verifying a Cut-Off of Fissile Material Production

Several candidate technologies exist for confirming that facilities have either produced fissile materials in the past or have ceased production. For example, Laser Breakdown Spectroscopy could be used to turn particles on any surface or sample of materials at a nuclear facility into ionized plasma that would emit light with wavelengths characteristic of the particles' constituent atoms. If spectral lines characteristic of uranium and fluorine were found together, that would be an indicator of gas centrifuge enrichment. This technique could also be used to detect signatures associated with plutonium reprocessing.

Laser *Laser induced vapor on unknown materials*



Spectrograph *Spectral Analysis*

Laser breakdown spectroscopy. A laser is used to vaporize a microscopic amount of material on a surface of unknown materials. The light emitted by the resulting incandescent vapor is analyzed by a spectrometer.

A fissile material cut-off treaty would also have to confirm the absence of undeclared enrichment or reprocessing. Environmental sampling has long been used by the IAEA to contribute to confirming the absence of undeclared nuclear material or nuclear activities. The collection of environmental samples at or near a nuclear site combined with ultrasensitive analytical techniques such as mass spectrometry, particle analysis and low level radiometric techniques can reveal signatures of past and current activities in locations where nuclear material is handled.

Samples are analyzed in either bulk or particle mode, depending on the sampling objectives and the activity levels of the collected samples. Bulk analysis involves the analysis of an entire sample, usually by gamma ray spectrometry or isotope dilution mass spectrometry, where the analytical measurements represent average results for the material contained in the sample. Particle analysis relies on the detection and analysis of individual particles in the micrometer size range and on the measurement of the isotope ratios of uranium and/or plutonium in them. A scanning electro-microscope is one proven technology for this application, but future improvements in software performance and miniaturization are possible.[10]

Scanning electron microscope for particle analysis.

In addition to the technologies described above, the table below presents a broad range of new and novel nonproliferation and verification technologies that could be explored for further development under a national program.

[10] Safeguards Techniques and Equipment," 2011 edition, Vienna, International Atomic Energy Agency, 2011. http://www-pub.iaea.org/MTCD/Publications/PDF/nvs1_web.pdf

New and Novel Technologies for Nonproliferation Verification and Monitoring

Equipment Description	Application
CALADIOM® Smart camera	Sensor that integrates behavioral and pattern analysis technologies at the front end and could potentially be used to enhance surveillance capabilities.
Differential die-away self-Interrogation (DDSI)	Measurement of plutonium in spent fuel using spontaneous fission neutrons from 244Cm that are present in the assembly as the interrogating source.
HF detector laser system (HFLS)	Portable instrument for HF gas detection, in airborne and ground based mobile searches for enrichment activities.
Laser item identification system (L2IS)	Laser based system for unique identification of UF6 cylinders and monitoring the flow between cylinders in process areas.
Reflective particle tags (RFPTs)	Reflective particles in a transparent adhesive matrix applied to detect any tampering with welds and for unique identification.
Self-interrogation neutron resonance densitometry	Measurement of plutonium in spent fuel using 235U and 239Pu fission chambers placed adjacent to the assembly.
Superconducting gamma spectrometer	Ultra-high energy resolution gamma ray spectrometer (operated at temperatures of ~0.1 K) for accurate enrichment measurements and plutonium isotopics.
Universal NDA data acquisition platform	Standardized acquisition platform for NDA data.
UF6 detector based on laser spectrometry (UFLS)	On-site analytical instrument based on tunable laser diode spectroscopy for the measurement of enrichment of UF6 samples.
Antineutrino detector	Remotely measures Pu content, effective power and burn-up of various operating reactor cores outside its biological shield using detection of the generated antineutrinos.
Atmospheric gases sampling and analysis	Indicates nuclear activities (e.g. reprocessing) from a distance by the detection and analysis of airborne gaseous compounds emanating from nuclear processes. Sampling could be done on-site or near the site. Advanced applications aim to trace the origin of a signature (e.g. 85Kr) using modeling of its atmospheric distribution over time.
Fourier transform infrared (FTIR) system	Detects the presence of molecules such as U3O8, UO2, UO3 and ThO2 that have characteristic absorption bands in the infrared region.
Light detection and ranging (LIDAR) system	Senses the presence of characteristic gaseous compounds emanating from nuclear fuel cycle processes into the atmosphere from a distance of some kilometers of a suspected site by laser based techniques.
Microseismic monitoring	Detects unauthorized design changes and containment breaches in final nuclear depositories that would allow access to stored nuclear material by monitoring excavation activities with a network of seismic sensors.
Nanocomposite semiconductor technology	Enables small solid state neutron detectors using silicon nanopillars.
Optically stimulated luminescence (OSL)	Measures past exposure of objects to radiation to reveal past nuclear activities and to verify integrity of containers.
Remote sensing	Detects and identifies the location of an undeclared nuclear activity by satellite views with different spectral bands (e.g. determines temperature distribution geophysical and chemical characteristics of the surface).
Ultra-low field nuclear magnetic resonance (ULF-NMR)	Determines the presence of 235U in UF6 and could be used to monitor flow and enrichment at gas centrifuge enrichment plants.

Priorities for a National Program

As numerous recent governmental studies and national security panels have agreed, there is a continuing need for a more integrated, expansive and adequately funded program to develop nonproliferation, verification and monitoring technologies to serve a broad range of national security needs. Despite this nearly decade long consensus, the U.S. government has not yet taken the steps necessary to create such a program with the required leadership, institutional stature and technical and financial resources. For example, the Defense Science Board in its 2014 "Assessment of Nuclear Treaty Monitoring and Verification Technologies" concluded:

"*Monitoring for proliferation should be a top national security objective––but one for which the nation is not yet organized or fully equipped to address."*[11]

A major 2014 study by the nongovernmental Nuclear Threat Initiative reinforced this message:

"Years of inattention and underfunding has set back disciplines relevant to verification and monitoring. This deficiency is a crucial issue in the United States and Russia, and capacity is even less developed in other states…There is a lack of urgency in advancing verification policy and technical research."[12]

Almost five years after the 2010 Nuclear Posture Review called for a national program on "*expanded work on verification technologies and the development of transparency measures,"* there has been no substantial follow-up.[13] No U.S. government agency or team of agencies has been assigned responsibility for creation or implementation of such a program. As a consequence, the technical and human capabilities needed to reduce the most likely nuclear threats to the nation are being neglected with perilous consequences.

This shortcoming in national nuclear security strategy must be overcome. Unfortunately, the current political and fiscal environment is not conducive to initiating a strong national nonproliferation and verification program at this time. However, there are several factors that can enable the creation of such a program, if sufficient insight and leadership are exercised within the executive and legislative branches, which this report seeks to encourage.

---

[11] Defense Science Board - Assessment of Nuclear Treaty Monitoring and Verification Technologies, January 2014. http://www.acq.osd.mil/dsb/reports/NuclearMonitoringAndVerificationTechnologies.pdf

[12] Nuclear Threat Initiative, "Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks: Overview," July 2014. http://www.nti.org/media/pdfs/VPP_Overview_FINAL.pdf?_=1405445582

[13] 2010 Nuclear Posture Review Report: http://www.defense.gov/npr/docs/2010%20Nuclear%20Posture%20Review%20Study.pdf

Funding

A robust national program to meet nonproliferation, verification and monitoring technology needs is highly affordable when the benefits of such a program are considered and the cost is compared to other national security investments. For these activities during the period 1997-2011 the U.S. government spent the shockingly low figure of less than $200 million cumulatively.[14] NNSA, the largest agency investor in this area, has typically spent less than one percent of its nonproliferation budget on these technologies over the last decade. Moreover, for the third year in a row, the President's 2015 budget proposal dramatically reduces nonproliferation and verification investment across the government. For example, NNSA's proposed 2015 nuclear nonproliferation budget has been cut by $152 million, or 20 percent.[15]

These NNSA nonproliferation program cuts, while unhelpful, need not prevent the creation of the recommended national program because the funding for such a program can come from other accounts within NNSA, such as its nuclear infrastructure modernization accounts, and from multiple agencies across the government, including the Departments of Defense and State. To develop new verification technologies over the next decade, a program with annual funding on the order of $125 million to $150 million should be initiated now. This amounts to far less than 1 percent of the $185-200 billion identified for nuclear weapon infrastructure spending over the next decade. To put this modest funding requirement in perspective, the estimated $1.5 billion cost for the tail-kit of the proposed B61 Mod12 nuclear bomb would be enough to fund a dedicated nonproliferation and verification technology program as recommended here for a decade.[16] In contrast to the consensus within U.S. national security community for more investment in nonproliferation and verification technologies, there is active debate regarding the utility of a modernized "tactical" nuclear bomb.

Problem Definition

One of the reasons that the U.S. government has been unable to follow through on its declared intention to create an effective program for nonproliferation, verification and monitoring technology is because the importance of this mission has not been effectively articulated. These technical and human capabilities are essential for nuclear security and will become more so in the future. They are much more relevant to preventing a nuclear terrorist attack on the United States and its allies than the new generations of nuclear weapons and nuclear weapon production facilities to which the U.S. government is devoting tens of $billions annually. Unlike nuclear weapons, development and deployment of verification and monitoring systems can actually reduce tensions and build confidence

[14] Burgess Laird, "Survey of Emerging Technologies for Monitoring and Verification of the New Arms Control-After-Next Regime," Institute for Defense Analyses, Draft Final Report, December 23, 2010.

[15] Fact Sheet: FY 2015 Budget Request for Nuclear and Radiological Material Security and Nonproliferation Programs, Center for Arms Control and Nonproliferation, Apr 16, 2014.

[16] "Sandia National Labs Achieves B61 Milestone," Albuquerque Journal, May 18, 2014. www.abqjournal.com/.../sandia-national-labs-achieves

between nations, leading to improved international stability. Cooperative research and joint development of these capabilities can establish valuable international relationships.

The missions of nonproliferation and arms verification have for too long been considered part of the "soft power" tools of the diplomatic and arms control communities. As such, responsibility for them has been scattered across mid to low level departments within several different agencies without strong national champions in the interagency bureaucracy or Congress. The transformed nuclear security environment requires that we now consider these capabilities as vital elements of our national security infrastructure. They are potent "smart power" tools offering unique advantages in a rapidly evolving nuclear security environment. It is critical that they are recognized in this perspective and afforded a corresponding degree of attention and resources.

Acquisition of robust capabilities for nonproliferation, verification and monitoring should be considered part of nuclear infrastructure modernization effort and partly funded from these accounts. Responsibility for these missions should be assigned to high-level officials who have budget and program authority across the nuclear weapons and nonproliferation programs within the Departments of Defense and NNSA. The State Department Undersecretary for Arms Control and International Security should assign a senior task force leader with input from the Bureaus of Arms Control, Verification and Compliance, and International Security and Nonproliferation to coordinate with the DoD and NNSA program directors.

Comprehensive Strategy

The guiding strategy for the program needs to identify and organize the full range of nuclear security objectives. Many of these are mentioned in the body of this report and include but are not limited to capabilities for verifying or monitoring:

- A comprehensive nuclear test ban treaty.
- An agreement to cease the production of fissile materials for nuclear weapons purposes.
- Adequate security for nuclear weapons and weapon grade nuclear materials worldwide.
- The accuracy of declarations of stocks of nuclear weapons and fissile materials.
- The storage, transportation and dismantlement of nuclear warheads without revealing information considered sensitive or restricted by the participating states or international organizations.
- Attempts to openly or clandestinely transfer nuclear weapons or materials across national boundaries.
- A future convention banning the possession or manufacture of nuclear weapons.
- The absence of undeclared nuclear weapons activities.
- The disposition or disposal of former nuclear weapons and materials into non-weapons usable forms.
- The non-use of civil nuclear facilities and materials for weapons purposes.

Other objectives that should be considered are the capability to verify that nuclear weapons have been placed in a non-deployed or non-alert status and the capability of missile defense systems to deny a second strike nuclear retaliatory capability, which is the essence of nuclear deterrence.
In addition, capabilities for the detection of illegal transfers of nuclear weapons, materials and technology should be an element of the national program.

While considering these objectives, a program structure should be created that emphasizes cooperative verification and monitoring over espionage. This approach will maximize the program's potential to build international confidence and contribute to stability. While many of the objectives identified above require the cooperation of nations that are not willing to participate at the present time, the R&D efforts should nevertheless go forward with nuclear weapons states and non-nuclear weapons states that will contribute now. This increases the future political and technical environment for success and builds cohesion among like-minded states.

National and International Testing Capabilities

The program should identify and equip a network of actual and virtual testing facilities. These can be physically distributed but institutionally integrated and linked through information technology. The network will need to include:

- Test ranges and laboratories, including actual, former or simulated nuclear weapons and materials storage facilities and deployment sites, along with related transportation assets.
- Information and data management systems with simulation and modeling capabilities.
- The capability to conduct experiments with nuclear weapons and special nuclear materials when necessary.
- A red team (simulated adversary) activity, including R&D on parties' attempts to evade monitoring and treaty verification, including by deception and denial.
- The capability to cover the full range of experiment, test, demonstrate, exercise, and train for technology demonstration, followed by both routine and challenge on−site inspections as confidence building measures.
- Provisions for international participation as necessary for confidence−building purposes, or ideally as an integral part of the phased strategy for cooperative verification and monitoring regimes.

Innovative Implementation

As stressed by the recent study by the Nuclear Threat Initiative, the program should include initiatives that utilize collaborative innovation and international partnerships. This can expand understanding and awareness about verification concepts and promote sustainability. The program should also launch an initiative to share experiences and lessons learned from existing verification activities among international partners. Common understandings of information security processes and procedures should be developed both within the U.S. Government and with international partners. Even if the information security processes of interested countries are not similar, understanding the similarities and differences will make cooperation more effective.

NTI also rightly recommended that IAEA containment and surveillance technologies, which are in widespread use, should be assessed for possible future use in nuclear warhead limitation regimes. Currently, the IAEA employs a wide variety of safeguards tools and techniques, including tags, seals, remote monitoring, and environmental sampling. An international team of experts should explore whether or not these technologies would be useful for verification and could be used in a warhead environment.

Another potential innovation is to link the program on nonproliferation and verification technologies to the network of nuclear security support centers and centers of excellence across the globe. These centers have mixed objectives, but do include nuclear materials security, counter nuclear terrorism and nonproliferation. In addition, the program should arrange for periodic review of its operations and research and development. Organizations like the Nuclear Threat Initiative, the National Academy of Sciences and the American Physical Society or other expert groups could play this role.

A final innovation is to make greater use of the national laboratories. Consistent with their nuclear security mission, the national labs can contribute to the formulation of a national verification and monitoring program. They have the skills and experience to successfully develop the needed technology and procedures and should be assigned a leading role in program implementation. Some construction or refurbishment of appropriate R&D and testing facilities for nonproliferation, verification and monitoring technology at the national labs and other NNSA/DoD sites will be required. This will help prevent disruption at current facilities involved with nuclear stockpile operations and allow experimentation with foreign-designed equipment and technology.

Conclusions and Recommendations

There is strong and enduring U.S. Government support for improving nonproliferation, verification and monitoring technologies and capabilities. Despite this, national investment in this aspect of nuclear security remains insufficient to fill gaps in current capabilities and prepare for future challenges. Almost five years after the 2010 Nuclear Posture review called for a national program on *expanded work on verification technologies and the development of transparency measures* there has been no substantial follow-up.

Nuclear weapons, which are receiving sufficient funding and attention, cannot alone counter the full spectrum of nuclear security challenges facing the nation and the world in the decades ahead. Nor can they counter or deter the most likely nuclear threats to the nation. The technical and human capabilities for nonproliferation, verification and monitoring are being neglected with perilous potential consequences. These capabilities are essential to verify compliance with current and anticipated nuclear arms agreements and to move safely towards a world without nuclear weapons.

To remedy this, we make these recommendations:

- A new, integrated multiagency program to develop nonproliferation, verification and monitoring technologies for nuclear security should be initiated without delay.
- The program should be funded as a core aspect of the nation's nuclear infrastructure modernization plan, and thus implemented jointly by the National Nuclear Security Administration and the Department of Defense, with guidance from the State Department, intelligence community and National Academy of Sciences.
- Such a program is affordable at a fraction of the cost of other nuclear infrastructure modernization tasks, and is needed to maintain nuclear security in an evolving security environment. This modest investment, which could pay back immense dividends, should be made now, even in the pending FY 2016 appropriations process.
- These capabilities are essential to verify compliance with current and anticipated nuclear arms agreements and to move safely towards a world without nuclear weapons.
- The need for this program was formally codified as an objective in the 2010 Nuclear Posture Review, and has been repeatedly articulated by both the U.S. government and independent assessments. That need should be met now. Failure in the form of a nuclear detonation on American soil (or anywhere) is not an option.

Key Reference Documents

Committee on International Security and Arms Control. *U.S. National Academy of Sciences, Monitoring Nuclear Weapons and Nuclear-Explosive Materials.* Washington, DC: National Academy Press, 2005.

Office of Arms Control and Nonproliferation. *Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement.* Washington, DC: U.S. Department of Energy, May 19, 1997. The report is classified FOUO.

Office of Nonproliferation Research and Engineering, Arms Control & Nonproliferation Technologies Project. *Technology R&D for Arms Control*. Washington, DC: U.S. Department of Energy, 2001.

2010 Nuclear Posture Review Report:
http://www.defense.gov/npr/docs/2010%20Nuclear%20Posture%20Review%20Study.pdf

Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks series, Nuclear Threat Initiative, Washington, DC, July 2014.

Nuclear Non-Proliferation Treaty 2010 Review Conference Action Plan, Action 19:
http://www.un.org/ga/search/view_doc.asp?symbol=NPT/CONF.2010/50%20(VOL.I

Secretary of Energy Advisory Board -Interim Report of the Task Force on Nuclear Nonproliferation, August 1, 2014.
http://energy.gov/sites/prod/files/2014/08/f18/SEAB%20TFNN%20Interim%20Report_August%201%202014%20with%20appendices.pdf;

Under Secretary for Arms Control and International Security, remarks to United Nations General Assembly First Committee on Disarmament, New York City, October 7, 2014. http://www.state.gov/t/us/2014/232698.htm

NNSA Strategic Plan, May 2011: http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/2011_NNSA_Strat_Plan.pdf

Acton, James M., and George Perkovich. *Abolishing Nuclear Weapons*. London: Routledge, 2008.

APS Panel on Public Affairs. *Technical Steps to Support Nuclear Arsenal Downsizing*. Washington, DC: American Physical Society, 2010.

Bukharin, Oleg and James Doyle. "Transparency and Predictability Measures for US and Russian Strategic Arms Reductions." *Nonproliferation Review 9,* No.2, (2002): 1-19.

Bunn, Matthew. *Monitoring Stockpiles: Mayak Storage Facility Transparency*, 19 Oct 2007. Accessed at www.nti.org/e_research/cnwm/monitoring/mayak.asp

Confidence, Security & Verification: the challenge of global nuclear weapons control. Reading, UK: Atomic Weapons Establishment, 2000. Accessed at http://www.carnegieendowment.org/static/npp/awe_report.pdf

Cliff, David, Hassan Elbahtimy and Andreas Persbo. ―Verifying Warhead Dismantlement: Past, Present, Future,‖ *VERTIC Research Reports*, No. 9 (Sep. 2010): 8-99. Accessed at www.vertic.org

Doyle, James E. and Elizabeth Meek. *Supporting the President's Arms Control and Nonproliferation Agenda: Transparency and Verification for Nuclear Arms Reductions,* LA-UR 09-04214, July 2009.

El Bahtimy, Hassan. Disarmament: Security Context and Verification Challenges, *Trust & Verify,* VERTIC Newsletter, Jul-Sep 2009, Issue No. 126, accessed at http://www.vertic.org/trustandverify.asp

Feiveson, Harold A., ed. *The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons.* Washington, DC: Brookings Institution Press, 1999.

Fetter, Steven and Ivan Oelrich. Verifying a Prohibition on Nuclear Weapons, *Elements of a Nuclear Disarmament Treaty: Unblocking the Road to Zero*, edited by Barry Blechman and Alex Bollfrass, pp. 27-56. Washington, DC: Henry L. Stimson Center, 2010.

Fuller, James. Verification on the Road to Zero: Issues for Nuclear Warhead Dismantlement, *Arms Control Today*, Vol. 40, Dec 2010.

Garwin, Richard L. Technologies and Procedures to Verify Warhead Status and Disarmament. Paris: SIPRI Workshop, 2001.

George, Garry J. *Integrated Nuclear Security in the 21st Century: Thinking Multilaterally*, Sandia Report, SAND2009-5641, October 2009.

Gerdes, Eric R., Roger G. Johnston, and James E. Doyle. A Proposed Approach for Monitoring Nuclear Warhead Dismantlement. *Science and Global Security*, Vol. 9 (2001): 113-141.

Hart, John. —On-Site Inspections in Arms Control & Disarmament Verification, *Verification Matters*, VERTIC Research Reports, No. 4, Oct. 2002. Accessed at http://www.vertic.org/publications/verification%20matters.asp

Hinderstein, Corey, ed. *Cultivating Confidence: Verification, Monitoring and Enforcement for a World Free of Nuclear Weapons*. Washington, DC: Nuclear Threat Initiative & the Hoover Institution Press, 2010.

International Panel on Fissile Materials. *Global Fissile Material Report 2009: A Path to Nuclear Disarmament*. Princeton, NJ: International Panel on Fissile Materials, 2009. Accessed at www.fissilematerials.org

O'Neill, Jr., Philip. D. *Verification in an Age of Insecurity: The Future of Arms Control Compliance*. New York: Oxford University Press, 2010

Persbo, Andreas. Verifying a Ban of Fissile Material Production,‖ *Trust & Verify,* VERTIC Newsletter, Jul-Sep 2009, Issue No. 126, accessed at http://www.vertic.org/trustandverify.asp

Persbo, Andreas & Marius Bjorningstad. Verifying Nuclear Disarmament: The Inspector's Agenda, *Arms Control Today*, May 2008, accessed at www.armscontrol.org/print/2979

Pifer, Steven. The Next Round: The United States and Nuclear Arms Reductions After New START, *Brookings Arms Control Series*, Paper 4, Dec. 2010.

Podvig, Pavel. *Consolidating Fissile Materials in Russia's Nuclear Complex*, A research report of the International Panel on Fissile Materials, May 2009.

Pregenzer, Arian. "Advancing the Goals of NPT Article VI: Near-Term Opportunities through International Technical Cooperation," *The Nonproliferation Review*, vol. 15, no. 3, Nov. 2008, pp. 529-538.

Rinne, Robert L. *An Alternative Framework for the control of Nuclear Materials*, Center for International Security and Cooperation, Stanford University, May 1999.

Sanders, Lani Miyoshi; DeLand, Sharon M. and Pregenzer, Arian L. Integrating Nuclear Stockpile Management and Nuclear Arms Control Objectives to Enable Significant Stockpile Reductions, *The Nonproliferation Review*, Vol. 17, No. 3, Nov 2010, pp. 475-489.

von Hippel, Frank & Roald Z. Sagdeev, eds. *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in Nuclear Weapons.* New York: Gordon & Breach Science Publishers, 1990.

Woolf, Amy F. Monitoring and Verification in Arms Control, *CRS Report for Congress*, R41201, April 21, 2010

Wuwen, Zhao. Promoting Nuclear Warhead Reductions: Regimes, Approaches and Technologies, *CISSM Working Papers* (Sep. 2004). Accessed at http://www.cissm.umd.edu/papers/files/wuwen_promoting_nuclear__reductions.pdf

Zarimpas, Nicholas, ed. *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions.* Oxford: Oxford University Press, 2003.

Author's Bio

Dr. James E. Doyle is an associate fellow of the Belfer Center for Science and International Affairs at Harvard University and an associate of the Stimson Center in Washington, D.C. From 1997 to July 2014 Dr. Doyle was a specialist in the Nuclear Nonproliferation Division at Los Alamos National Laboratory. His professional focus is on systems analysis, strategic planning and policy development. Dr. Doyle holds a PhD in International Security Studies from the University of Virginia. At Los Alamos he managed projects with Russia's nuclear weapons institutes on the joint development of technologies and procedures for verifying the dismantlement and storage of nuclear warheads and fissile materials.

All photographs are courtesy of either the U.S. government or James Doyle.

This report is made possible by the generous support of the Ploughshares Fund.

Contact information: Nuclear Watch New Mexico, 903 W. Alameda #325, Santa Fe, NM 87501
Voice and fax: 505.989.7342 • info@nukewatch.org • www.nukewatch.org
http://www.nukewatch.org/watchblog/ • http://www.facebook.com/NukeWatch.NM