Smart Drum Technology for Radioactive and Other Hazardous Materials - 18273

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ABSTRACT

Smart drum technology is the result of a coupling between a robust drum-type package containing radioactive and other hazardous materials and the ARG-US radio frequency identification (RFID) system that enables "unattended" remote monitoring of the State of Health of the package and contents — in real time, 24/7, with automatic alert/alarm capabilities. Recent educational demos of the system are highlighted.

INTRODUCTION

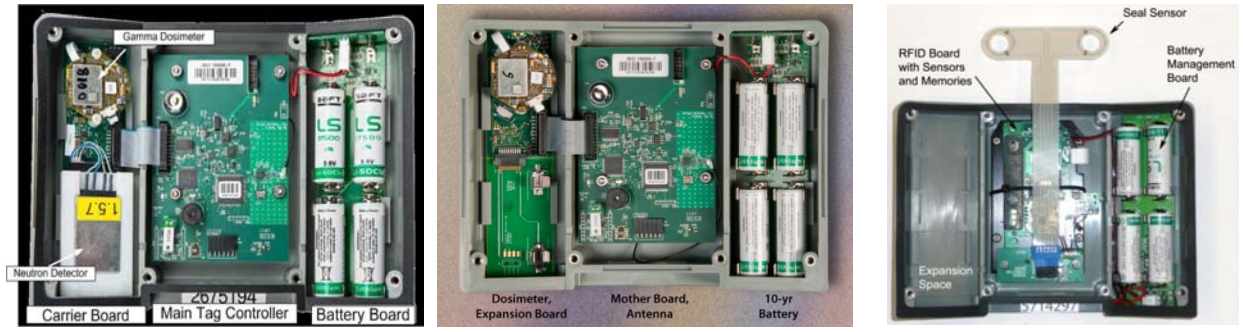
The "smart drum" technology is the result of a coupling between a robust drum-type package containing nuclear and other radioactive materials and the ARG-US radio frequency identification (RFID) system with multiple sensors that enables "unattended" remote tracking and monitoring of the State of Health of the package and contents — in real time, 24/7, with automatic alert/alarm capabilities. The ARG-US — meaning "watchful guardian" — RFID system was developed by Argonne National Laboratory (Argonne) since 2007 for the U.S Department of Energy (DOE) Packaging Certification Program, Office of Packaging and Transportation, Office of Environmental Management [1-11]. The system consists of RFID tags, readers, and software for local and web-based applications that can continuously monitor and track tagged packages during storage, processing, transportation, and disposal. Since 2010, demonstrations and field-testing of the ARG-US RFID systems for storage and transportation applications have been conducted at selected DOE sites, including Argonne, Savannah River, and the Nevada National Security Sites [12-14]. Development, testing, and integration of radiation sensors (gamma and neutron), tactile and electronic loop seals, readers and multiple communication platforms, secured servers, and web application user interfaces have also continued over the years [15-17]. The patented RFID surveillance tag licensed to Evigia Systems, Inc., in 2014, is now commercially available and meets export control requirements. This paper highlights recent educational demos of the ARG-US RFID system as a key element of the "smart drum" technology for radioactive and other hazardous materials.

ARG-US RFID SYSTEM TECHNOLOGY

The ARG-US RFID system technology is composed of the following major components: RFID surveillance tags with sensors, RFID readers, communication devices, control software, secured database servers, and web application user interfaces. The RF communication follows the ISO 18000-7 standard, operating at 433 MHz. During transportation operations, with the tagged cargo and RFID reader in the vehicle, a communication package, such as a cellular modem, is required to relay the collected tag information from the moving vehicle to a control center. The original combination of the ARG-US system and a communication platform (Qualcomm and later Omnitracs) was named ARG-US TransPort. With further enhancements and modifications to the system, two variants of it are the ARG-US CommBox and CommBox-mini. The salient features of these key components are briefly described below, followed by highlights of recent educational demos and development of a new web application user interface.

RFID Surveillance Tag

Figure 1 shows the ARG-US RFID sensors tags with exposed interiors. The low-power design of the electronic circuitry, and the 10-year long-life batteries mounted on a smart battery management board, are among the unique features of the patented ARG-US RFID surveillance tag. The suite of sensors in each tag includes those for temperature, humidity, physical shock, tactile seal, and radiation (gamma, neutron), as well as an external electronic loop seal (not shown in Fig. 1). A fixed reader that communicates via 433-MHz radio waves can poll tens of RFID-tagged packages within its read range (~100 m) at regular intervals to retrieve the sensor data and status measured and recorded in the tags. Conversely, the reader receives tag-initiated alarms automatically when any of the preset sensor thresholds in the tags is violated. The RF communication implements ISO/IEC 18000-7: Information technology – Radio frequency identification for item management—Part 7: Parameters for active air interface communications at 433 MHz. Data encryption by Advanced Encryption Standard-256 is optional for the RFID tag.



(a) (b) (c)

Figure 1. The ARG-US sensors surveillance tag, with back plate cover removed showing three compartments in each tag: battery board (right), mother board (center) and radiation sensor board (left): (a) with gamma and neutron detector on a carrier board, (b) with gamma dosimeter only, and (c) without radiation sensors.

The modular design of the sensors platform allows for customization of the tag according to the application environment; for example, an ARG-US RFID tag can be built without radiation sensors, or with gamma sensor only, which would reduce cost and prolong battery life.

Certified "Smart" Drum-type Packagings

Figure 2 shows ARG-US RFID tags mounted on four DOE-certified Type B, a DOT 7A, and a Type AF transportation packagings for nuclear and other radioactive materials. The tags have a universal form factor for drum-type packages; the metal back plate and the tactile seal sensor (concealed behind the back plate), both inexpensive, are customized to suit different drum closure design configurations.

Figure 2. ARG-US RFID tags mounted on certified Type B (9975, 9977, 9978, and ES-3100), DOT 7A, and Type AF 9979 transportation packages (from left to right).

The DOE-issued Certificates of Compliance (CoCs) for the above Type B and AF drum-type packages can be found at https://rampac.energy.gov/home/package-certification-information/certificates/doe. These CoCs contain an option of using the ARG-US RFID tag, which is not considered a safety-important component of the package. However, the sensors in the tags monitor environmental exposure parameters (e.g., temperature, humidity, and radiation) near the packages, whereas the tactile seal sensor [shown in Fig. 1(c) for the 9975 packaging] may be credited as a Tamper-Indicating Device (TID) for enhanced security and safeguards. The seal integrity sensor has been evaluated and judged to be adequate, following U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 5.80 "Pressure Sensitive (PS) and Tamper Indicating Device Seals for Material Control and Accounting (MC&A) of Special Nuclear Material," dated December 2010. Thus, the ARG-US RFID tag can be used as a TID seal. The robust plastic front cover of the ARG-US RFID tag and the stainless-steel back plate provide adequate protection of the tag against damage under normal handling and transport.

Fixed Reader/CommBox/CommBox-Mini

Figure 3 shows an ARG-US RFID fixed reader, CommBox, CommBox-Mini, and their relative sizes. Before the development of CommBox, all of the demonstrations, road tests, and an actual shipment were conducted by using a fixed reader pre-installed in the cargo area of the vehicle trailer with its own power supply, a laptop computer in the cab, and a cable between the fixed reader and the laptop for data transmission and interface with cellular/satellite communication systems. While the system performed satisfactorily during transportation, the configuration was not practical as it required vehicle modifications, training for the vehicle driver, and the imposition of additional administrative burden, as well as logistic challenges. Furthermore, if companies are leasing a vehicle for shipment, modifications to the vehicle are often prohibited.

CommBox and CommBox-Mini are both stand-alone, "all-in-one" units containing a RFID fixed reader and a cellular and a satellite modem with battery-supplied power. They are reusable and transferable, making their installation very simple in the cargo space of vehicles for tagged packages. The major difference between CommBox and CommBox-Mini is in their satellite communication. Qualcomm MCP200 is used in CommBox to enable tracking and monitoring via DOE TRANSCOM [14], whereas a cellular router, backed up by an Iridium satellite modem, is used in CommBox-Mini for shipments that do not require tracking by DOE TRANSCOM. The web application user interfaces for ARG-US RFID/CommBox or CommBox-Mini have been developed for tracking and monitoring multi-vehicle shipments via a secured website. The performance and reliability of the ARG-US RFID/CommBox or CommBox-Mini systems have been demonstrated in field-testing and transport applications [17].

(a) (b) (c) (d)

Figure 3. The ARG-US RFID fixed reader (a), CommBox (b), CommBox-Mini (c), and the latter two stacked closed, with an open laptop on top for scale comparison (d).

Table 1 provides a summary comparison of fixed-mount assets in ARG-US/RFID transport applications (TransPort) versus the portable CommBox and CommBox-Mini. A stand-alone CommBox containing the reader, a battery power supply, and the Omnitracs MCP200 system for communication weighs ~22 lb, including the Pelican case shown in Fig. 3(b). The CommBox-Mini with all the gears and case weighs ~12 lb. Both CommBox and CommBox-Mini provide a level of tracking and monitoring of RFID-tagged packages in transportation comparable to that of the ARG-US TransPort system. A U.S. patent was granted for CommBox/CommBox-Mini in 2016.

Table 1. Summary comparison of ARG-US/RFID (TransPort), CommBox, and CommBox-Mini

Attribute	ARG-US TransPort	CommBox	CommBox-Mini
Location of components	Cab roof, cab, cargo bay	One box	One briefcase-size box
External connections	Power and cable	None	None
Tracking	Argonne, TRANSCOM	Argonne, TRANSCOM	Argonne
Transfer between vehicles	Difficult	Easy	Easy
Relative cost	High	Low	Low

EDUCATIONAL DEMOS

The ARG-US Command Center (CC) was inaugurated in October 2010 at Argonne as a multiple-use facility for training and education, platform/protocol development, and a monitoring and control center for various field-testing and applications of the ARG-US remote monitoring systems technology. Educational demos of the ARG-US RIFD system are frequently conducted in the CC for visitors, as well as for participants in DOE training courses on Nuclear and Other Radioactive Material Transport Security [18]. Figure 4 shows four drum-type packagings (9979, ES-3100, DOT-7A, and 9975) with ARG-US RFID tags in the CC and a pole-mounted fixed reader (top) on a movable cart near a corner of the CC opposite the drums. The distance between the fixed reader and the tagged drums is ~30 ft, with 6 monitors lining the adjacent wall of the CC [Fig. 4(c)] for webpage displays, as well as news and weather channels.

(a) (b) (c)

Figure 4. ARG-US Command Center: (a) 9979, ES-3100, DOT-7A, and 9975 with ARG-US RFID tags (from left to right); (b) pole-mounted fixed reader (top) and two handhelds on a movable cart; (c) large-screen monitors for webpage displays, as well as news and weather channels.

Figure 5 shows two screen shots of a schematic grid layout of the CC showing the State of Health of the four tagged drum-type packagings, where "normal" is represented by green, and "alert/alarm" is represented by red. Figure 5(a) displays the shock sensor alarm in 9979 after the tag was moderately tapped (40% shock) by hand. The tag-initiated alarm message was sent to the fixed reader located at the corner of the CC [shown in Fig. 4(b)] and then the server — prompting the change of color from green to red on the monitor screen in ~5 s. Clearance of the shock alarm (i.e., change of icon color from red to green) was faster ~1 s.

(a) (b)

Figure 5. Screen shots of the State of Health of four tagged drums in the CC: (a) shock sensor alarm for 9979 and (b) loop seal alarm for 9975 [The loop seal is shown attached to the RFID tag in Fig. 4(c)]

Figure 5(b) displays the electronic loop seal alarm after the loop cable was disconnected from its socket. Here, the tag-initiated alarm message to the fixed reader and server took longer (~15 s) to manifest itself (i.e., changing color from green to red). The red alarm status continued, however, so long as the loop cable remained disconnected from its socket. Clearance of a loop seal alarm was achieved only after the loop cable was physically reconnected into the socket. The Current Status tables in Figs. 5(a) and 5(b) show four drums, each with one alert; the History tables in these figures show the Tag ID and the associated Drum ID, and the events (such as tag queried and alert cleared). The entire events history can be downloaded for plotting to quickly identify the occurrences of events.

Vehicle Road Tests of CommBox-Mini and RFID Tags

As part of the educational demos, a vehicle road test of CommBox-Mini and two RFID tags was conducted for participants during the DOE transport security training course in August 2016. The route chosen was from Argonne to Morris, Illinois, ~39 miles round trip, including a stop to perform two staged incidents involving triggering of the tactile seal on one RFID tag (#5217) and the electronic loop seal on the other RFID tag (#5168). Each tag alert incident was followed by clearing of the alarms remotely from the CC after the seals were reconnected before resuming the vehicle drive back to Argonne. Figure 6 displays the screen shots of the tactile seal alarm in the RFID tag (#5217) at 1:49:47 pm GMT, August 19, 2016; the satellite overhead view of the geographical location (latitude and longitude) and time stamp of the vehicle/tag alarm in the parking lot (red); and after the tactile seal alarm was cleared at 1:51:17 pm GMT, August 19, 2016. The screen shots associated with the loop seal alarms of the RFID tag (#5168) are similar to those depicted in Figure 6 and will not be repeated. Participants viewed the webpage of the entire vehicle road test of CommBox-Mini and RFID tags in real time during the training class; some participants also viewed the progress on their laptop, tablet, or smart phone.

Figure 6. Screen shots of the tactile seal alarm sent by the RFID tag (#5217, top); satellite view of the time stamp and geographical location (latitude and longitude) of the vehicle/alarm in a parking area (middle); and after the tactile seal alarm was cleared at 1:51:17 pm GMT, August 19, 2016 (bottom).

WEB APPLICATION USER INTERFACE

Figure 7 is a web application user interface showing a recent vehicle road test of CommBox-Mini with three ARG-US RFID tags round trip from Chicago, Illinois, to Baltimore, Maryland, October 10–12, 2017.

Figure 7. Web application user interface summarizing a road test of CommBox-Mini with three RFID tags round trip from Chicago, Illinois, to Baltimore, Maryland, October 10–12, 2017.

The entire journey was summarized and displayed in clusters of aggregated breadcrumbs, totaling 1,105 in two and a half days. Each breadcrumb, when selected, would display the geographical location (latitude, longitude) and the time stamp, whereby the map scale can be enlarged or reduced, and the map view can be toggled among road view, aerial view, or topographic view. The search box on the webpage allows quick location of the vehicle by latitude and longitude, and the box near the bottom left corner displays the current status of the three RFID tags that, if any one of them is selected on the webpage, a window would pop up showing the readings and status of all the sensors in the tag. This new web application user interface has other features currently under development, including additional functionalities of geo-fencing, alert/alarm annunciation, and linkage to an existing geographic information system for emergency response and management.

DISCUSSION

When deploying the ARG-US RFID system for monitoring tagged packages in facilities, as shown schematically in Fig. 8, the fixed readers are strategically mounted in a facility so as to provide complete communication coverage of all the tagged packages stored within the facility. The readers should be connected, if the option of Power-Over-Ethernet is available, to the local information technology infrastructure via Ethernet. The use of one line for both communication and power reduces the additional cabling needs in deploying fixed readers in a facility. This has been implemented for the ARG-US RFID system in the Alpha Gamma Hot Cell Facility at Argonne [16].

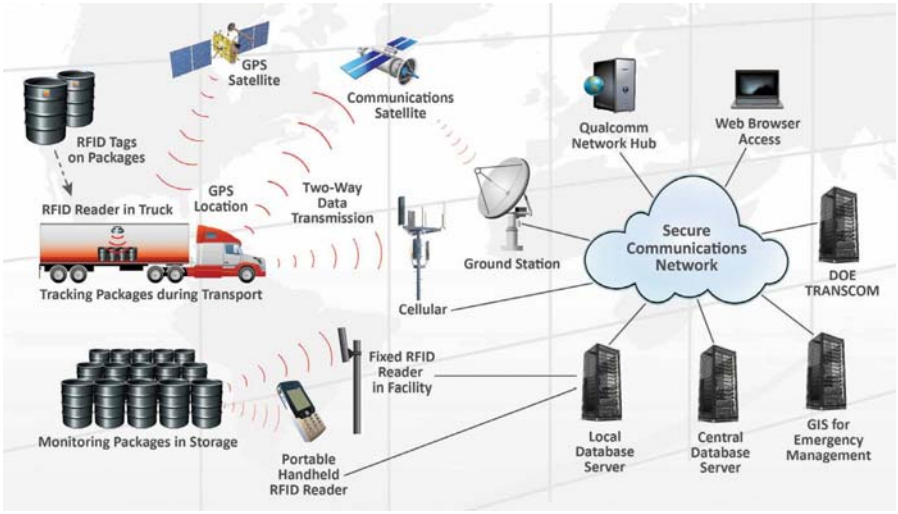


Figure 8. Application of ARG-US RFID system for drum-type packages in storage and transportation.

Further size reduction for CommBox-Mini is also feasible by using a small-form factor reader, smaller rechargeable lithium-ion batteries and compact communication devices. Commercial development of products in these areas are very active, and they should be leveraged for potential improvement of system performance and cost reduction.

SUMMARY AND CONCLUSION

The smart drum technology is the result of a coupling between a robust drum-type package containing nuclear and other radioactive materials and the ARG-US RFID tag with multiple sensors that enables "unattended" remote monitoring of the State of Health of the package and contents — in real time 24/7 and with automatic alert/alarm capabilities. Through years of field-testing and applications under realistic operating environments, the ARG-US RFID system appears to be able to achieve all potential benefits

envisioned originally for the management of nuclear materials packaging — enhanced safety and security, reduced need for manned surveillance, real-time access of status and history data, and overall cost-effectiveness. Future development continues to improve overall system performance, reduce costs, and find wider applications of the system to other hazardous materials, such as disused radiological sources.

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