US Monitoring and Verification Technology: 
On-site Inspection Experience and Future Challenges

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Abstract:

The United States has a long and successful history of cooperation with treaty partners in monitoring and verification. For strategic arms reduction treaties, our collaboration has resulted in the development and application of systems with limited complexity and intrusiveness. As we progress beyond New START (NST) along the “road to zero,” the reduced number of nuclear weapons is likely to require increased confidence in monitoring and verification techniques. This may place increased demands on the technology to verify the presence of a nuclear weapon and even confirm the presence of a certain type. Simultaneously, this technology must include the ability to protect each treaty partner’s sensitive nuclear weapons information. Mutual development of this technology by treaty partners offers the best approach for acceptance in treaty negotiations. This same approach of mutual cooperation and development is essential for developing nuclear test monitoring technology in support of the Comprehensive Nuclear Test Ban Treaty (CTBT). Our ability to detect low yield and evasive testing will be enhanced through mutually developed techniques and experiments using laboratory laser experiments and high explosives tests in a variety of locations and geologies.

Introduction:

“While the New START treaty is an important first step forward, it is just one step on a longer journey. …going forward, we hope to pursue discussions with Russia on reducing both our strategic and tactical weapons, including non-deployed weapons.”

The Comprehensive Nuclear Test Ban Treaty (CTBT) places a global ban on “any nuclear weapon test explosion or any other nuclear explosion.” As a signatory, the United States is committed to improving the capability to monitor and verify nuclear tests. Current international monitoring and analysis provide a baseline capability to monitor nuclear detonations with seismology, radionuclide analysis, hydroacoustics, and infrasound. The Treaty’s verification regime also includes provisions for on-site inspection and confidence building measures.

Our objectives in this discussion are to describe the experience of the Defense Threat Reduction Agency (DTRA) in conducting and supporting on-site inspections and monitoring and verification, and to compare lessons learned with future challenges, especially in developing technology. Key points are:

- On-site inspection for strategic and conventional arms control treaties is an important DTRA mission
Nuclear-weapons test monitoring is a key DTRA mission

DTRA’s cooperation and coordination with interagency partners – especially DOE’s National Nuclear Security Administration (NNSA) and the Department of State Arms Control, Verification, and Compliance Bureau (DOS AVC).

DTRA’s technology development programs anticipate the possible needs of future treaties and support negotiations by demonstrating what is possible to achieve. Basic research is a key part of this integrated technology development.

International cooperation is essential in developing technology. Technology developed by treaty partners enhances transparency and increases the probability that this technology will be included by treaty negotiators in monitoring and verification regimes.

DTRA is a Department of Defense agency committed to combating the threat of weapons of mass destruction. Our Agency, started in World War II under the Manhattan Project, has supported an understanding of nuclear weapons effects as we transitioned from the Armed Forces Special Weapons Project, Defense Atomic Support Agency, Defense Nuclear Agency (DNA), then the Defense Special Weapons Agency (DSWA), and conducted nuclear weapons effects testing. In 1998 DTRA was formed from DSWA, the U.S. On-Site Inspection Agency, and the Cooperative Threat Reduction program to provide an integrated DoD approach to countering weapons of mass destruction (CWMD). Cooperative threat reduction, on-site inspection, operational support for combating WMD, and technology development continue to be important DTRA missions.

**Experience in On-Site Inspections for Nuclear Arms Reductions**

DTRA and its predecessor organizations have emphasized support for nuclear arms reduction treaties to include the Intermediate-range Nuclear Forces (INF) treaty, the Strategic Arms Reduction Treaty (START), and the current New START Treaty (NST). Inspections for such treaties are primarily visual and are characterized by the use of practical and “off-the-shelf” tools. Inspectors comment that, to date, among their most important tools are tape measures and flashlights to support visual inspections and measurements to examine treaty-limited items of inspection. For objects where appearances and size are not sufficient (objects in missile front sections or in or on bombers), radiation detection equipment (RDE) can be used to resolve ambiguities.

Current RDE is based upon a simple thermal neutron detector that measures neutrons produced by spontaneous fission from special nuclear material (SNM). Current neutron detectors in use for inspections are based upon helium 3 (He3). The interaction of the He3 nucleus with thermal neutrons produces charged particles which are detected by the ionization in the gas filled tube. Because of the scarcity and cost of He3, current research focuses on alternative neutron detection materials.
RDE is used primarily to confirm that objects declared to be non-nuclear (e.g., objects on a missile front section other than reentry vehicles, non-nuclear ordnance on bombers) really are. This simple equipment provides limited information to characterize an inspection object, intrinsically protecting sensitive weapons information. Measuring a sufficient number of neutrons would indicate the presence of SNM.

Current neutron detector technology was developed in the U.S. by Sandia National Laboratories and in Russia by the Russian Institute of Automatics (VNIIA). Polyethylene is used to reduce the neutron energy (moderation) through scattering so as to maximize sensitivity. Calibration sources are essential to assure accurate measurements. Current calibration sources are based on radioactive sources such as americium 241 which produce alpha particles in their decay. These alpha particles generate neutrons when they impact light materials such as lithium or beryllium.

**Use of Radiation Detection Equipment under INF (1987)**

The Intermediate-range Nuclear Forces (INF) Treaty was signed in 1987 to limit the use of intermediate range nuclear weapons. Multiple reentry vehicle (RV) SS-20s were not permitted under INF, and RDE was used to confirm that SS-20 launch canisters for intercontinental-range road-mobile SS-25s did not contain missiles with multiple RVs. A comparison of the absolute neutron count from an inspected object with benchmark values indicated the presence of no more than a single warhead. Inspectors were granted visual inspection of one randomly selected SS-25 RV to provide additional confidence. During INF, we saw the use of portal perimeter monitoring equipment to provide confidence that ballistic missile production facilities in both the United States and the Soviet Union were no longer producing and deploying banned delivery vehicles. We also used cargo-scan x-ray imaging of SS-25 road-mobile ICBM launch canisters to confirm they didn’t contain missile stages for the banned SS-20.

![Figure 1: Neutron detectors were used to confirm that SS-25 launch canisters did not contain missiles with multiple re-entry vehicles](image-url)
RDE Use Under START/NST

With START, we moved from the use of RDE to provide confidence that a particular type of weapon was no longer being deployed at all, to a regime in which RDE was used to provide confidence that warhead numbers attributed to two classes of delivery systems – ICBMs and SLBMs – did not exceed agreed ceilings. The bottom line, of course, is that in START, RDE was used to prove that additional objects present during an inspection were non-nuclear.

Other important provisions of START were agreements that each side would not impede the ability of national technical means to verify strategic weapons systems through concealment and would not encrypt data telemetry in test launches.

The New START Treaty limits the number of deployed strategic warheads to 1,550. Warheads on missiles are counted on an actual load-out basis. Each heavy bomber is attributed with one countable nuclear weapon. An object counts against the nuclear warhead limits unless it is verified to be non-nuclear. RDE will be used to confirm that conventional ordnance, if loaded on a heavy bomber, isn’t nuclear.

It is critical that RDE operate reliably and safely. Specific design factors that must be considered include:

- Rugged (Planes, trains, and automobiles/temperature extremes)
- Portable (battery operated)
- Easy to observe internal components without damaging equipment
- Ease of operation
- Efficient (e.g. acceptable counting times)
- Safe around ordnance

Although NST does not require the use of substantially improved verification technology, such technology may be necessary for future strategic arms control treaties. Mutual development of improved technology, along with appropriate information barriers to protect sensitive weapons information, (e.g. high resolution gamma spectroscopy, imaging neutron and gamma detectors) by prospective treaty partners may provide a better foundation for future agreements and treaties.

The TOBOS Program. An Example of International Cooperation.

TOBOS is the Russian acronym for Safety and Security Technologies for Russian Warheads. This program was started in 2001 as a DoD component of the NNSA – Russian Federation Minatom (now ROSATOM) Warhead Safety and Security Exchange (WSSX) program. TOBOS developed technology for automated monitoring and inventory, for safe
warhead storage in containers, and for shipment in specially designed safe and secure railcars. It evaluated new safety, security, and monitoring technologies, including antiterrorism technologies, and tamper-indicating equipment, radiation monitors, container content identification devices, and information protection technologies, and trained personnel in the operation of these technologies for secure and safe storage and transportation. Sandia National Laboratory and Russia’s Institute for Automatics (VNIIA) provided equipment, integration, and test support.

Figure 2. TOBOS Storage and Shipment Facilities and Equipment in St. Petersburg, Russia

Nuclear Test Monitoring Experience

The Limited Test Ban Treaty in 1963 limited atmospheric testing and the release of radioactive material into the atmosphere. The Threshold Test Ban Treaty (TTBT) in 1974 limited the yield from an underground test with a single device to less than 150 kt. The United States developed hydrodynamic diagnostics using Continuous Reflectometry for Radius vs Time Experiments (“CORRTEX”) and Hydro Plus, which were used to verify compliance with TTBT.

Hydro Plus provided independent measurements of peak stress, particle velocity, and very accurate time of arrival at three different locations in the range of 20-1,000 kbar. The yield was determined by comparison with computer calculations for various yields.

CORRTEX used time-domain reflectometry to interrogate the two-way transit time of a coaxial cable. As the shock front advanced the cable was shorted or destroyed and the resultant transit time was shorter. Interpretation of these changes as a function of time allowed the position of the shock front to be inferred also as a function of time, providing a basis for assessing yield.

The Joint Verification Experiment (JVE) represents a remarkable cooperation in nuclear test monitoring. In August and September of 1988, the U.S. and USSR conducted underground nuclear tests at their respective test facilities in Nevada and near Semipalatinsk, Kazakhstan. Treaty partners observed each test and participated in on-site hydrodynamic yield measurements and in regional and long range (‘teleseismic’) seismic measurements.
This program demonstrated bilateral cooperation and transparency in monitoring and verification technologies and provided a geophysical calibration of each test site.

Discussions about conducting a new series of Joint Verification Experiments using higher explosives and a broader range of test sites has continued over the years. The recent NNSA-Rosatom lab director’s meetings in June and October, 2011, have revived and expanded these discussions.

Figure 3. US and Soviet Flags atop the experiment tower at the Nevada Test Site in the first Joint Verification Experiment in August, 1988.

Future Challenges for Strategic Arms Reductions

Michele Smith and John Dunn\textsuperscript{2} and Burgess Laird\textsuperscript{3} have pointed out that as future arms control treaties continue the reduction of nuclear weapons, the value of confirming that each is nuclear and of a specific type may be increasingly important for verification. This might stretch a country's comfort zone with regard to allowing access or permitting measurements of its weapons’ characteristics.

As we contemplate technology needs for future treaties which may focus on the full stockpile including non-strategic and non-deployed nuclear weapons, the following challenges must be addressed:

- Developing an effective technique for confirming that warheads are nuclear and of a specific type
- Developing information barriers and attribute or template matching procedures so that sensitive information can be protected by the warhead owner while providing verification.\textsuperscript{4}
- Developing “transparent” instrumentation whose function and capabilities can be easily authenticated.

Some of the technology approaches that we are investigating, in partnership with NNSA and DOS AVC, include:
Portable high resolution gamma ray spectroscopy systems based on high purity germanium (HpGe) for identifying specific isotopes and materials
Neutron and gamma ray imaging systems
Actively-illuminated fast neutron imaging techniques based on associated particle imaging (determining the direction of the neutron which transits the SNM by tracking the alpha particle produced in the opposite direction). The Oak Ridge National Laboratory (ORNL) Nuclear Material Identification System (NMIS) and more compact Fieldable NMIS² are prime examples.

Figure 4. The ORNL NMIS System Can Characterize Warheads

Examination of other attributes of nuclear weapons subject to measurements including weight, geometry, presence of specific materials, etc.
Development of templates of characteristics for specific warhead types through radiation measurements.
Cosmic Ray Muon Imaging. In this technique, cosmic ray muons are used to produce an image of dense material through scattering by measuring the angle before and after the muon transits the test object. The arrival of the muons can be time-gated and correlated with radiation induced from fission by the muon stopping in the SNM. This technique has the virtue of producing no additional radiation exposure and might be used to image an object without removing it from a strategic launch vehicle. It is worth noting that this technique was developed by scientists at Los Alamos National Laboratory (LANL) for portal monitoring to interdict any smuggled nuclear weapons and is currently the subject of commercial development by Decision Sciences Incorporated.

Future Challenges for Life Cycle Monitoring and SNM Production

Future nuclear arms control treaties may require monitoring from SNM production through storage and finally dismantlement. The Fissile Material Cutoff Treaty (FMCT) is intended to limit the production of SNM by ensuring that fissile material produced through uranium enrichment and reactor production of plutonium is limited in quality (e.g. the degree
of enrichment of uranium) so as to prevent its use in a nuclear weapon. The ability to negotiate and ratify an FMCT may depend upon the ability to perform effective verification. Specific challenges include

- Developing on-site and remote methods for monitoring the enrichment of uranium to weapons grades levels to include both traditional enrichment techniques and new laser isotope separation (LIS) methods.\(^6\)\(^7\)
- Monitoring production reactors and the chemical processes needed to separate plutonium from reactor fuel
- Monitoring materials disposition in dismantlement.

Some of the technology approaches that we have assessed or are developing in partnership with NNSA and DOS AVC include the following:

- The use of laser induced breakdown spectroscopy (LIBS)\(^8\) and laser ablation molecular isotopic spectrometry (LAMIS)\(^9\) to measure the degree of enrichment. A conceptual system might consist of a fiber laser in a backpack with a high resolution optical system which could be used to make measurements during an on-site inspection. For example, the laser could illuminate the surface of a bench inside a glove box and assess enrichment. LIBS/LAMIS and other laser techniques – Raman scattering, laser induced fluorescence, etc, are also useful to measure other materials associated with weapons including high explosives.

![Figure 5: Laser Induced Breakdown Spectroscopy Can Measure Isotopic Fractions](image)

- Multispectral and hyperspectral imaging can be used for remote measurements from an aerial platform to measure chemicals emitted from an enrichment facility.
- Lawrence Livermore National Laboratory has investigated the utility of monitoring neutrinos from reactors as a technique to monitor possible Pu production. Neutrino induced charged particles produce Cerenkov radiation and/or scintillation tracks and
can be used together in an anti-coincidence mode for directionality. The rapid growth
in the number of underground neutrino observatories for cosmological and
géophysique measurements offers the opportunity for an experimental verification of
the utility of this technique.

**Future Challenges for Safeguarding Nuclear Material**

DTRA’s Cooperative Threat Reduction and international engagement programs such
as TOBOS have emphasized the development and application of techniques to safeguard
nuclear material. The DTRA Basic Research Program is investigating novel methods to
monitor and protect nuclear materials, devices, and weapons in storage and transport. Key
challenges include:

- Ensuring chain of custody through tamper-proof tags and seals and tamper-indicating
  enclosures
- Development of unique identifiers to monitor the undisturbed storage of nuclear
  components and weapons

Some of the innovative technology approaches that DTRA is developing in our basic research
program include the following:

- The use of optical quantum entanglement that employs a fiber laser and optical crystal
  which creates two energy down-shifted quantum entangled photons. A Mach-Zender
  interferometer is used to detect any change in the entangled states as an indication of
  tampering\(^{10}\)
- Nanoparticles for tags and seals which provide unique reflectivity for long term
  identification and tracking and environmentally sensitive constituents to measure
  radiation, temperature, pressure and other factors indicative of movement of
  tampering.\(^{11}\)

![Quantum Entanglement for Safeguarding Nuclear Material](image)

**Figure 6. Quantum Entanglement for Safeguarding Nuclear Material**
Future Challenges in Nuclear Test Monitoring

Monitoring underground nuclear testing to limit proliferation is an important US national goal and DoD priority. Traditional techniques employing seismic signatures, infrasound, and radionuclide (RN) releases may not detect all low-yield and evasive underground testing. It is important to develop alternative techniques with improved sensitivity and different phenomenology, which may provide an increased signature in a large underground cavity intended to reduce the seismic coupling. Specific challenges include the following:

- Understanding and differentiating seismic signatures (e.g. pressure waves, shear waves) produced by nuclear and conventional explosions, as well as by earthquakes.
- Understanding the effects of decoupling by determining the change in seismic signatures from testing in large cavities or pre-fractured geologies.
- Assessing the utility of electromagnetic and radiofrequency signatures and the range at which such signatures can be measured as a function of nuclear yield and distance from the test site. Understand the relationship between cavity size and signal strength in the context of decoupling.
- Understanding the RN “source term” from fission products and neutron activation and develop a predictive capability as a function of yield and geology.
- Assessing particular radionuclides suitable for on-site inspection.
- Developing flexible collection systems and platforms for RN particle and gas collection and prompt on-platform analysis.
- Understanding the coupling of atmospheric infrasound waves to the ionosphere and the measurement of resulting ionospheric perturbations

Figure 7. The NIKE Laser at the Naval Research Laboratory and the National Ignition Facility at LLNL are used to understand signatures from underground nuclear testing
DTRA is working with the NNSA, the national labs, the DOS, and the Naval Research Laboratory to conduct experiments and to validate codes for nuclear testing signatures for both low-yield and decoupled tests. The experimental program ranges from microexperiments with several kilojoules of laser energy to field experiments with high explosives ranging from yields of kilograms to tons. The flagship experimental program is the NNSA Source Physics Experiment (SPE) at the Nevada National Security Site. DTRA supported NNSA for SPE 1 on 3 May, 2011, and SPE 2 on 25 October 2011 with instrumentation, test site infrastructure support, fielding acoustic and shock/seismic sensors, and performing pre-test predictions. Specific approaches and technology programs include the following:

- Understanding seismic signatures as a function of geology and yield and developing high-frequency, high-fidelity 3D models for seismic source terms.
- Evaluating “magnetic bubble” and source region EMP as signatures for decoupled tests.
- Assessing the ability of VLF magnetic bubble EMP to propagate to teleseismic (1000’s of km) distances and to be distinguished from lightning strike produced EMP.
- Performing scaled decoupling experiments with lasers at the Naval Research Laboratory and LLNL.
- Developing and testing high frequency acoustic sensors for close-in test site monitoring.
- Evaluating the use of gravity gradiometers to detect underground cavities produced by testing to enable selecting an appropriate drilling and sample collection site for on-site inspection.
- Evaluating an architecture of wirelessly connected close in sensors for monitoring.
- Assessing ionospheric perturbations created by infrasound and the measurement of these perturbations through induced fluorescence, high frequency radar scattering, or phase shifting in transmitted electromagnetic signals.

**Future Challenges: The Importance of International Cooperation**

The acceptance of technology for monitoring, verification, and on-site inspection depends upon transparency enabled through cooperative development. Successes from the Joint Verification Experiments for nuclear test monitoring, the Warhead Safety and Security Exchange, and TOBOS programs illustrate the promise and possibilities for cooperative programs. NNSA is reviving cooperation with the Russian Federation Rosatom through lab directors meetings and lab-to-lab cooperation. The DOS is advocating a program of test site transparency with Russia and other nuclear powers.

DTRA supports our NNSA and DOS partners with several efforts to promote international cooperation for nuclear test monitoring and strategic arms reductions. Cooperative threat reduction programs support global nuclear security and test site
remediation. The DTRA funded National Academy of Sciences – Russian Academy of Sciences “Track 2” dialog promotes candid discussion of arms control issues and technology. DTRA is collaborating with the Nuclear Threat Initiative Verification Pilot Project, an effort which, as Corey Hinderstein describes at this meeting, will examine the implications of multilateral strategic arms control treaties and the role of non-nuclear weapons states.

In partnership with NNSA, DTRA is planning to initiate university-based international partnerships for cooperative research. Columbia University, in partnership with the Institute for Geophysical Research and National Data Center of the Republic of Kazakhstan, is planning to examine seismic data from Eurasian nuclear test sites. First historical data will be digitized and then analyzed to provide a characterization of each test site based upon its geology. This model of matching a US university with an international laboratory counterpart will be expanded.

Summary

DTRA’s long history of conducting on-site inspections and cooperative research programs provides the focus for future technology development for monitoring and verification. Working with interagency and international partners, we will develop technology to support future treaties and to enhance the acceptance of this technology through transparency partnerships.

Our initial focus is on nuclear test monitoring and supporting future strategic arms limitations treaties through technologies to characterize and safeguard nuclear weapons and materials. Future work will address technology needs for chemical and biological warfare monitoring and verification.

1 Remarks by President Obama at the New START Treaty Signing Ceremony, 8 April 2010
2 Michele H. Smith, John Dunn, and Kevin Seager, Proceedings of the 51st Annual INMM, July, 2010
3 Burgess Laird, Institute for Defense Analysis, private communication, 2011
4 Arden Dougan, John Dunn, Kevin Seager, Michele Smith, David Beach, Justin Clinton, Peter Vanier, 7th INMM/ESARDA Joint Workshop, 17-20 October 2011
An International Cooperative Verification Agenda for Arms Reductions,” Corey Hinderstein, 7th INMM/ESARDA Joint Workshop, 17-20 October 2011