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ARG-US RFID FOR MONITORING AND TRACKING NUCLEAR MATERIALS — THE OPERATING EXPERIENCE

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ABSTRACT

Under the auspices of the U.S. Department of Energy (DOE) Packaging Certification Program (PCP), Office of Packaging and Transportation, Office of Environmental Management, Argonne National Laboratory (Argonne) has developed a monitoring and tracking system for nuclear materials based on radio frequency identification (RFID) technology. The system, called ARG-US (which means "Watchful Guardian"), has been in field-testing and deployments at selected DOE sites since 2010. This paper describes the operating experience of ARG-US at three of the sites — Savannah River Site, Nevada National Security Site, and Oak Ridge National Laboratory — in both storage and off-site transportation applications.

ARG-US utilizes battery-powered tags to remotely and continually monitor the vital parameters of packages in storage and transportation. The tags report the results to readers and the attached database via the 433-MHz radio frequency. No line-of-sight is necessary, and the read range can be >100 m. The tags contain a suite of sensors, including seal (tamper-indicating), temperature, humidity, and shock, as well as a gamma dosimeter and neutron detector. When sensor conditions are normal, the values of the parameters are recorded and stored at prescribed intervals. If any of the thresholds of a sensor are violated (for instance, a loss of seal-bolt tension), the condition is reported instantaneously to responsible parties for action.

The ARG-US RFID system has a modular and flexible platform. Of all the sensors, the neutron detector is the latest addition. In conjunction with the gamma dosimeters, the ARG-US RFID technology has the potential to provide all vital information about the packages to the facility operator while minimizing the need for personnel to be present for surveillance. Doing so not only streamlines facility operation and enhances productivity but also improves the implementation of the As-Low-As-Reasonably-Achievable (ALARA) principle for nuclear and radiological facilities.

INTRODUCTION

Argonne National Laboratory has developed a monitoring and tracking system for nuclear materials based on radio frequency identification (RFID) technology. The system [1–14], called ARG-US (which means "Watchful Guardian"), has been used in field-testing and applications at selected DOE sites since 2010. ARG-US utilizes battery-powered tags to remotely and continuously monitor the vital parameters of packages in transportation and storage. The tags report the results to readers and the attached database via the 433-MHz radio frequency. No line-of-sight is necessary, and the read range can be >100 m. The tags contain a suite of sensors, consisting of seal (tamper-indicating), temperature, humidity, and shock sensors, as well as a gamma dosimeter and neutron detector. When sensor conditions are normal, the values of the parameters are recorded and stored at prescribed intervals based on operating environments. If any of the thresholds of the sensor are violated (for instance, a loss of the seal-bolt tension), the condition is reported instantaneously to responsible parties for action.

The ARG-US RFID system can be readily integrated with existing communication equipment in the transport vehicle and provide both tracking and monitoring at all times. The integrated tracking and monitoring functionality offers a number of advantages over tracking of only the transport vehicle — package integrity and environmental parameters are monitored continuously; content- and event-specific Geographic Information System (GIS) buffer zone reports can be issued promptly to aid first responders in case of an incident; administrative work at the receiving end may be reduced because of the complete, end-to-end transport surveillance records; and situation awareness for all need-to-know circumstances can be materialized on a near-real-time basis. These attributes were verified in multiple laboratory and road tests [4,5,7,10,14]. The ARG-US tracking system has also been integrated with the DOE TRANSCOM — the established DOE satellite tracking and communication system used to monitor high visibility, radioactive materials shipments from DOE and Nuclear Regulatory Commission (NRC) licensee facilities.

The ARG-US RFID system is developed on a modular and flexible platform. Of all the sensors, the neutron detector is the latest addition. In conjunction with the gamma dosimeters, the ARG-US RFID system has the potential to provide all vital information about the packages to the facility operator, which minimizes the need for personnel to be present for surveillance. Doing so not only streamlines facility operation and enhances productivity but also improves the implementation of the As-Low-As-Reasonably-Achievable (ALARA) principle for radiological facilities. Over the past three years, the ARG-US RFID system has been used at multiple DOE sites. The operating experience from three of the sites — the Savannah River Site (SRS), Nevada National Security Site (NNSS), and Oak Ridge National Laboratory (ORNL) — is the subject of this paper.

OPERATIONS

SRS Phase I Deployment

The objective in the development of the ARG-US RFID system was to monitor the state-of-health of packages (drums) of nuclear materials during transport and storage. Drum packages used in transportation have to be leak tested annually to ensure that their O-ring seals have not been degraded through aging. Simulations, both experimental and analytical, were performed to assess the effect of temperature on O-ring seal degradation. On the basis of simulations and the maximum decay heat load of the drum, it was determined that if the temperature of the skin of the drum stayed below a certain threshold, the O-ring seals would remain functional for extended period. These findings led to the initial "Phase I" deployment of the ARG-US RFID system at the Savannah River Site in March of 2010.

In Phase I testing, multiple ARG-US RFID tags were placed within a Category 1 vault. Some of the tags were mounted on actual drums used for storage, while others were mounted on stanchions placed throughout the vault. As RFID readers were not installed in the vault to continually poll the tags, the temperature and humidity data collected by the tags were manually downloaded in a batch process on a weekly basis. The Phase I test lasted for approximately 6 months. The goal of the deployment was to demonstrate that the ARG-US system could be used to reliably monitor the state of health of packages, including temperature. Figure 1, which shows a subset of the collected data [15], illustrates that the system was able to achieve that goal. Because the vault was not air-conditioned, the tags tracked essentially the seasonal changes of the outside ambient conditions. All tags displayed reliable and consistent performance; none showed abnormal behavior. The ability to use ARG-US RFID tags to monitor the temperature conditions of packages was thus demonstrated.

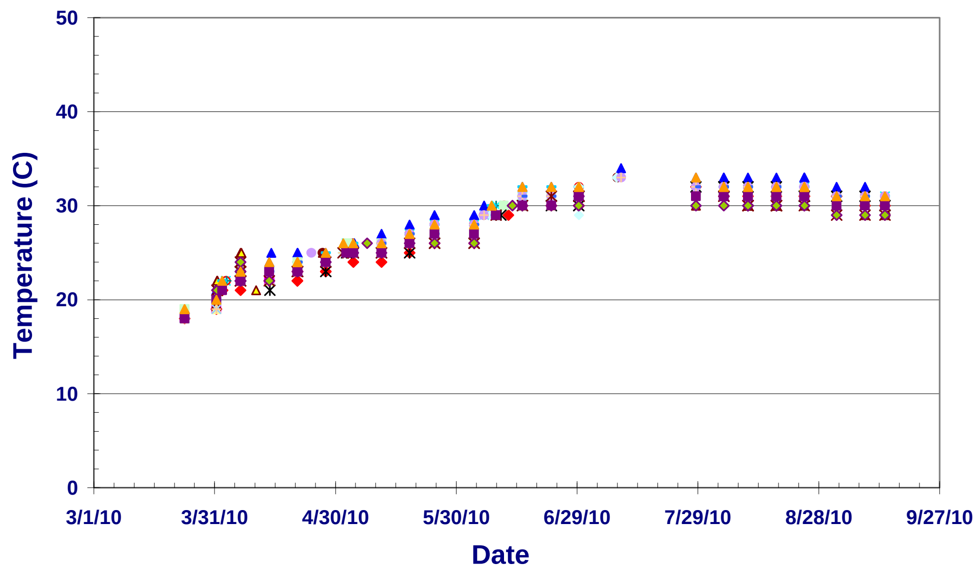

Figure 1. Aggregated temperature data collected weekly for 20 Mk-II RFID tags distributed in the Category 1 vault at SRS. (The ARG-US system was not available during several weeks in July 2010.) [16]

NNSS Deployment

The second deployment of the ARG-US RFID system was to the Nevada National Security Site (NNSS), formerly the Nevada Test Site. In July of 2010 — in anticipation of multiple drum loading, storage, annual maintenance, and off-site transportation — Argonne provided NNSS with nine Mk-II tags [17]. NNSS staff used the Mk-II ARG-US RFID tags to extend the maintenance period of their drums used for transport from one year to two. By extending the maintenance period to two years, not only has NNSS reduced the exposure of personnel inspecting the drums in accordance with ALARA, but it has also saved on operating costs by US$2500–3000 per drum per year [1]. The revised practice therefore enhances personnel safety because the heavy drums do not need to be handled unnecessarily.

As in the Phase I deployment at SRS, staff at NNSS downloaded the data from their ARG-US RFID tags and provided them to Argonne for analysis and monitoring. Figure 2 is a graphic highlighting two of the drums used for storage and transport during the first few months of the ARG-US RFID deployment at NNSS and SRS. The tag temperatures were accurate and consistent with the daily patterns reported by a nearby weather station at Desert Rock Airport. The excellent performance of the ARG-US RFID system is again confirmed.

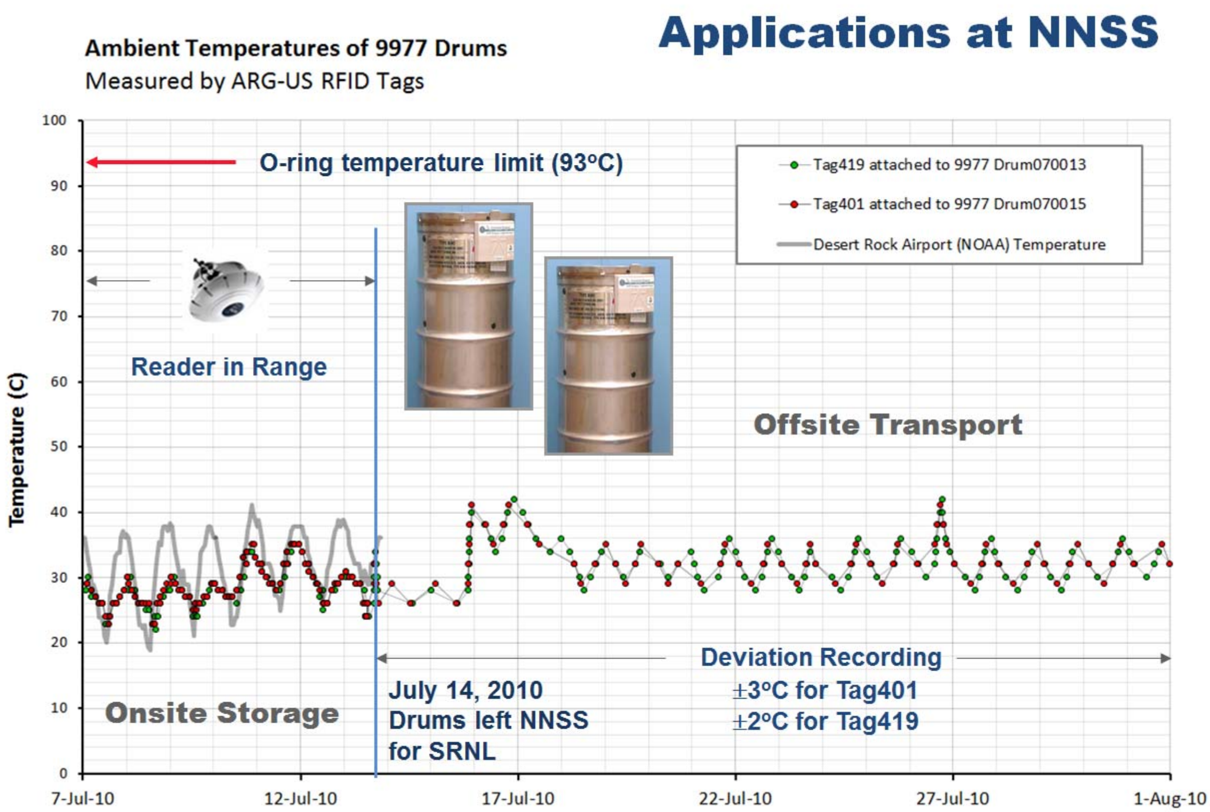

Figure 2. Tag-recorded temperatures for two 9977 Type B transportation packagings. (The drums were in storage at NNSS since early July; they left NNSS on July 14 in a shipment to Savannah River Site.)

SRS Phase II Deployment

After the initial success of the ARG-US RFID system in monitoring the environmental parameters of packages of nuclear materials, a gamma dosimeter was incorporated into the tags to further enhance the functionality of the ARG-US system. The gamma dosimeter is mounted on a carrier board that enables future expansion. The resultant tag, named Mk-III, is shown in Figure 3. The dosimeter regularly samples the dose rate and accumulates a total dose estimate that is stored in nonvolatile memory. In facilities with a large number of packages, dose rate readings from the tags can be collected to precisely map the radiation field — any significant perturbation from the norm can be used to generate alarms, thereby enhancing the safety, security, and safeguards posture of the operation. Because the radiation field data are constantly available, the number of routine inspections conducted by personnel with hand-held detectors (particularly those over local areas with high radioactivity) may be curtailed, thus reducing the exposure of personnel to radiation.

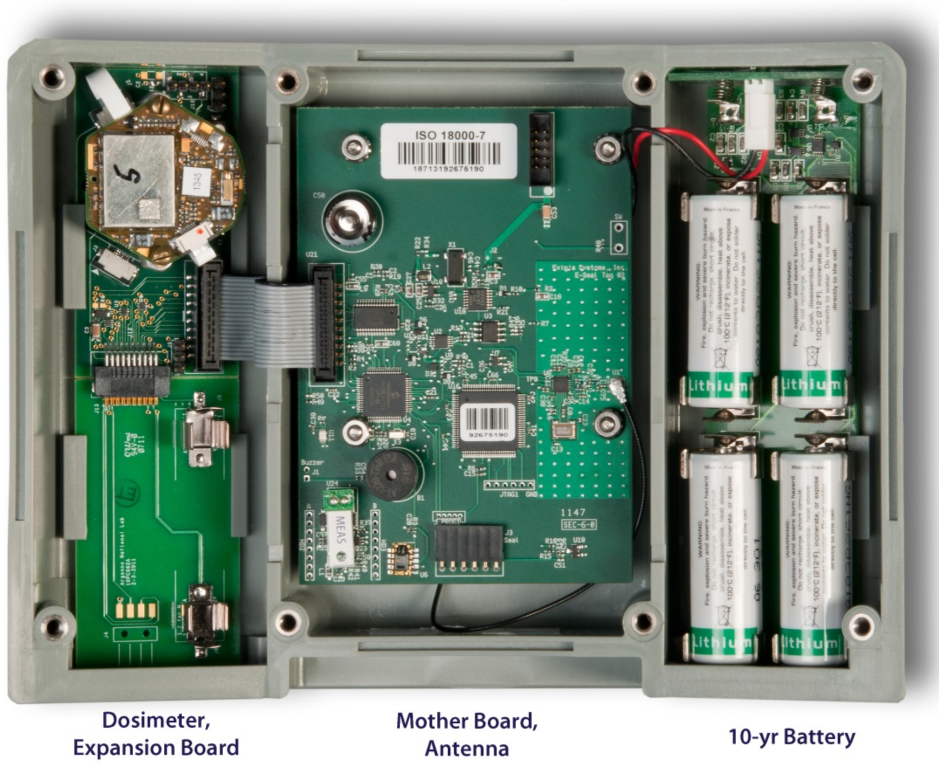

Figure 3. ARG-US RFID Mk-III tag with a gamma dosimeter mounted on expansion board in the left compartment.

For the initial deployment of the gamma dosimeter-enabled ARG-US Mk-III RFID tags, Argonne returned to SRS in March 2012. For the Phase II deployment, a different area of the storage complex was selected. The area was a smaller Category 2 vault. Twelve Mk-III tags were distributed inside this vault and operated for five months. Unlike the SRS Phase I deployment, the ARG-US RFID readers in the Phase II deployment were placed in the vault and integrated into the existing local area network at the facility. Over the five-month period, the radiation levels within the vault were recorded automatically every 6 hours. Figure 4 shows the collected dose and dose rate data for a set of four tags. The overall performance of the deployed ARG-US system was excellent — there were no aberrations or missed readings. All gamma dosimeters behaved satisfactorily and yielded results consistent with those from hand-held devices operated by SRS health physics professionals.

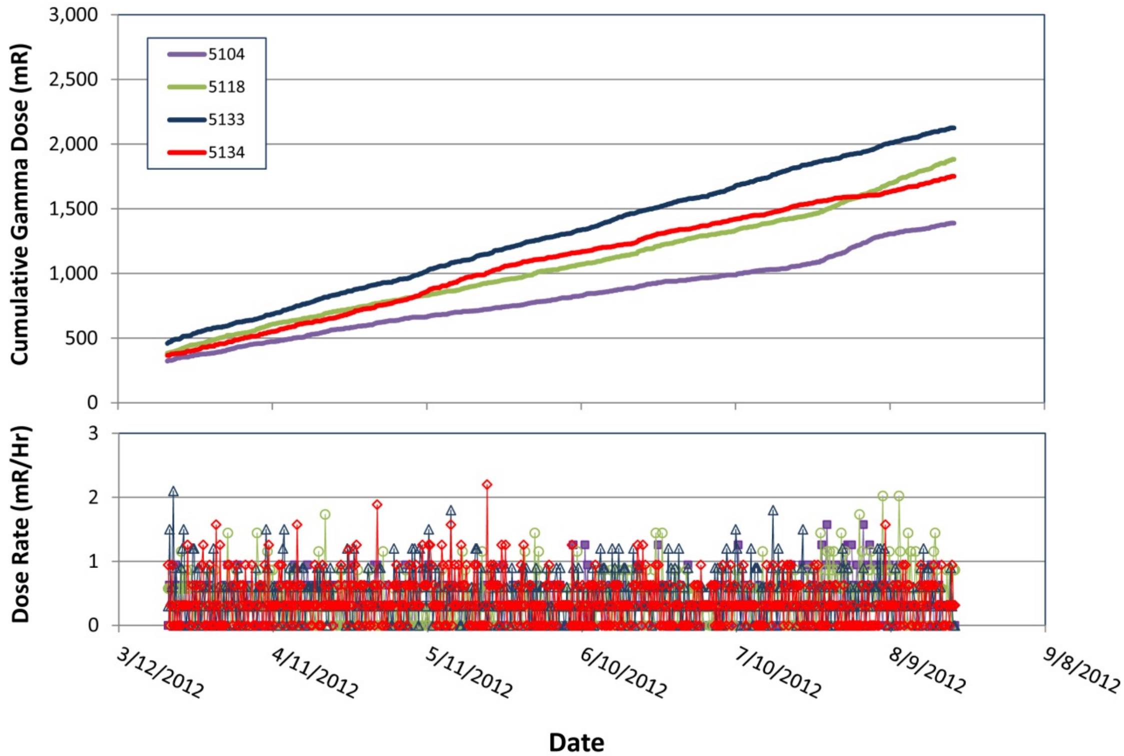

Figure 4. Cumulative dose and dose rates of 4 tags deployed during Phase II testing.

The highest cumulative dose attained with the tags in Phase II was 3.4 R. The performance of the dosimeter in this tag, Tag 5155, is summarized in Figure 5. The ARG-US dosimeter system's outstanding sensitivity is evident, for instance, in the two short-duration high-dose-rate events on May 7 and June 27, respectively, that produced accurately two noticeable jumps in the total dose. The marked changes of the slope of the dose trace on or around April 11 and July 24, caused apparently by the changes in the background dose rate conditions, further corroborated this positive finding.

All other sensors in the ARG-US RFID tags, such as temperature, humidity, seal, and battery strength, also performed well. A summary chart for Tag 5155 is shown in Figure 6.

Low-self-drain, high-capacity lithium thionyl chloride (Li-$SOCl_2$) primary cells are used in the tags (right compartment in Figure 3). To further extend battery service life, a smart battery management board is incorporated into the tag. Although up to four batteries may be loaded, auto-switching keeps only one battery on duty at any time. The performance of this important feature is confirmed in Figure 7, which shows a recorded rare battery-switching event in Tag 5134 on May 15.

The automatic gathering of the measured dose rates was a significant improvement over the manual collection performed during the Phase I testing. By integrating the ARG-US RFID system into the local information technology infrastructure, operators were able to remotely monitor cumulative dose and dose rates within the vault.

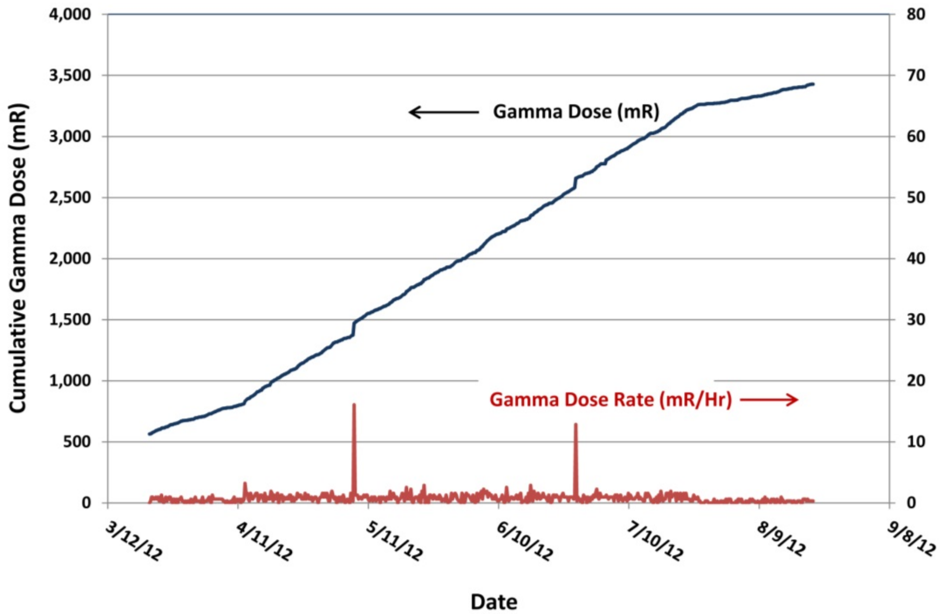

Figure 5. Performance of Tag 5155 with the highest total dose (3.4 R) in SRS Phase II testing. The high sensitivity of the dosimeter system is evident in the recorded data.

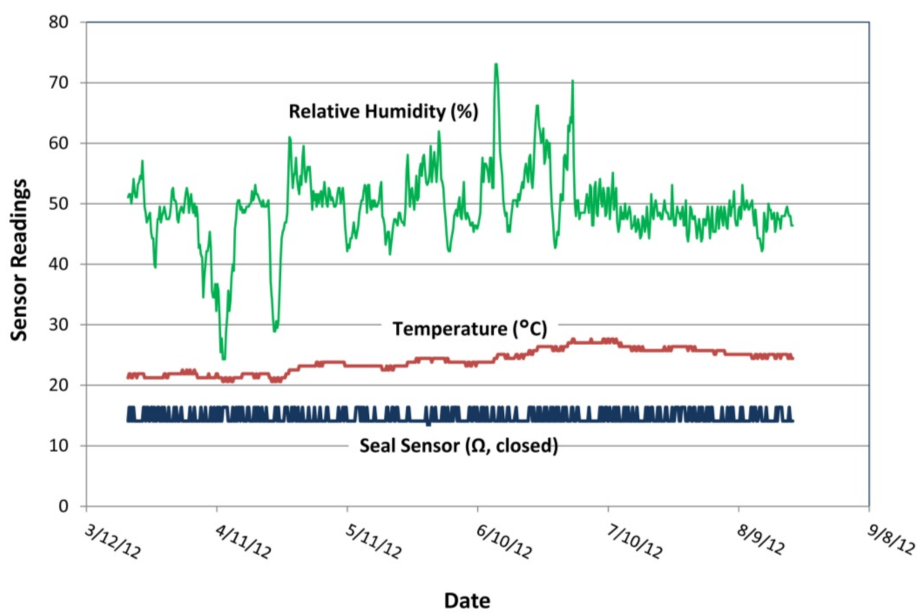

Figure 6. Typical temperature, humidity, and seal sensor performance in SRS Phase II deployment, as seen in Tag 5155.

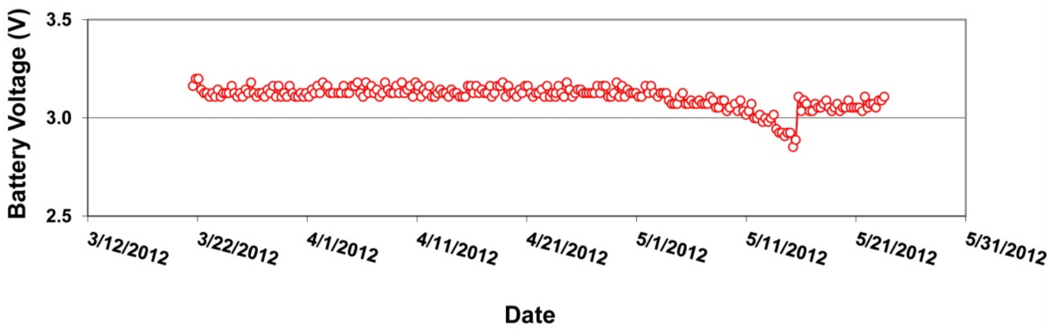

Figure 7. Auto switching to a fresh battery in the 4-battery pack (see Figure 3) on May 14. This is an important ARG-US feature designed to extend the life of the battery pack.

ORNL Transportation Campaign

Even during the early phase of ARG-US tag development, efforts were undertaken to integrate the ARG-US RFID system with a transportation communication carrier. Multiple carriers were tried, and Qualcomm's OmniTracs system was eventually selected. One key reason OmniTracs was selected was because of its use in DOE TRANSCOM tracking. As a result of integrating the ARG-US System with the Qualcomm OmniTracs system, Argonne was able to allow users of the system to track the packages during transport in near real-time. Sensor information was collected typically every 5 minutes, in combination with the communication system's GPS coordinates, and then transmitted through the communication channels to the central server, which resides at Argonne. Figure 8 is a graphic depicting the transfer of data from tag to server.

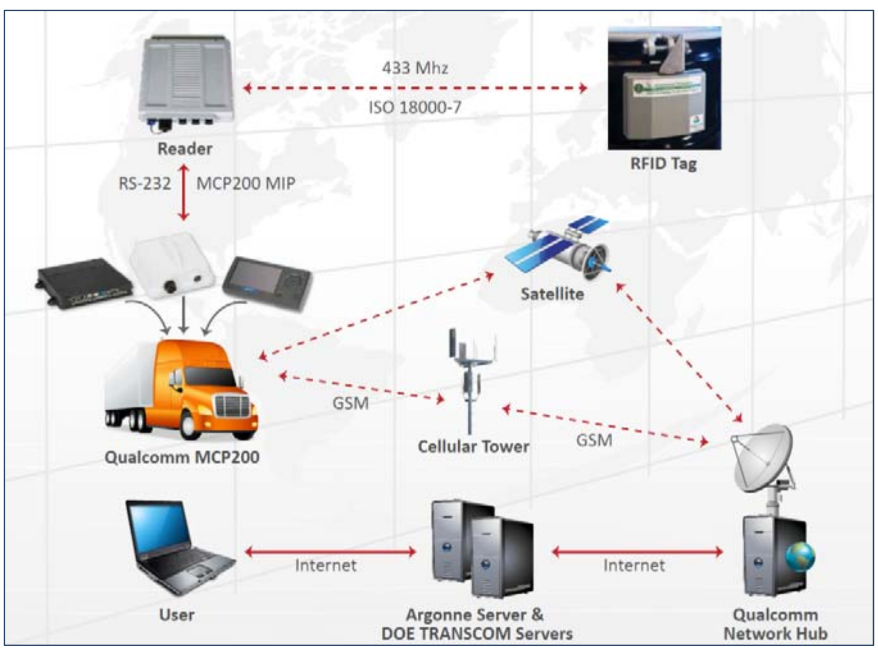

Figure 8. Integration of ARG-US RFID system with Qualcomm communication gear.

The first deployment of the ARG-US RFID system to track the transportation of nuclear materials was a shipment of nuclear material in the 5X22 packages from Oak Ridge National Laboratory (ORNL) to NNSS. The shipment occurred in early June 2012 with the transportation-enabled ARG-US RFID system installed just before departure. The shipment was tracked and the 5X22 packages were monitored in near real-time at the Argonne RFID Command Center. Figure 9 shows a screen capture of the truck location at a truck stop in Baxter, TN, on June 5, 2012. The status of the RFID tag sensors, including earlier alarms (in red), is shown at the bottom of the screen capture. The temperature and humidity data, transmitted near real-time via radio and satellite links, are accurate and consistent as in other deployments. At the conclusion of the shipment, the system was dismantled at NNSS and left for future use at the site.

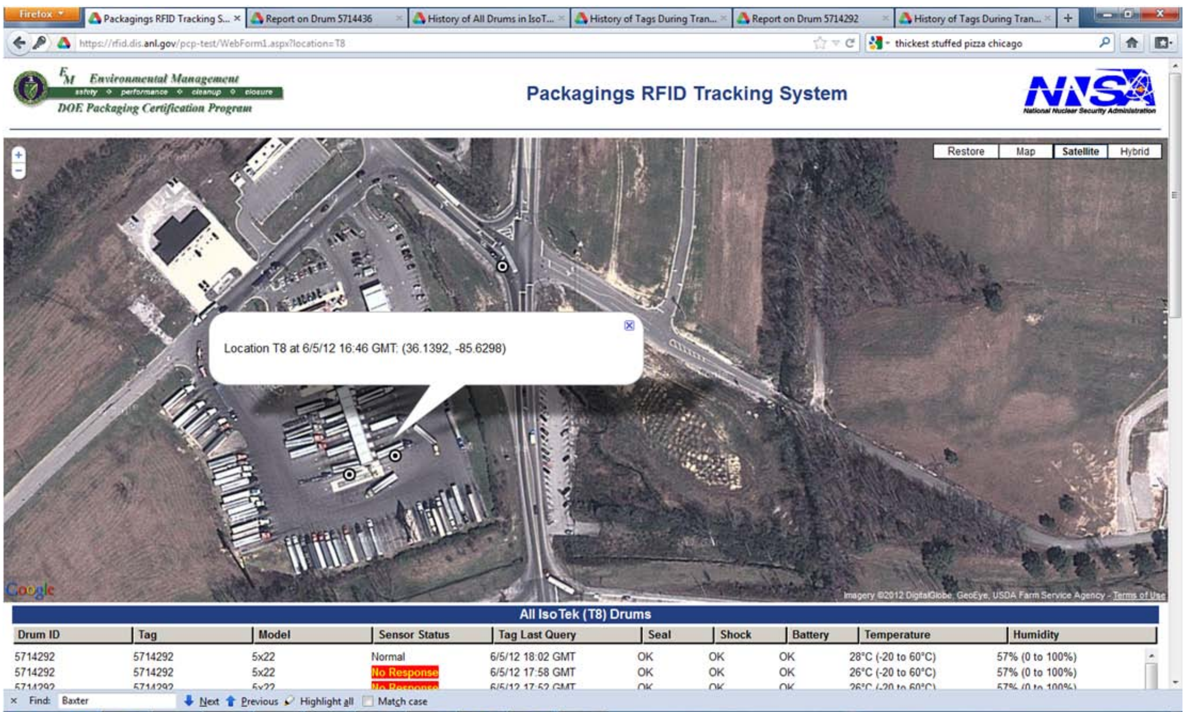

Figure 9. Screen capture of ARG-US transport tracking during an ORNL to NNSS shipment.

DISCUSSION

From the onset, by design, the ARG-US tag platform is made modular. Incorporation of specialty sensors, such as neutron detectors for monitoring fissionable materials and other sensitive neutron emitters, can be readily accomplished. Indeed, a solid-state neutron detector has been incorporated and benchmarked in laboratory tests against an AmBe neutron source. The detector selected is a high-efficiency, low-power solid-state device with build-in micro-channels impregnated with ^{6}LiF to increase the interaction surface area and volume (i.e., counting efficiency). The detector is accommodated on the lower half of the expansion board that houses the gamma detector (Figure 3). As a result of judicial component selection and design, the added neutron detector does not adversely affect the battery life of the tags, as shown in extensive testing conducted with AmBe (and PuBe) neutron sources [18]. To verify neutron detector performance in deployments, a Phase III testing program is scheduled with SRS in a vault where neutron flux is present. This program is to commence shortly.

The Alpha Gamma Hot Cell Facility (AGHCF) is a Cat-2 non-reactor nuclear facility at Argonne National Laboratory that is in the process of being decommissioned. As such, large quantities of radioactive materials and wastes are being discharged from the hot cell, loaded into transport containers, and shipped away. These operations can result in elevated radiological risks to the facility and workers. To demonstrate that ARG-US system with radiation-detector-enabled tags can assist in environmental monitoring and help protect personnel, a compact system consisting of four tags and two readers was recently installed in the facility. Three of the tags are positioned in the worker area, which has very low dose rates, while the fourth one is installed in an area where materials exit the hot cell and are packaged. As this area is separated from the cell only by alpha walls, the dose rate can be significant, particularly when material is moved. Thus far, the system is performing satisfactorily and yielding results that can be corroborated by existing surveillance means. In time, the benefits of automated monitoring 24/7 by ARG-US should become apparent, which may lead to a fuller system to be installed in the hot cell areas until the AGHCF is fully decommissioned.

Parallel to the RFID effort, an ARG-US system operating on a wireless sensor network (WSN) principle is being developed for monitoring critical facilities, such as nuclear power plants. This system, called ARG-US Remote Area Modular Monitoring (RAMM) [19], is to supplement the existing surveillance infrastructure of a nuclear facility. When the condition of the facility is normal, the ARG-US RAMM would collect data but generally stay in the background. If conditions change as a result of an accident, RAMM, powered by an onboard battery and operating on a wireless communication platform, would take over facility surveillance and report status automatically and autonomously. Failure of landline-based surveillance assets due to plant accidents or natural calamities would thus be a more manageable burden with RAMM in place. Because personnel do not need to be present for RAMM operation, high radiation and/or contamination are not restrictive factors. A subsystem for RAMM is being envisioned to monitor spent (or used) nuclear fuel dry cask storage facilities. A patent has been filed for the RAMM system.

CONCLUSION

In all applications to date, the ARG-US RFID system for monitoring and tracking sensitive nuclear materials performed well in both storage and transportation situations. The platform of the system, being modular and flexible, is readily reconfigurable for diverse applications. Development and enhancement of the ARG-US RFID system is a continuing process driven by programmatic and user needs. Additional sensors, such as loop seals, RF portal monitor and handheld reader, and video camera capabilities are among the items under development as part of ARG-US RFID and RAMM for future applications in general — and domestic and IAEA safeguards in particular.

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