ARG-US – An RFID-Based Tracking and Monitoring System for Nuclear Material Packages*

Kun Chen, Hanchung Tsai, Yung Liu, and Jim Shuler[1]

Argonne National Laboratory, Argonne, IL, USA
[1]Department of Energy, Washington, D.C., USA

ABSTRACT

ARG-US is a system for the management of nuclear materials that is based on radio frequency identification (RFID) technology and the concept of a wireless sensor network. When deployed with RFID tags equipped with environmental sensors, ARG-US is capable of monitoring thousands of packages continuously and reporting incidents instantaneously. Mk-1 sensor tags for nuclear materials management have been successfully developed by the RFID development team at Argonne National Laboratory in parallel with ARG-US; the tag sensor suite currently includes temperature, humidity, seal, shock, and battery status. ARG-US has an immediate application at the Nevada Test Site (NTS), where the system would be used to monitor the ambient temperature of Model 9977 packages. The system may help NTS staff to reduce the number of leak-rate tests required for the packages, thus decreasing operating costs. To ensure the reliability of the system, long-term performance tests of both hardware and the software are being conducted in the laboratory; the results so far are highly encouraging. ARG-US has the potential to be a platform for other types of sensors, including radiation dosimeter, gas detector, and pressure monitor. Further, it has network functions that enable local ARG-US components to be connected to central servers via local networks or secured Internet. The web-based applications can be linked to multiple sites, making it possible to record and, indeed, integrate nuclear materials management activities over the entire complex. ARG-US is a powerful yet flexible system that can help to enhance and ensure the safety, safeguards, and security of the nuclear material packages and to better protect workers, the public, and the environment. Development of ARG-US devices, systems, and applications is continuing, including participation in the development of the ISO 18000-7 standard as part of the DASH7™ activities. This work is conducted by Argonne National Laboratory, which is supporting the Packaging Certification Program of U.S. Department of Energy Environmental Management, Office of Safety Management and Operations (EM-63).

INTRODUCTION

The U.S. Department of Energy's (DOE's) Packaging Certificate Program (PCP) has developed a packaging tracking and monitoring system for nuclear materials, called ARG-US, based on radiofrequency identification (RFID) technology. ARG-US is an integrated system that consists of tags, readers, local application software (ARG-US OnSite), a database, and web applications. One of the major utilities of ARG-US is the ability to continuously and autonomously track the physical locations and monitor the environmental conditions of the nuclear material packages during storage and transportation. At present, ARG-US can monitor the temperature, humidity, shock, and seal integrity of individual packages and issue automatic alarms if any of the preset

* Proc. 50th INMM Meeting, Tucson, AZ, July 12–16, 2009.

sensor thresholds are violated. Long-life (>10 years) battery design, sizeable (128-kB) non-volatile memories, and advanced encryption (AES 256) are other key features built into the tags. Potential benefits of the ARG-US system are enhanced safety, safeguards, security, and materials accountability; reduced radiation exposure and reduced need for attended operation and manned surveillance; real-time access to status (i.e., state of health) and event history data, including continuous monitoring of environmental conditions of packaging for aging management; and overall cost-effectiveness.

Early development, testing, and demonstration of the packaging RFID tracking and monitoring system have been published elsewhere.[1–5] This paper focuses on ARG-US as it relates to software quality assurance, sensor calibration and performance testing, long-term system performance and reliability testing, and potential new applications to safeguards and tracking of sources and by-product materials.

ARG-US SYSTEM

The hardware of ARG-US includes tags and readers. Tags are attached to the packages that are to be tracked and monitored. Sensors — such as temperature, humidity, shock and seal — are integrated into the tag to monitor environmental conditions. Readers communicate with the tags via 433-MHz radio waves. The communication range is up to ≈100 meters (300 feet). Readers are connected via Ethernet cables to a control computer on which the resident software ARG-US OnSite manages the data flow among the tags, readers, database, servers and web via a connection to the local IT network. Figure 1 shows an ARG-US system configured for

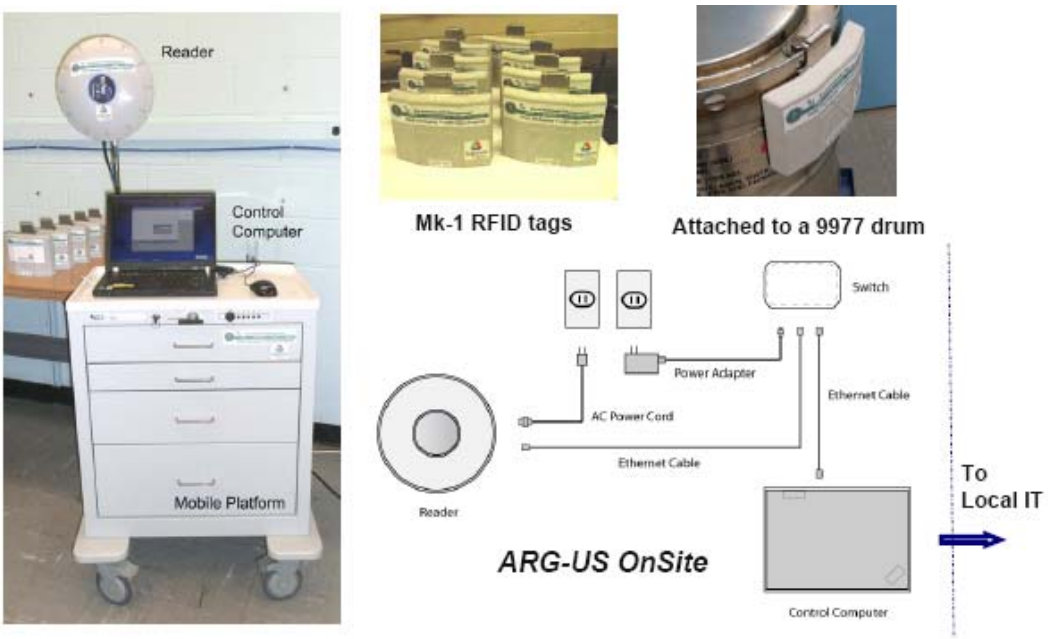

Figure 1. An ARG-US system on wheels, demonstrating system mobility.

several implementation projects at selected DOE sites. The mobile platform and simple connections to power and Ethernet make the system essentially "plug and play" — it is easily deployable to buildings and facilities where packages are stored.

SOFTWARE QUALITY ASSURANCE

The ARG-US software package includes ARG-US OnSite, database, and web applications.[3] ARG-US OnSite controls the readers that are connected via a switch box to the computer. It provides a graphical user interface (GUI) that allows the user to conveniently operate the hardware — for instance, the user can read the temperature of a single tag or have the system automatically read the temperatures of all tags at specified intervals. ARG-US OnSite also processes the data collected from the tags and stores them in a local database. The data can be encrypted, authenticated, and uploaded to a central server, where a secure web site has been set up. Authorized users can access the web site to retrieve information of the packages near real time. The ARG-US software architecture is shown in Figure 2.

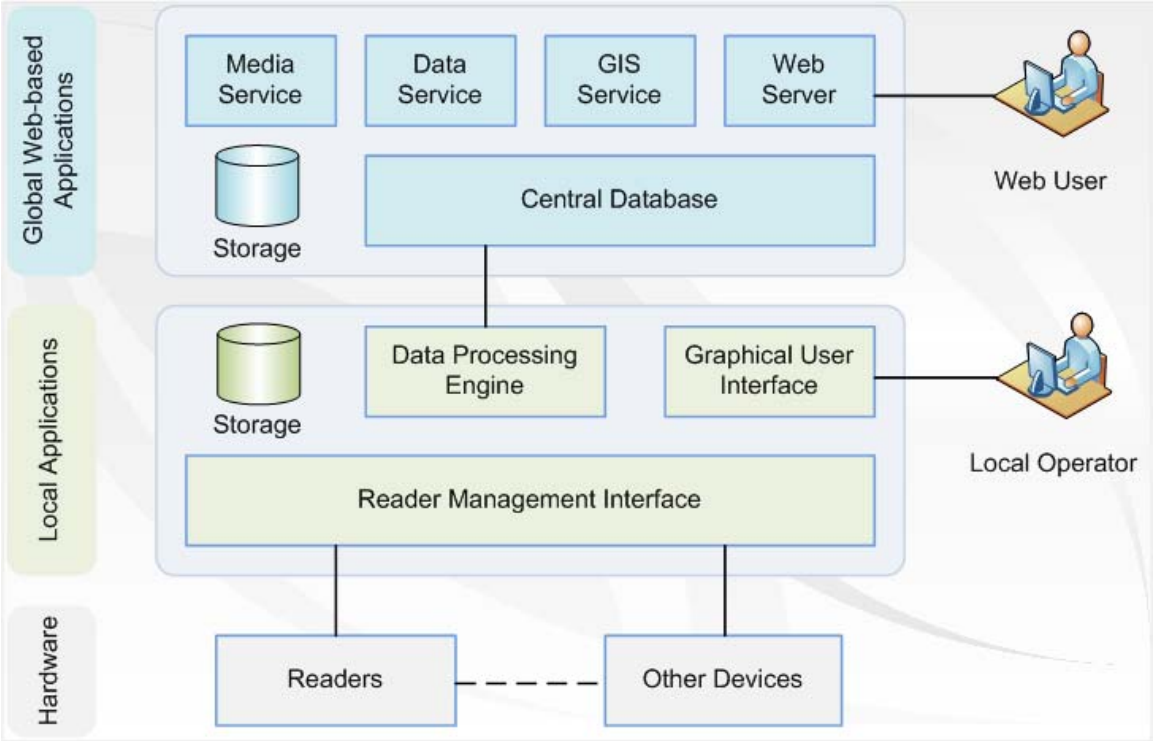

Figure 2. Software architecture of ARG-US.

A software quality assurance (SQA) program has been established for ARG-US. The SQA program determines the level of activities and documentation necessary for assuring the quality of ARG-US, as well as the practices to be followed in the course of the life cycle of the development effort. The program emphasizes design control, version control, software functionality and reliability tests, user documentation, and document control. Each version of ARG-US will be tested, reviewed, and approved on the basis of the SQA program before it can be released. The ARG-US SQA program is governed by the quality assurance plan (QAP) of the Decision and Information Sciences (DIS) Division of Argonne National Laboratory. The DIS QAP satisfies the requirements of the Argonne Quality Assurance Program Plan (Argonne QAPP), which governs all work undertaken by Argonne. The SQA Plan for the ARG-US system and other associated documents can be found in the Documentation Package for the RFID Temperature Monitoring System (Model 9977 packages at NTS).[6] A generic version of this documentation package applicable to other packagings (e.g., Models 9975, 9978, and ES-3100) is under preparation.

SENSOR CALIBRATION AND PERFORMANCE TESTING

ARG-US is designed for tracking and monitoring nuclear materials packages in storage and transportation. For storage, the duration may be significant (e.g., years). Sensors and onboard memories are the key elements of the system, whereas radiofrequency (RF) is a carrier of messages. Sensor performance and system reliability are critical in the field applications. System reliability depends on the reliability of the sensor components and the data communication system. Calibration of the temperature sensors in the tags and performance testing of the seal sensor are described in the following sections, followed by a discussion of the testing conducted so far in the laboratory on long-term system performance and reliability.

Temperature Sensor Calibration

One of the applications of ARG-US is to monitor the ambient temperature of the package by using the built-in thermistors in the tags (Figure 3, left) that would trigger an alarm and record the event when the temperature exceeds a preset threshold. To confirm the performance of the thermistors, the tags were placed inside an isothermal chamber along with certified Type K thermocouples. The RF reader was located outside the chamber and recorded the temperature data of the thermistors over the anticipated working temperature range of 0–65°C (32–149°F).

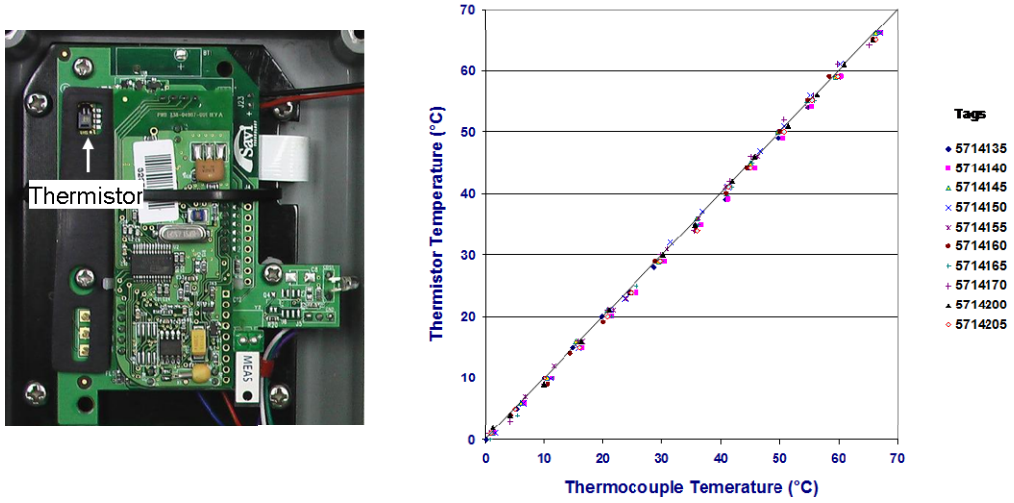

Figure 3. Calibration of tag thermistors versus certified thermocouples.

Figure 3 (right) shows the calibration results of thermistors in a random group of ten (10) tags. For all tags calibrated, the difference between the temperatures measured by the tag thermistor and that of the certified thermocouple is well within ±2°C. The thermistors used in the tags are of a commercial grade; the long-term reliability of similar thermistors has been documented in a National Bureau of Standards (now National Institute of Standards and Technology) report[7] to be excellent.

Seal Sensor Performance

The seal sensor of the tag containing piezoresistive pads[8] is custom-designed for packagings so that one or more of their lid bolts can be used for its attachment. Figure 4 (left) shows the sensor head for 9977 drums for a single-bolt mount. When the bolt is tightened or loosened, a slight change in torque causes the resistance to vary from kΩ (compressed) to MΩ (relieved). The high sensitivity of the seal sensor to compression (torque) makes the seal sensor an effective tamper-indicating device for packages with bolted closures. However, since the tags may stay on the

packages for years with the seal sensors in the compressed state, the long-term performance and reliability of the seal sensors needs to be investigated to determine if the pads stay pliant.

In the tests of seal sensor performance conducted to date, the seal sensors are pressed and held by a bolt and a nut with washers that are identical to those used for the actual packages. The performance testing was divided into four groups, according to the torque levels: (1) 4.5 ft·lb (6.075 N·m), which is at the low end of the torque range; (2) 30 ft·lb (40.5 N·m), which is the required torque for the Model ES-3100 package; (3) 45 ft·lb (60.75 N·m), which is the required torque for the Model 9977 and 9978 packages; and (4) 60 ft·lb (81 N·m), which is an over test with an estimated pressure of 8.6 MPa (1,250 psi) applied to the seal sensor pads.

The seal sensors were compressed for the entire tests, except for the brief moments when the bolt was loosened to obtain the uncompressed resistance readings. As long as the readings from the compressed and uncompressed states are sufficiently separated (e.g., by a decade or more in resistance), the seal sensors are regarded as functional because the difference can be readily detected by the tag electronics for alarm purposes.

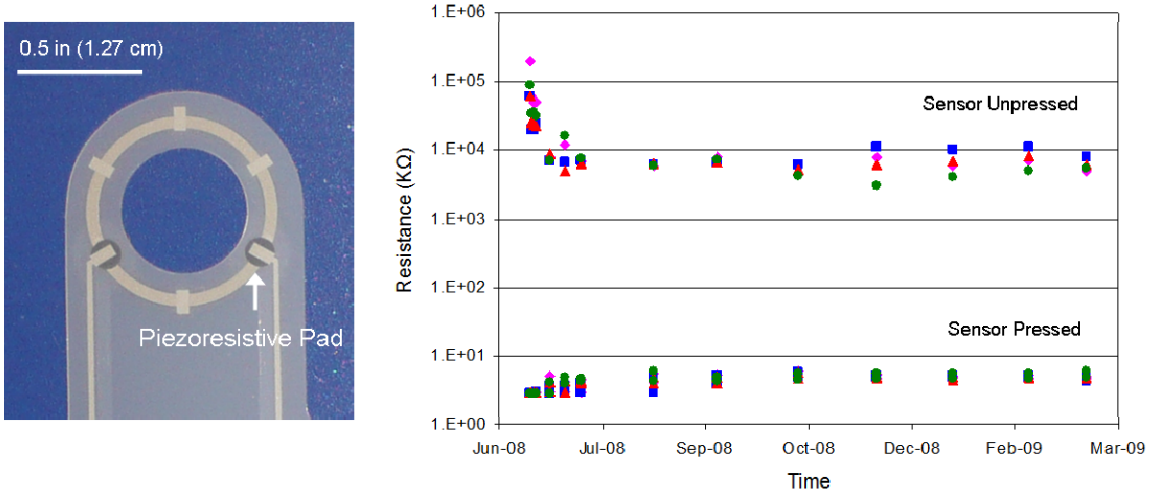

Figure 4. Performance testing of seal sensors for the 9977 drums. Applied torque was 45 ft·lb (60.75 N·m) and the test employed four duplicate sensors.

Figure 4 (right) shows the responses of four duplicate seal sensors to the applied torque of 45 ft·lb (60.75 N·m) for 9977 drum applications. The tests have been conducted for almost a year and the results show all four sensors performed as desired and the pads remained pliant after prolonged compression. Equally positive results were obtained from sensors tested at different torque levels. The seal sensor long-term performance testing is continuing.

LONG-TERM SYSTEM PERFORMANCE AND RELIABILITY

ARG-US is designed to collect data on the environmental conditions of packagings over extended periods of service. To test the system performance and reliability, data are being collected from forty-nine (49) Mk-2 tags in the laboratory polled continually, with intervals ranging from one hour to twenty-four (24) hours.

Figure 5 shows typical sensor data on the temperature and humidity recorded by a tag over a 10-day period, with a polling interval of 6 hours. The temperature of the tag tracked close to 22°C, which was the set temperature for the air-conditioned lab. The humidity, however, was more sensitive to the local weather conditions and, as expected, showed greater variations. Similar

sensor responses were observed in the demonstration (DEMO) of the packaging RFID tracking system conducted in April 2008.[4] The long-term testing of system performance and reliability is continuing in the laboratory, including simulation of various operation scenarios and crash recovery.

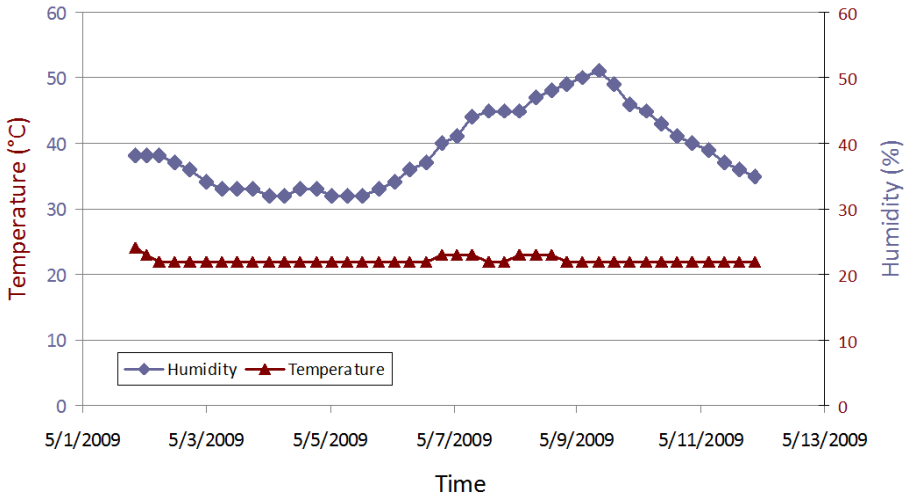

Figure 5. Typical sensor data of Mk-2 tags monitored by ARG-US OnSite (6-hour interval).

APPLICATIONS

Several ARG-US systems are currently being implemented at selected DOE sites. The projects involve Model 9977 and Model 9975 drums for (1) interim storage of nuclear materials for up to five (5) years, and (2) transport of these drums between DOE sites and other locations. Each drum will be fitted with an RFID tag for continuous monitoring of environmental conditions, particularly the ambient temperature, which would provide the basis for extending the interval of periodic leakage-rate testing of the containment O-rings at significant cost savings.[5] These drums will be transported by using the DOE Safeguards Transporter[9], for which the acceptance criteria for the RFID tags are being developed. The acceptance criteria include such necessary documents as the Transportation Shipping Request, the Certificate of Compliance, the tiedowns instructions, and other safety information and measures to ensure information security during transport.

International safeguards of nuclear materials,[10] tracking of sources[11], and tracking of by-product material[12] are areas in which a robust container-based ARG-US system can be applied. Millions of dollars have been spent in the design and certification of Type-B transportation containers (e.g., Model 9975/9977/9978 and ES-3100) that meet stringent U.S. and international safety standards for nuclear materials.[13,14] Attaching RFID sensor tags to any of these robust containers would readily add safeguards functions via the tamper-indicating seals, continuous remote monitoring, and automatic alarm notification by the ARG-US system with demonstrated long-term performance and reliability. There is an established process to convert a DOE- or Nuclear Regulatory Commission (NRC)-issued Certificate of Compliance (CoC) for a Type B transportation container to a Certificate of Competent Authority (CCA) issued by the U.S. Department of Transportation (USDOT). The USDOT CCAs can then be presented to the International Atomic Energy Agency (IAEA) Safeguards member States for approval and authorization in terms of the transport of radioactive material.[15] Whereas the design of the RFID tags can be easily modified for attachment to other types of packagings in the IAEA Safeguards member States, the CoC-CCA routes may be more economical and easily implemented for international safeguards applications.

According to the definition of technology readiness levels (TRLs) of the U.S. Department of Defense (DoD),[16] the TRL of the ARG-US system has been recently rated between 7 and 8, where TRL = 7 indicates system prototype demonstration in an operational environment and TRL = 8 indicates actual system completed and "flight qualified" through test and demonstration. A TRL of 9 is the final step during which the actual system is "flight proven" through successful mission operations. The ARG-US system is expected to reach a TRL of 9 by the end of 2009, if not sooner.

FUTURE PLANS

Enhancement of the ARG-US system is an ongoing effort. On the hardware side, the Mk-series RFID tag has interior space for adding other sensors, such as a radiation dosimeter or hydrogen fluoride gas sensor. On the software side, search functions will be developed for the ARG-US OnSite with user input, as well as advanced mapping capabilities. The ARG-US system will evolve with the ISO 18000-7, the global air interface standard for 433 MHz. Argonne and the DOE PCP are members of the Board of Technical Advisors for DASH7™ — an industry consortium (consisting of RFID vendors, system integrators, and end users) formed in March 2009 to support the ISO 18000-7 Standard and enhance product innovation, system interoperability, and reliability.[17]

SUMMARY

The ARG-US system has been developed for tracking and monitoring nuclear materials packagings during storage and transportation. All key features of the system were successfully tested in a weeklong, 1,700-mile DEMO by using containers certified by DOE and the NRC for the shipment of nuclear materials. Several ARG-US systems are currently being implemented at selected DOE sites involving 9977 and 9975 packagings for the interim storage and transportation of nuclear materials. International safeguards of nuclear materials and the tracking of source and by-product materials are new areas of application, and a robust container-based ARG-US system would integrate safety, safeguards, security, and materials management functions all in one compact package.

ACKNOWLEDGMENT

The authors would like to acknowledge Brian Craig, Mark Jusko, Craig Swietlik, and Bud Fabian for their contribution to the software development, testing, and quality assurance of the ARG-US system.

REFERENCES

1. Y. Liu, S. Bellamy, and J. Shuler, "Life Cycle Management of Radioactive Materials Packagings," Packaging, Transport, Storage & Security of Radioactive Material, Vol. 1, No. 4, 2007.

2. H.C. Tsai, K. Chen, Y. Liu, et al., "Applying RFID Technology in Nuclear Materials Management," Packaging, Transport, Storage & Security of Radioactive Material, Vol. 19, No. 1, 2008.

3. K. Chen, H. Tsai, and Y. Liu, "Development of the RFID System for Nuclear Material Management," Proceedings of the Institute of Nuclear Materials Management (INMM) 49th Annual Meeting, Nashville, TN, July 2008.

4. H. Tsai, K. Chen, and Y. Liu, "Report on Demonstration (DEMO) of Radio Frequency Identification (RFID) Tracking System," Argonne National Laboratory, Argonne, IL, September 30, 2008.

5. K. Chen, H. Tsai, Y. Liu, and J. Shuler, "A Radiofrequency Identification (RFID) Temperature-Monitoring System for Extended Maintenance of Nuclear Materials Packaging," Proceedings of 2009 ASME Pressure Vessels and Piping Division Conference, Prague, Czech Republic, July 2009.

6. Documentation Package for the RFID Temperature Monitoring System (Model 9977 packages at NTS), prepared by Argonne National Laboratory for the DOE Packaging Certification Program, February 17, 2009.

7. Wood, S.D, et al., Journal of Research of the National Bureau of Standards, Vol. 83, Issue 3, pp. 247–263, May-June, 1978.

8. Tactilus® Real-Time Surface Pressure Mapping Technology, Sensor Products Inc., 2009. www.sensorprod.com.

9. K. Sorenson, "Physical Protection Attributes for Secure Shipment of Commercial Nuclear and Radioactive Materials," U.S. Transport Council and Sandia National Laboratories Joint Workshop on Secure Civilian Transport of Nuclear and Radioactive Materials, Washington, D.C., December 4, 2008.

10. http://www.iaea.org/OurWork/SV/Safeguards/index.html.

11. http://www.nrc.gov/security/byproduct/nsts.html.

12. Proposed Rules Nuclear Regulatory Commission, 10 CFR Part 37 Physical Protection of Byproduct Material, Federal Register, Vol. 74, No. 83, May 1, 2009.

13. Title 10 of the U.S. Code of Federal Regulations, Part 71 - Packaging and Transportation of Radioactive Material, 2004.

14. IAEA Safety Standards, Regulations for the Safe Transport of Radioactive Material, 2005 Edition, No. TS-R-1, Safety Requirements. http://wwwpub.iaea.org/MTCD/publications/PDF/Pub1225_web.pdf (accessed June 2009).

15. National Competent Authorities Responsible for Approvals and Authorizations in Respect of the Transport of Radioactive Material, December 22, 2008. http://www-ns.iaea.org/downloads/rw/radiation-safety/competent-authorities-list.pdf (accessed June 2009).

16. Department of Defense, *Technology Readiness Assessment (TRA) Deskbook,* May 2005. http://www.darpa.mil/STO/solicitations/sn07-44/pdf/TRA_Desktop.pdf (accessed June 2009).

17. http://www.dash7.org/.