Review of Prior U.S. Attribute Measurement Systems

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Abstract

Attribute Measurement Systems have been developed and demonstrated several times in the United States over the last decade or so; under the Trilateral Initiative (1996-2002), FMTTD (Fissile Material Transparency Technology Demonstration, 2000), and NG-AMS (Next Generation Attribute Measurement System, 2005-2008). Each Attribute Measurement System has contributed to the growing body of knowledge regarding the use of such systems in warhead dismantlement and other Arms Control scenarios. The Trilateral Initiative, besides developing prototype hardware/software, introduced the topic to the international community. The "trilateral" parties included the United States, the Russian Federation, and the International Atomic Energy Agency (IAEA). With the participation of a Russian delegation, the FMTTD demonstrated that measurements behind an information barrier are feasible while meeting host party security requirements. The NG-AMS system explored the consequences of maximizing the use of Commercial off the Shelf (COTS) equipment, which made construction easier, but authentication harder. The 3rd Generation Attribute Measurement System (3G-AMS) will further the scope of previous systems by including additional attributes and more rigor in authentication.

1 – Introduction

In order to better understand the 3rd Generation Attribute Measurement System (3G-AMS), it would be helpful to review the systems which served as predecessors for the 3G-AMS. These include the Trilateral Initiative Demonstration, the Fissile Material Transparency Technology Demonstration, and the Next Generation Attribute Measurement Systems. Each system built upon the knowledge gained by preceding systems.

An Attribute Measurement System (AMS) is used to perform non-destructive measurements on a sealed container that contains agreement relevant items provided by the host party.) and determine simple, unclassified attributes (yes/no answers) about the items that increase the confidence of the monitoring party that the items are consistent with the host declaration. If a full data set of the non-destructive measurements were revealed to the monitoring party, it might reveal sensitive or classified information about the declared item.. The full data is processed and analyzed into simple, unclassified attributes which are strictly controlled by an Information Barrier (IB).

Once an AMS is complete, it is thoroughly examined by both sides. In the host country, the system is subjected to *certification*, a process which evaluates the ability of the system to prevent the release of possible sensitive information. The monitoring party subjects the system to a process known as *authentication*, this process increases the confidence that the results of a measurement properly reflect the item being examined. A system that is authenticated performs robustly and precisely as intended. In general, systems which are simpler and have an open design are easier to certify and authenticate.[1]

2 – Trilateral Initiative Demonstration

The Trilateral Initiative was a six-year effort (1996-2002) to determine the legal, fiscal and technical framework for placing sensitive items under IAEA safeguards. A portion of this program was to develop a measurement system that might allow the Russian Federation and the United States to submit classified

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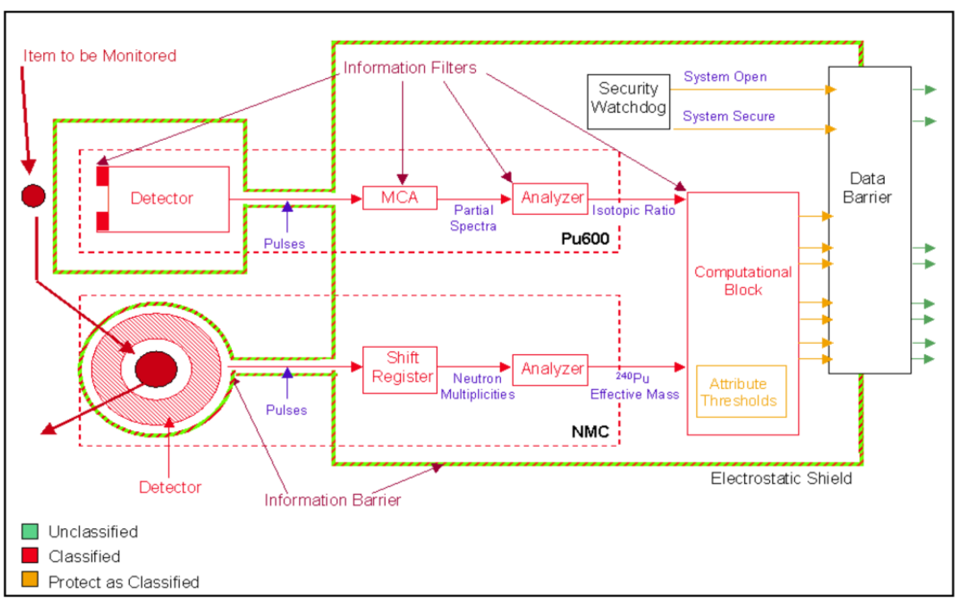
forms of weapons-origin fissile material to the IAEA for verification and monitoring.[2] In support of this effort, the U.S. demonstrated an Attribute Measurement System with an Information Barrier at the Trilateral Initiative Technical Workshop held at Los Alamos in June 1999. The U.S. technical experts built the system based on technical discussions up to that time, but used several possible technical solutions in the prototype to stimulate further discussion. The neutron analyzer ran standard IAEA software (INCC[3]) running on a desktop computer platform (using the Windows operating system). The gamma analyzer was a PC/104 microcomputer running minimal software and MS-DOS[4] and booted off of an approximately floppy-sized CD-ROM image.[5]

Three attributes were determined: presence of Plutonium, Plutonium isotopic ratio consistent with weapons-grade Plutonium (^{240}Pu/^{239}Pu < 0.1), and Plutonium mass above a threshold. The system was neither certified by the U.S. for use on sensitive items, nor authenticated. However, the system demonstrated many important technologies, such as: layered barriers, creative use of volatile memory, spectral segmentation with Pu600[6], security interlocks to withdraw power in case of irregular events, and a simplified data display using red/green light pairs to indicate the status of attribute results.[7]

The following is a picture of the demonstrated system and a functional diagram of the system.



The system consisted of one high-purity germanium (HPGe) detector and one small Neutron Multiplicity Counter (capable of holding a 1-gallon drum). The HPGe detector had a mechanical iris to keep the gamma ray count rate constant independent of the source being measured. The entire system was enclosed in a series of shielded enclosures connected with shielded cables. Attributes were determined sequentially, first using the gamma system, then the neutron system.[8]

The U.S. system led to the design of the Attribute Verification System with an Information Barrier Utilizing Neutron Multiplicity Counting and High-Resolution Gamma-Ray Spectrometry (AVNG) system, a similar system jointly designed and then manufactured by the Russian Federation. It was funded under the U.S./Russian Warhead Safety and Security Exchange (WSSX) Agreement. It was demonstrated at Sarov, Russia in June 2009.[9,10] It determined three attributes: presence of Plutonium, Plutonium isotopic ratio consistent with weapons-grade Plutonium ($^{240}Pu/^{239}Pu < 0.1$), Plutonium mass above a threshold. It ran on a simple, open source operating system (eCos). It was certified for use at the Russian facility and had many features and procedures to aid with the authentication process.[11]

3 – Fissile Material Transparency Technology Demonstration (FMTTD)[12]

The purpose of the Fissile Material Transparency Technology Demonstration (FMTTD) was for the U.S. to demonstrate an attribute measurement system with an information barrier to the Russian Federation on unclassified plutonium samples and a U.S. nuclear weapon component. The stated objectives of the FMTTD were:

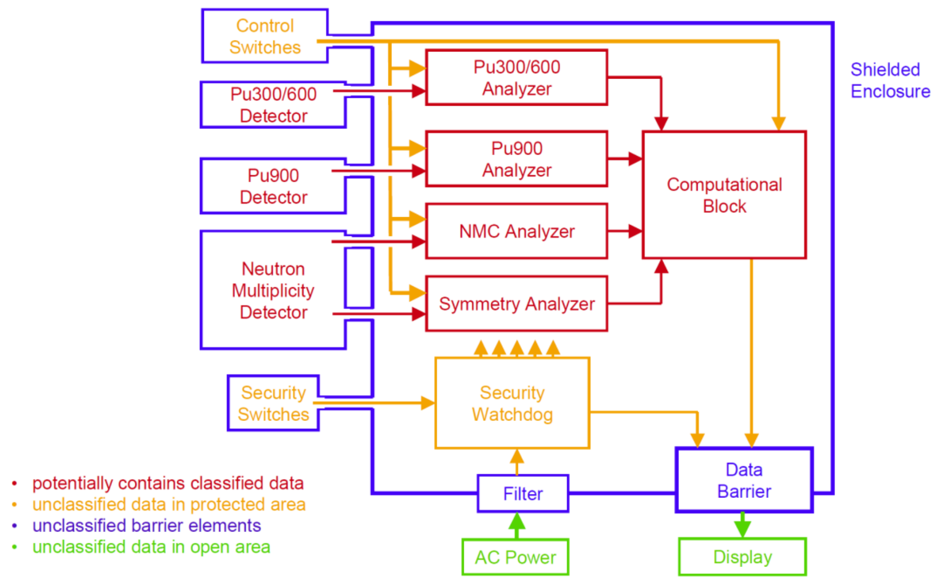
1) To demonstrate to the Russian delegation that an attribute measurement system (AMS) could be built with sufficient protection to allow examination of classified components without revealing classified information, and
2) To construct this AMS in such a manner as to convince the Russian delegation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

The project was sponsored by the U.S. Defense Threat Reduction Agency (DTRA). The work was performed by a multi-laboratory team including Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL) and Pacific Northwest National Laboratory (PNNL). The demonstration was hosted at LANL from August 14-17, 2000 and was very successful.

Six attributes were confirmed: presence of Plutonium, Plutonium isotopic ratio consistent with weapons-grade Plutonium ($^{240}Pu/^{239}Pu < 0.1$), Plutonium mass above a threshold (500 grams), Plutonium age since chemical separation, not Plutonium oxide*, and symmetry along an axis (less that ± 15% from symmetrical).[13] The system determined these attributes concurrently in about an hour.

The following is a picture of the demonstrated system and a functional diagram of the system.

* The item was declared to not contain Plutonium oxide.



The system consisted of a two high-purity germanium (HPGe) detectors and one large Neutron Multiplicity Counter (capable of holding a 30-gallon drum). Each of the HPGe detectors had a mechanical iris to normalize the gamma count rate independently of the source being measured. The entire system was enclosed in a series of shielded enclosures with shielded cables between enclosures. Each of the analyzers consisted of a commercial data acquisition system, connected to a small PC/104 computer with an Intel processor, running MS-DOS. The Computational Block had a similar computer. Each computer ran solely off a floppy-sized software image on programmable read-only memory (PROM).[14] An important feature of the system is that each analyzer only processes the data for the measurements it is responsible.

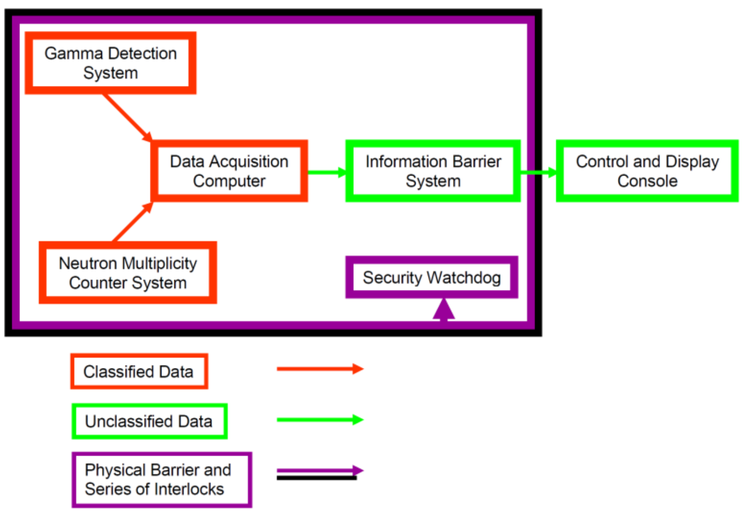
Measurements are initiated by the Control Switches. The Detectors collected the data and the Analyzers calculated the results. The purpose of the Computational Block was to receive the results from the detector systems, combine them (as required) and compare them with thresholds to produce binary attributes passed through the data barrier and displayed on the unclassified Display. The Security Switches verified the integrity of the shielded enclosures and determined the mode of the system: open (presence of an unclassified item) or closed (presence of a classified item). In the case of a loss of enclosure integrity or if a classified item is introduced into the system incorrectly, the security watchdog dropped power to the entire system[15], causing the loss of any information in the volatile memory of the detector systems.

The system was certified for use at the U.S. facility, and extensively documented as if it was to be authenticated by the Russian Federation.

4 – Next Generation Attribute Measurement System (NG-AMS)

The Next Generation Attribute Measurement System (NG-AMS) was designed and built between the years of 2005 and 2008. The system determined three attributes: Plutonium isotopic ratio consistent with weapons-grade Plutonium, Plutonium mass above a threshold, and Plutonium age since chemical separation. The purpose of the system was to explore the use of Commercial Off-The-Shelf (COTS) software and hardware wherever possible.[16] The argument was that commercial hardware and software is more reliable and more likely to be trusted (since it was developed by a third party) than custom hardware and software designed specifically for this system. Using blind buys and random selection for hardware and software can increase trust in a system.[17] All of the hardware and software in the system has been subject to worldwide, rigorous testing. It is well understood by a large group of scientists who are familiar with its function, operations, and limitations. Commercial hardware and software is less likely to be tampered with by either the host or the monitor.[18,†]

The following is a picture of the demonstrated system and a functional diagram of the system.



The instrument consisted of a High Purity Germanium (HPGe) gamma-ray detector and a small Neutron Multiplicity Counter (NMC). A single data acquisition computer was utilized. It ran Microsoft Windows XP Embedded, along with FRAM (for gamma analysis) and INCC (for neutron analysis), both commercial software released by ORTEC, but originally developed at LANL[‡]. The Windows software was controlled by a custom PERL script which simulated the keyboard and mouse. The system booted off an approximately 400MB CD-ROM.

[†] However, commercial hardware and software is often general purpose which leads to additional functionality and a more complex design. Rarely is commercial hardware and software released with an open design.

[‡] This is not unique to LANL. Software and hardware used to perform gamma and neutron analysis is often originally developed at a national laboratory, and then commercialized by commercial companies.

The NG-AMS team performed important work on analyzing the overall Mean Time Between Failure (MTBF) of the hardware system with respect to its components. They determined that there was an 82.5% probability that the system would operate correctly without any component replacement during a hypothetical 10-year regime.[19]

In addition to exploring the extensive use of COTS hardware and software, two significant advances were successfully demonstrated in the system. One improvement was the use of two weak gamma sources (one long-lived and one short lived) which were mounted to the HPGe detector to substitute for a battery powered real-time clock. The other improvement was the inclusion of a much simpler (in complexity) computational block that any previous U.S.-developed AMS. Instead of a general purpose 80386 based general purpose computer, a single 8-bit microcontroller was used.[20,21]

The NG-AMS system was extensively tested using a wide range of plutonium sources[22] and demonstrated on multiple occasions to external audiences.

5 - Conclusion

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References

[1] Software Authentication Using Rose and Compass, G. White, 51st Annual Meeting of the INMM, 2010

[2] *The Trilaterial Initiative: A Model for the Future?*, Thomas E. Shea, Arms Control Today, May 2008, http://www.armscontrol.org/act/2008_05/PersboShea.asp%2523Sidebar1

[3] *The IAEA Neutron Coincidence Counting (INCC) and the Deming Least-Squares Fitting Program*, M.S. Krick, et.al., LA-UR-98-2378, http://www.lanl.gov/orgs/n/n1/FMTTD/neut_mc/pdfs/LA_UR_98_2378.pdf

[4] *Attribute Verification Systems with Information Barriers for Classified Forms of Plutonium in the Trilateral Initiative*, Langer, et.al., IAEA-SM-367/17/02, http://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%2017/Paper%2017-02.pdf

[5] *Progress in Gamma Ray Measurement Information Barriers for Nuclear Material Transparency Monitoring*, J.K. Wolford, G.K. White, UCRL-JC-137484, https://e-reports-ext.llnl.gov/pdf/238136.pdf

[6] *Verification of the Presence of Weapons-Quality Plutonium in Sealed Storage Containers for the Trilateral Initiative Demonstration*, S.J. Luke, G.K. White, D.E. Archer, J.K. Wolford and T.B. Gosnell, IAEA-SM-367/17/08, http://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%2017/Paper%2017-08.pdf

[7] *Information Barriers*, JL Fuller, JK Wolford, IAEA-SM-367/17/01, http://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%2017/Paper%2017-01.pdf

[8] *Progress Towards Criteria for a Second-Generation Prototype Inspection System with Information Barrier for the Trilateral Initiative, D.G. Langer, D.W. MacArthur, N.J. Nicholas, R. Whiteson, T.Gosnell, J. Wolford.*

[9] *AVNG System Objectives and Concept*, S. Razinkov, A. Livke, D. MacArthur, J. Thron, LA-UR-10-02625, http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-10-02625

[10] *The Design and Implementation of the AVNG Measurement System*, S. Razinkov, et.al., Proceedings of the 51st INMM Annual Meeting, Baltimore, MD, July 2010

[11] *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

[12] *FMTTD Homepage*, http://www.lanl.gov/orgs/n/n1/FMTTD/index_main.htm

[13] *Technical Overview of Fissile Material Transparency Technology Demonstration – Executive Summary*, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/exec_sum.pdf

[14] *Attribute Measurement System with Information Barrier for the Fissile Material Transparency Technology Demonstration: System Overview*, D. W. MacArthur, R. Whiteson, D. Langner, LANL; J. K. Wolford, Jr., LLNL; LA-UR-99-5611, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/ams_5611.pdf

[15] *Proposed Attribute Measurement System (AMS) With Information Barrier*, D. W. MacArthur, G. Dransfield; C. Johnson; R. Ortiz; L. Sprouse, LANL, LA-UR-99-6053, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/ams_watchdog.pdf

[16] *Progress on a Next-Generation Attribute Measurement System*, J. Thron, et.al., 47th Annual Meeting of the INMM, 2006
[17] Use of Commercially Available Software in an Attribute Measurement System, D. MacArthur, et.al., 46th Annual Meeting of the INMM, 2005
[18] *Next Generation Attribute Measurement System*, J. Thron, et.al., 48th Annual Meeting of the INMM, 2007
[19] *System Reliability on the Next Generation Attribute Measurement System*, J. Gallegos, et.al., 47th Annual Meeting of the INMM, 2006
[20] *Implementation of an Information Barrier for the Next Generation Attribute Measurement System*, R. Williams, T. Johansen, P. Karpius, D. MacArthur, M. Smith, 48th Annual Meeting of the INMM, 2007
[21] *Advantages and Disadvantages of Small Chip Count Device in an Information Barrier*, R. Landry, D. MacArthur, K. Frame, M. Smith, R. Williams, 46th Annual Meeting of the INMM, 2005.
[22] *Next Generation Attribute Measurement System*, J. Thron, et.al., LA-UR-08-03802, 49th Annual Meeting of the INMM, 2008