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THE FISSILE MATERIAL TRANSPARENCY TECHNOLOGY DEMONSTRATION

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Abstract

The United States Department of Defense, Defense Threat Reduction Agency Cooperative Threat Reduction program is supporting the construction of a fissile material storage facility at Mayak in the Russian Federation. Up to 34 tons of weapon-grade plutonium will be stored in the facility to await disposition. In order to meet arms control and nonproliferation objectives, the U.S. Congress has requested assurances that the nuclear material stored at the Mayak facility is derived from dismantled nuclear weapons.

The usual approach to identify the origin or state of radioactive materials is to measure the intensity and energy of neutron and gamma radiation emitted. However, the Russian Federation considers such details as isotopic composition and mass to be classified. The solution arrived at by a DOE multilaboratory team is to place the radioactive specimen, the gamma and neutron counters, and all the computational equipment behind an information barrier. In the Fissile Materials Transparency Technology Demonstration (FMTD), this equipment was configured and programmed to measure the following six attributes: isotopic ratio, threshold mass, absence of oxide, presence of plutonium, age, and symmetry.

On August 16, 2000, at Los Alamos National Laboratory, a delegation of Russian officials observed the successful demonstration of this new technology (called an Attribute Measurement System with Information Barrier, or AMS/IB). The scientists were able to demonstrate without releasing classified information that the nuclear material sample being tested (a nuclear weapon pit) had the declared weapon-grade plutonium characteristics.

Once fully developed, AMS/IB technology will protect sensitive information while providing the United States increased confidence that the mandated Russian fissile materials have been stored. Attribute measurement systems can play a role in a number of U.S.-Russian nuclear security regimes such as the Trilateral Initiative, the Plutonium Production Reactor Agreement, and future strategic arms agreements. This paper discusses the details of this new inspection equipment, the August 2000 demonstration, and potential future applications.

Introduction

This paper provides an overview of the Fissile Material Transparency Technology Demonstration (FMTTD), which occurred at Los Alamos National Laboratory on August 16, 2000. During the demonstration, radiation emitted from a U.S. nuclear weapon component was measured for a Russian Federation delegation using an attribute measurement system that included an information barrier that prevented the loss of classified information about the component.

The demonstration was intended to be a “proof of concept.” It showed one way in which the challenge of measurement without release of sensitive data was met. The concept requires further development before it can be implemented. An additional goal of the demonstration was to begin cooperative development, in which different U.S. and Russian Federation subgroups could begin working together on the next steps for several possible specific applications. Treaties and agreements where attribute measurement systems with information barriers (AMS/IBs) might be applied are listed below.

- START I and START II to reduce accountable nuclear-weapons launchers;
- the highly enriched uranium/low-enriched uranium (HEU/LEU) agreement, whereby the U.S. purchases from the Russian Federation LEU derived from weapons HEU;
- the Trilateral (US-RF-IAEA) Initiative to apply bilateral and IAEA inspections to nuclear materials no longer needed for weapons purposes;
- the Plutonium Production Reactor Agreement (PPRA), which supports in the cessation of plutonium production for weapons purposes and monitors Pu produced in the interim; and
- the Fissile Material Storage Facility, which is designed to safely and securely store fissile material from nuclear weapons.

As part of this process, the two countries rely on mutually agreed methods, sometimes referred to as “transparency measures,” to provide confidence that the objectives and conditions underpinning these initiatives are being satisfied.

Through joint work, significant progress has been made in the development and implementation of mutually acceptable transparency arrangements. As technology has progressed and as experience has been gained, the transparency measures have become increasingly sophisticated and effective. Transparency measures are now being used routinely in applications that, in the past, would have been regarded as too sensitive for any form of bilateral or international interaction.

Based on past experience, the optimal approach to overcoming these challenges is cooperative work. By combining the best of Russian and American technologies and ideas, practical solutions can be developed that are well-adapted to the requirements and conditions in each country. A major goal of the Fissile Material Transparency Technology Demonstration was to pave the way for further technical cooperation in this area.

The information barrier was a critical enabling technology that allowed measurement of sensitive items to produce useful results without compromising sensitive data. In the demonstration, the information barrier was a specific set of equipment and accompanying procedures. The AMS/IB can be thought of as a box with the measuring and computational systems on the protected side (inside) and the unclassified display on the open side (outside). All classified data generated by the measurement system remained inside the box.

The attribute measurement system determined whether a given object possessed, or failed to possess, certain “attributes” or characteristics. It did this by making direct measurements of specific energy spectra of the radiation emitted by the sample. The results of the measurements were compared inside the protected area with unclassified thresholds. The results of these comparisons determined the unclassified “attributes” of the sample, which were then transmitted through the information barrier to the unclassified display.

The six attributes used for the Fissile Material Transparency Technology Demonstration were:

- (1) plutonium isotopic ratio,
- (2) plutonium mass,
- (3) absence of oxide,
- (4) presence of plutonium,
- (5) symmetry of the plutonium, and
- (6) plutonium age.

These are six of the seven attributes that were discussed in previous technical exchanges among U.S. and Russian experts. The seventh attribute discussed in those exchanges, the presence of gallium, was dropped because measurement of this attribute was not feasible.

Measurement of any of these attributes requires use of a detection system that generates classified data when used in conjunction with a classified object. Thus, the information barrier hides all of the “raw” data, and only unclassified yes/no threshold evaluations are capable of being displayed.

The thresholds used in the FMTTD have been discussed in previous technical exchanges. In some cases, they were selected for pragmatic reasons, solely for purposes of the demonstration. The following is a brief summary of the thresholds chosen.

Presence of plutonium—determined by looking for several characteristic plutonium gamma-ray peaks. The threshold was based on a statistical test at the five-sigma level.

Plutonium isotopic ratio—as discussed in previous technical exchanges, the isotopic ratio threshold was whether the ratio of ^{240}Pu to ^{239}Pu is greater or less than 0.1.

Plutonium mass—the threshold was 500 grams. It is an unclassified fact that “all U.S. weapon pits that contain plutonium contain at least 500 grams of plutonium, no elaboration.”

Plutonium age—the threshold date between “old” and “new” was defined as 1 January 1997.

Absence of oxide—the oxide attribute is based on two thresholds. Oxide is determined to be present only if alpha (a neutron multiplicity parameter) is greater than 0.5, **and** the 871-keV gamma peak is present (at the three-sigma level). Otherwise, oxide is determined to be absent.

Symmetry—as discussed in previous technical exchanges, the symmetry threshold is a 15% deviation, in any one of eight banks of detectors, from the mean neutron response averaged over all eight.

As shown in Figure 1, the data generated in the detection systems pass into the analyzers. Both the raw data from the detectors and the processed data from the analyzers was classified if a classified item is being measured. The analyzed data pass into the computational block where the threshold values are stored and threshold comparisons are performed. The outputs from the computational block, in the form of yes/no data, are passed through the data barrier and to the unclassified display. Although the outputs from the computational block are unclassified, these signals are inside the shielded enclosure and are treated as possibly classified until they pass through the data barrier and leave the enclosure.

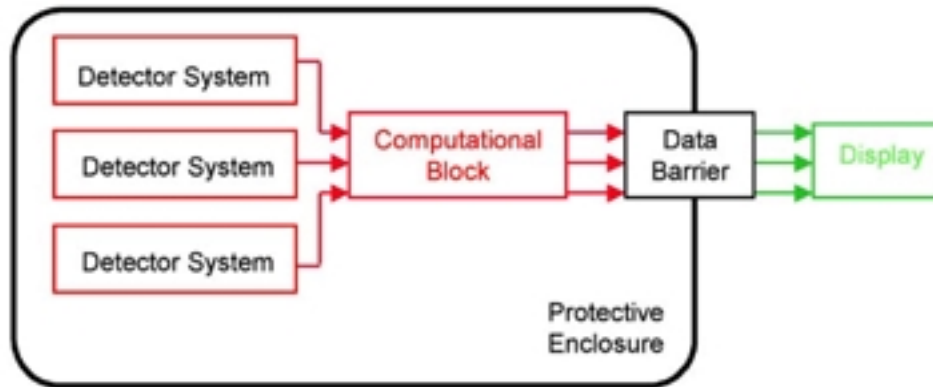


Figure 1. A simplified drawing of the AMS/IB concept showing the measurement detectors, computational block, data barrier, and display.

An additional element of the AMS/IB is that all power for the AMS/IB enters the through an AC line filter. A security watchdog monitors the security status of the entire system. The watchdog removes all power from the AMS/IB if any access door is opened.

Detection Systems

The demonstration AMS/IB consisted of three detector systems: a large high-resolution germanium spectroscope (HRGS), a medium-sized HRGS, and a neutron multiplicity counter (NMC) modified to provide access to the signals coming from individual banks of ^3He tubes (Figure 2). All three detector systems are collocated around a single measurement position within the NMC. Both HRGS detectors are aligned to “look” through the walls of the NMC at the source position.



Figure. 2. The three AMS/IB detectors. On the left is the Pu300/600, a HRGS system. In the center is a NMC. On the right is the Pu900.

Power to all electronic elements and detectors was controlled by the security watchdog. The filtered power cable leading to the security watchdog and all cables between the shielded electronics rack (SER) (Figure 3) and all detectors were shielded.

Pu300/600—The aforementioned medium-sized germanium detector (50%) was used to supply the raw data for both the Pu300 and Pu600 analysis programs. These analysis programs run sequentially in a single computer so that, although Pu300 and Pu600 are separate analysis programs, they were both running in a single HRGS system.

The Pu300 analysis used data from a region between 330 and 350 keV in the plutonium gamma-ray spectrum. This region included spectral lines from ^{241}Am that can be used to determine the amount of americium present in the object and to infer the age of the plutonium in the object, because as plutonium ages, ^{241}Am is created through β -decay of ^{241}Pu .

The spectral region from 630 to 670 keV was analyzed by the Pu600 code both to provide an isotopic ratio ($^{240}\text{Pu}/^{239}\text{Pu}$) for the sample being measured and to provide an indicator of the presence of plutonium. This spectral region included lines from both ^{240}Pu and ^{239}Pu . A comparison of the strengths of these lines provided a measure of the isotopic ratio of the sample, and the existence of the lines is indicative of the presence of plutonium.

Pu900—The larger (66%) germanium detector supplied raw data for the Pu900 analyzer. The Pu900 analyzer utilized data from the region between 860 and 880 keV in the plutonium gamma-ray spectrum. This region included lines that were thought to be indicative of ^{17}O content in the plutonium being measured. Thus, the Pu900 measurement was used as one test to indicate the presence of oxide in the plutonium being measured. We have since learned that the 871 line is due to ^{15}N .

The germanium detectors for the Pu300/600 and the Pu900 systems are located in an interlocked “Hoffman Box” enclosure that provides shielding and physical protection for the detectors. The analysis computers for these subsystems are located in the shielded electronics cabinet with all the other AMS/IB electronics. The detector enclosures are connected to the shielded electronics rack by a set of shielded cables specific to the HRGS system.

Neutron Multiplicity Counter—The NMC used in this demonstration consisted of 32 ^3He tubes mounted within the four walls of a rectangular polyethylene enclosure. During normal operation,

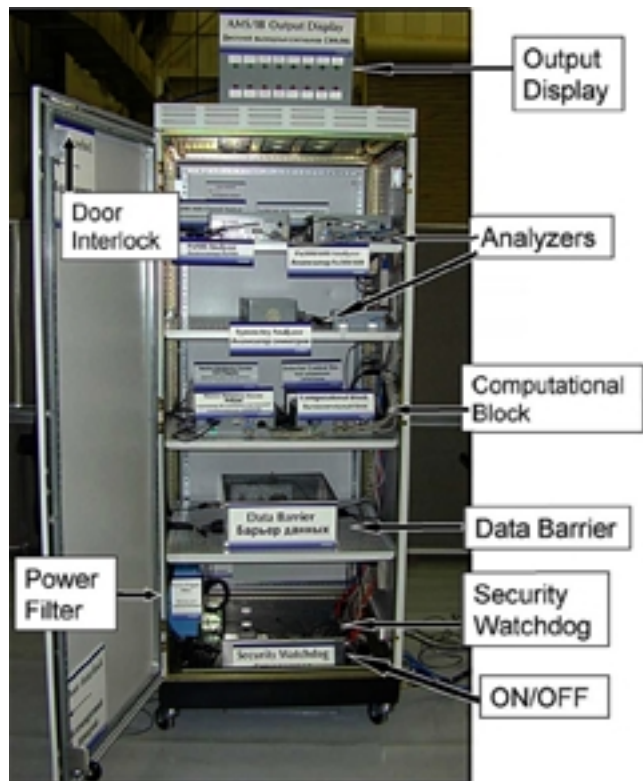


Figure 3. Shielded electronics rack.

the count rates for noncoincident, doubly coincident, and triply coincident events (singles, doubles, and triples) are measured in the NMC detector. If the efficiency of this detector has been measured, then the singles, doubles, and triples can be used to calculate the ^{240}Pu -effective mass, the fraction of (α, n) reactions (or α), and the multiplication in the sample. Together with the isotopic ratio obtained from the Pu600 analyzer, the ^{240}Pu -effective mass is used within the computational block to calculate the Pu mass, and α is used as a second indicator of oxide presence (in addition to the output from the Pu900 analyzer). The final absence-of-oxide determination, requiring the concurrence of both indicators, is also made in the computational block.

The neutron detectors and polyethylene of the NMC are located in a solid metal enclosure that provides shielding and physical protection for the detector. The shift register and analysis computer for this subsystem are located within the electronics rack with all of the other AMS/IB electronics. The detector enclosure is connected to the electronics rack by a set of shielded cables specific to the NMC system. This bundle of shielded cables is located within an electrical conduit.

Symmetry Detector—As well as being combined for the multiplicity measurement, signals from the eight octants of the neutron detector are counted individually to provide an indication of the axial symmetry of the sample.

Analyzers

All of the CPUs used in the AMS/IB were small and easily inspectable, with documented functionality. Each of the four measurement systems includes a separate CPU as its analyzer. Among other advantages, dedication of these functions to separate CPUs allows each measurement system to be tested separately without requiring the remainder of the AMS/IB to be operational.

The analyzer CPUs are all implementations of the PC/104 standard, and all use DOS operating systems. The software is stored in ROM memory, which cannot be modified or erased. The CPU boards are commercially available; for this demonstration, the commercial boards were used with their original excess functionality disabled. All of the analyzers are located within the SER and all receive their power from the security watchdog.

Computational Block

The attribute threshold values are stored in the computational block in read-only memory. Attribute threshold comparisons are performed in the computational block. In addition, any calculations requiring the results from more than one analyzer are performed in the computational block. There is no interconnection between analysis computers except within the computational block. The inputs to the computational block from the analyzers are potentially classified but the outputs from the computational block to the data barrier are unclassified (yes/no) values.

As implemented in this demonstration, the computational block uses a small, easily inspected computer with limited hardware and software functionality. The demonstrated computational block is based on an Ampro 3SXI 386 computer with an Emerald digital I/O card. This PC/104 specification CPU runs a DOS operating system. As with the analysis CPUs, there is no data connection between the security watchdog and the computational block.

Data Barrier

The only function of the data barrier is to pass unclassified information in one direction, from inside the SER to the display. In ordinary operation, no classified information is presented to the data barrier by the computational block. In any event, the data barrier is constructed from simple hardware so that it cannot be “reprogrammed” to pass other information.

As implemented in the demonstration system, the data barrier utilizes fiber optics drivers and fiber optic links to the display to ensure that no data can pass back into the SER. The fiber optic links also ensure that no extraneous electrical signals are picked up or radiated by the links to the display. The fiber optics drivers are driven by either flip-flops or low-pass filters. The flip-flops are clocked once each measurement cycle so that only one change of output state is allowed for each measurement.

Display

The unclassified display is another simple hardware circuit with no computer-controlled functions. The optical signals transmitted by the data barrier are received in optical receivers. The optical receivers in turn are connected to LED drivers, which are connected directly to the red and green LEDs. All power for the display is DC and is generated within the shielded enclosure and sent to the display through a shielded cable. Thus, the security watchdog also controls the power to the display.

The display for the FMTTD AMS/IB has eight red and eight green LEDs. Six pair of LEDs are used to indicate passing or failing the six attribute tests. The remaining two pair of LEDs display system functions. One pair indicates the security status of the AMS/IB (whether the system is open [red] or secure [green]). An additional green LED indicates that a measurement has been completed and the final red LED is indicative of a malfunction within the AMS/IB.

The Demonstration

The objectives of the FMTTD were the following:

- (1) demonstrate to the Russian delegation that an attribute measurement system with information barrier (AMS/IB) could be built with sufficient protection to allow measurement of classified components without revealing classified information, and
- (2) construct this AMS/IB in such a manner as to convince the Russian delegation that it would be possible for an inspecting party to fully authenticate operation of the system.

The demonstration took place in the Los Alamos National Laboratory Technical Area 18 “High Bay” facility, where special arrangements were made to accommodate the AMS/IB equipment and the large number of visitors. Special security procedures were implemented, including most notably a requirement for all participants to change clothes and shoes before entering the High Bay.

The demonstration consisted of the following steps:

- (1) AMS/IB startup—after arrival of the first Russian visitors, the attribute measurement system was started.
- (2) Background and energy calibrations—background and energy calibrations were performed and a measurement-control procedure for the NMC was carried out.

- (3) Authentication measurements—in the open mode, two unclassified sources were measured to show the correct operation of the system. The first sample was an asymmetric array of fuel grade (high ^{240}Pu) plutonium metal plates. The second sample was 1.5 kilograms of plutonium oxide.
- (4) Nuclear weapon component—the AMS/IB was placed in secure mode, and the nuclear weapon component was measured.
- (5) Remeasurement—one of the authentication sources was remeasured, this time in secure mode, to show consistency of the attribute response. The Russian delegation selected the plutonium oxide sample for the remeasurement.
- (6) Security watchdog function—the security watchdog function was demonstrated, showing that the system shuts down if any attempt is made to breach the information barrier.
- (7) Shut down and secure AMS/IB—the system was shut down.
- (8) Equipment viewing—the Russian visitors were invited to approach the equipment for closer examination and for detailed discussions with technical experts.

The AMS/IB performed perfectly during the demonstration. Complete details of the demonstration can be found at the following WWW site: http://www-safeguards.lanl.gov/FMTT/index_main.

The FMTTD was intended as a proof of concept demonstration. A goal was to establish that the six attributes could be measured while protecting classified information and that it would be possible, through a series of authentication measures, to instill confidence that the system operated as it should. Full implementation of such a system is a more difficult task. What is straightforward in concept may become very complex when all the details of a particular application are considered.

The Cooperative Threat Reduction program through the Defense Threat Reduction Agency has funded a development effort to design the next generation AMS/IB. (Reference 2) The plan is to relay this design to the Russian Federation. Then Russian technical experts will use the U.S. design as a guide to design an AMS/IB for use in the Mayak Fissile Material Storage Facility.

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