Integration of ARG-US RFID and DOE TRANSCOM*

B. Craig, J.H. Lee, J. Anderson, H. Tsai, Y. Liu, and J. Shuler[1]

Argonne National Laboratory, Argonne, IL 60439
[1]U.S. Department of Energy, Washington, D.C. 20585

ABSTRACT
ARG-US, a radio-frequency-identification (RFID) system for secured tracking and monitoring of nuclear and radioactive material containers in storage and transport, has been developed by Argonne National Laboratory (Argonne) for the Packaging Certification Program of the U.S. Department of Energy (DOE), Office of Packaging and Transportation. The system consists of battery-powered RFID tags, readers, an application software suite, a secured database server, and Web pages. The tags are equipped with sensors for seal integrity, temperature, humidity, shock, radiation, and battery status to monitor the state of health of the packages to which the tags are attached. The DOE Tracking and Communications (TRANSCOM) system is a well-established vehicle tracking system that provides its authorized users with a Web portal to track shipments and communicate messages. Integration of ARG-US RFID for container monitoring with DOE TRANSCOM for vehicle tracking greatly enhances the efficacy of the ARG-US RFID system, and vice versa, especially during shipment of sensitive radioactive and hazardous materials. Development and testing for equipment compatibility, systems performance and reliability, and final application testing of the integrated system spanned a period of approximately 3 years. Multiple stationary and on-the-road tests were performed, and the results confirmed the functionality and successful integration of the ARG-US RFID container monitoring system and the TRANSCOM vehicle tracking system in October 2010. The integrated system is now ready for service.

INTRODUCTION

ARG-US RFID is a system for secured tracking and monitoring of nuclear and radioactive materials containers in storage and transportation. The system consists of battery-powered RFID tags, readers, an application software suite, a secured database server and Web pages. The ARG-US tags are equipped with sensors for seal integrity, temperature, humidity, shock, radiation, and battery status to monitor the state of health of the packages to which the tags are attached. TRANSCOM is the DOE Tracking and Communications System used to monitor the progress of various "high visibility" shipments, such as spent nuclear fuel and high-level and transuranic radioactive wastes. TRANSCOM utilizes onboard satellite Global Positioning System (GPS) equipment to track truck and rail shipments near real time, and provides shipment position and messaging data over the Web that can be viewed by authorized federal, state and tribal customers across the United States. TRANSCOM has been used to monitor over 12,000 DOE shipments since its deployment in September 2001.[1]

Ever since the first 1700-mile, four-and-half day demonstration (DEMO) of the ARG-US RFID system in storage and transportation in April 2008,[2] integration of ARG-US RFID container monitoring with TRANSCOM vehicle tracking has been identified as an important goal, or milestone. TRANSCOM already has a dedicated data/communication center established for tracking transportation vehicles that are equipped with satellite communication gear. Other tangible assets of TRANSCOM include structure and interfaces associated with user groups, training programs, Web/mapping infrastructure, data security

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provisions, and — most importantly — maturity from years of operation. Integration of ARG-US RFID with TRANSCOM greatly enhances the efficacy of the ARG-US RFID system, and vice versa, especially during shipment of sensitive radioactive and hazardous materials. This paper highlights the major phases of the integration: (1) development and testing for RFID/communication equipment compatibility, (2) determination of systems performance and reliability with multiple stationary and on-the-road tests over a period of ≈3 years, and (3) the final application testing of the integrated ARG-US RFID/TRASNCOM system in October 2010. The results confirmed the functionality and successful integration of the ARG-US RFID and TRANSCOM.

DEVELOPMENT AND TESTING

TRANSCOM uses on-board GPS and satellite communication equipment, called OmniTRACS, provided by Qualcomm, Inc. The on-vehicle components of OmniTRACS include a keyboard/display unit (tablet) and an external-mounted multidirectional satellite antenna communication unit. Together they are called the "Integrated Mobile Communication Terminal" (IMCT). In operation, the on-vehicle system obtains position information from U.S. GPS satellites and communicates pertinent information, including vehicle position, with the data satellite for data and message exchanges, as shown in Figure 1.

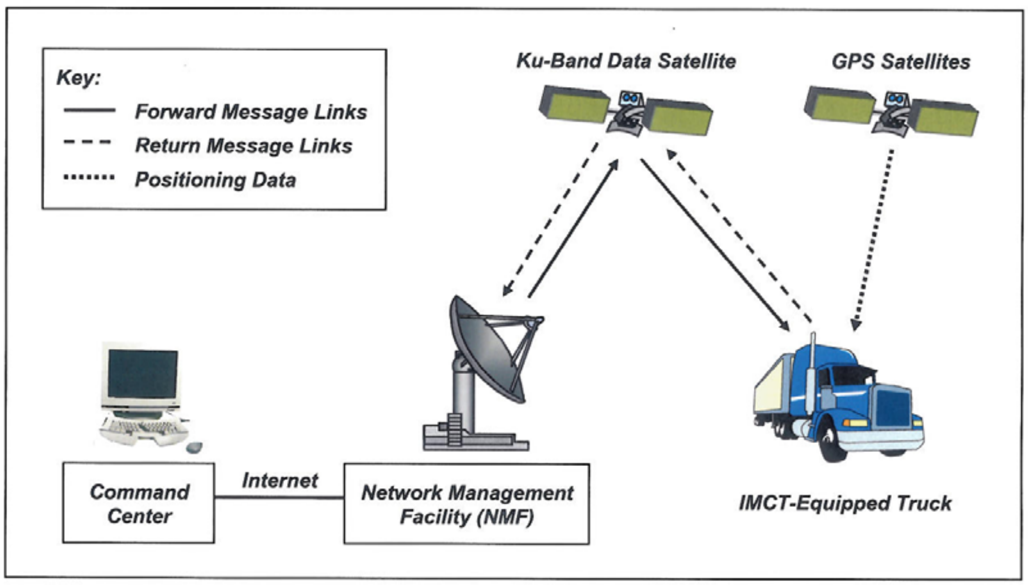

Figure 1. Schematic of Qualcomm's OmniTRACS system (Courtesy of Qualcomm Inc.)

In the implementation of the ARG-US RFID interface, the added tag information would be transmitted as part of the message to the data satellite and be received at Qualcomm/TRANSCOM for processing. Figure 2 is a schematic showing the communication paths between the various components in the ARG-US RFID equipment and the OmniTRACS satellite communication gear of Qualcomm/TRANSCOM. Data handling and communication interfaces have been developed and implemented on the control computer that must format the collected tag data for efficient transmission to the satellite via the OmniTRACS unit (Fig. 2). When the conditions are normal, this transmission takes place after each polling (e.g., every five minutes) of the tags by the reader (interrogator). If the tag-generated alert/alarm message is received by the reader, that message takes priority and is sent fist. The sending of the regular data packet to the satellite is resumed only after the alert/alarm message is sent. For each message sent, the current time is added to the sensor information. The time stamp and tag information are formatted in a Free Form Text (FFT) message per Qualcomm mobile interface protocol. The FFT message is then converted to a byte array that can be sent out via a three-wire serial port in the tablet display unit and the

OmniTRACS antenna. The format of the byte array is defined by Qualcomm and all message formation and conversion are done by the control computer.

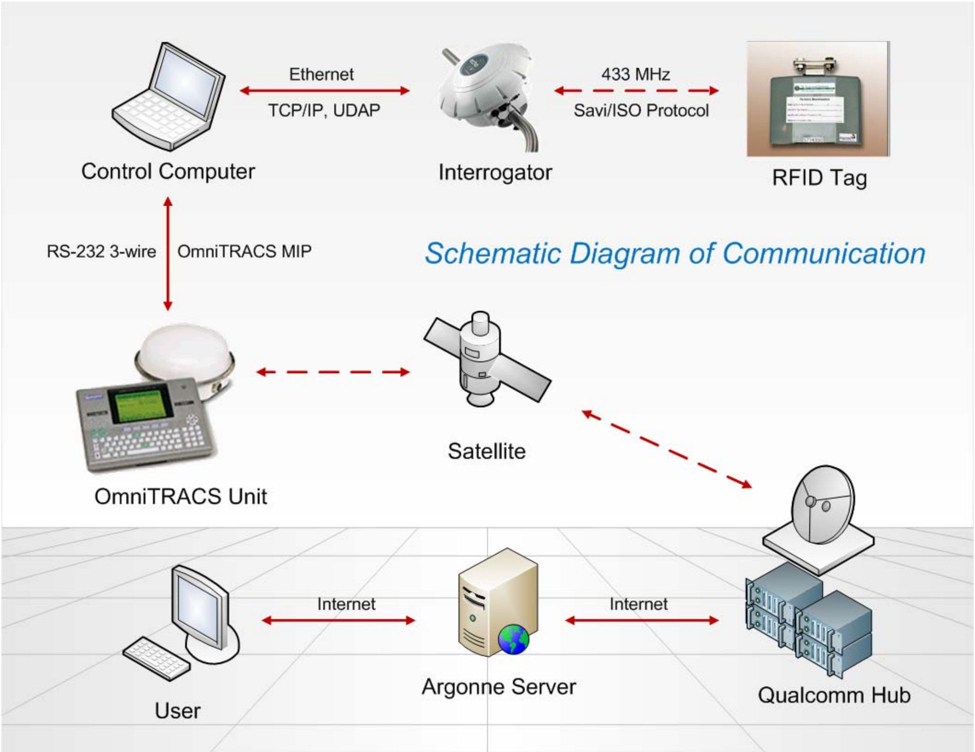

Figure 2. Schematic diagram of communication paths between the ARG-US RFID equipment and OmniTRACS satellite communication gear of Qualcomm/TRANSCOM

When the FFT message is sent from the vehicle, a vehicle position (VP) message is also generated and sent. The latest position, as well as the nearest cities/towns and a date/time stamp, are contained in the VP message. From the data satellite, the message is relayed to the Qualcomm Network Service Center (NSC) or Qualcomm Hub, as depicted in Figures 1 and 2. The current latitude and longitude information of the vehicle is appended after the tag status so that even if there are communication problems, the messages are tagged with their actual locations.

At the Argonne RFID Command Center, the RFID software continually polls the Qualcomm Hub at a high rate (e.g., 1-minute intervals) to check if any new transmissions have been received. When a transmission is returned, the software converts the message from the transmission encoding of Base 64 into an Extensible Markup Language (XML) collection of transmissions. After the message is converted, the software parses the XML to find the formatted text that represents the transmitted RFID tag data. Once the text has been located, the software parses the formatted text and inserts the latest sensor values into the RFID database. At this point, the newly obtained data are shown on the ARG-US RFID Website.

Significant improvements in Web functions have also been made since the initial April 2008 DEMO. One of the major emphases is improved mapping. Planned route, route tracking (“bread-crumbing”), zooming, and spot information are some of the new features. Detailed information on tags/drums in tabulated form for the current and past time steps can be directly displayed on the Webpage, without having to navigate through the server database. Another important improvement is Geographic Information System (GIS) reporting. Pre-formatted GIS reports, when warranted, can now be issued with a single click from the Argonne RFID Command Center. GIS reports, with a concise summary of local assets and vulnerabilities, are important for the first responders and emergency management in case of a transportation incident.

To test the equipment compatibility between the ARG-US RFID system and OmniTRACS, another demonstration, called mini-DEMO,[3] was conducted in August 2009, after development of the data handling format for efficient satellite transmission and significant improvements in Web functions.[2] The mini-DEMO used 25 RFID tags, a reader, a control computer, and an OmniTRACS tablet display unit inside the vehicle, with a rooftop-mounted satellite antenna (transponder) of the OmniTRACS communication unit. The vehicle was driven on interstate highways near Chicago for a total distance of ≈300 miles in slightly less than 6.5 h. Six staged incidents were conducted during the journey to test the automatic alert/alarm capability while the test vehicle was moving or stopped, and the entire trip was monitored in real time at the Argonne RFID Command Center. The results of the mini-DEMO showed that the equipment in the vehicle performed precisely as designed. Messages that contained information on the status of the tags were sent to the OmniTRACS transponder every five minutes, but the messages related to the staged incidents were sent immediately. Because of the satellite bandwidth, the transponder required approximately 1.8 minutes to send a full message containing information on 25 tags in the vehicle to the satellite. The time required for sending a message varied slightly, depending on the length of the message and the status of the satellite communication.

Perhaps the two most important findings of the mini-DEMO were the need for two-way communication between the reader in the vehicle and the RFID Command Center, and the need for high-frequency in-vehicle polling. Two-way communication offers operational flexibility, including the ability by the Command Center to reset a tag alarm or actively instruct the in-vehicle reader to poll a given tag so that the vehicle driver can concentrate on driving without performing all of the hands-on actions. High frequency polling is important to reduce the inherent latency of satellite communication that would ultimately define “real time,” or more precisely, the “nearness” to the real time capability of the present ARG-US RFID/OmniTRACS system. These needs, as well as further enhancements in Webpage functionality were addressed in 2010 when Argonne was asked by the DOE National Nuclear Security Administration (NNSA) to install the ARG-US RFID equipment in vehicles used by the Offsite Source Recovery Project (OSRP)[4] and the Transportation Security Technologies Testbed Evaluation.

SYSTEM PERFORMANCE AND RELIABILITY

Installation of the ARG-US RFID equipment in the NNSA vehicles (a Peterbilt truck and a Dodge Sprinter van) and integration with the in-vehicle OmniTRACS satellite communication gear were straightforward and took less than half a day. Only ordinary shop tools were necessary, and the overall cost of installation was minimal.

To verify system performance after the RFID equipment was installed in the truck, three stationary communication tests and a 300-mile road test were performed with the Peterbilt truck.[5]

The three stationary communication tests were conducted with the truck parked in an open lot at Argonne. The primary purpose of the stationary tests was to assess the reliability of the communication link — specifically, whether message lines sent from the truck are properly received at the Argonne RFID Command Center. A secondary purpose was to determine the time lags between when the message was sent and received (i.e., delays due to satellite transmission and processing at the intermediate hubs). Because the truck was positioned to enable an unobstructed view to the sky, the stationary tests represented the best possible conditions in terms of satellite communication. During the tests, the data of the tags were sent at 5-min intervals, and the internal polling rate at Qualcomm was set at 1-min intervals. The first stationary test was conducted on March 18–19, 2010, with a single MK-II RFID tag in the trailer. The duration of the test was 15.3 h (920 min). All 186 message lines were received at the

Command Center correctly and, even more importantly, with no lines dropped. The successful installation of RFID equipment and the reliability of the communication link were therefore confirmed. The typical time lags between sent and receipt were in the 0.5–2.0-min range, as shown in Figure 3. Compared to the 2–7-min lags experienced in the previous Mini-Demo road test,[3] this was a marked improvement. (The time lags reported by TRANSCOM using comparable Qualcomm OmniTRACS equipment are typically 4–7 minutes.[1]) The main reason for the improved performance was apparently the increased internal polling rate at Qualcomm — from every 5 min to every 1 min — made at the request of Argonne.

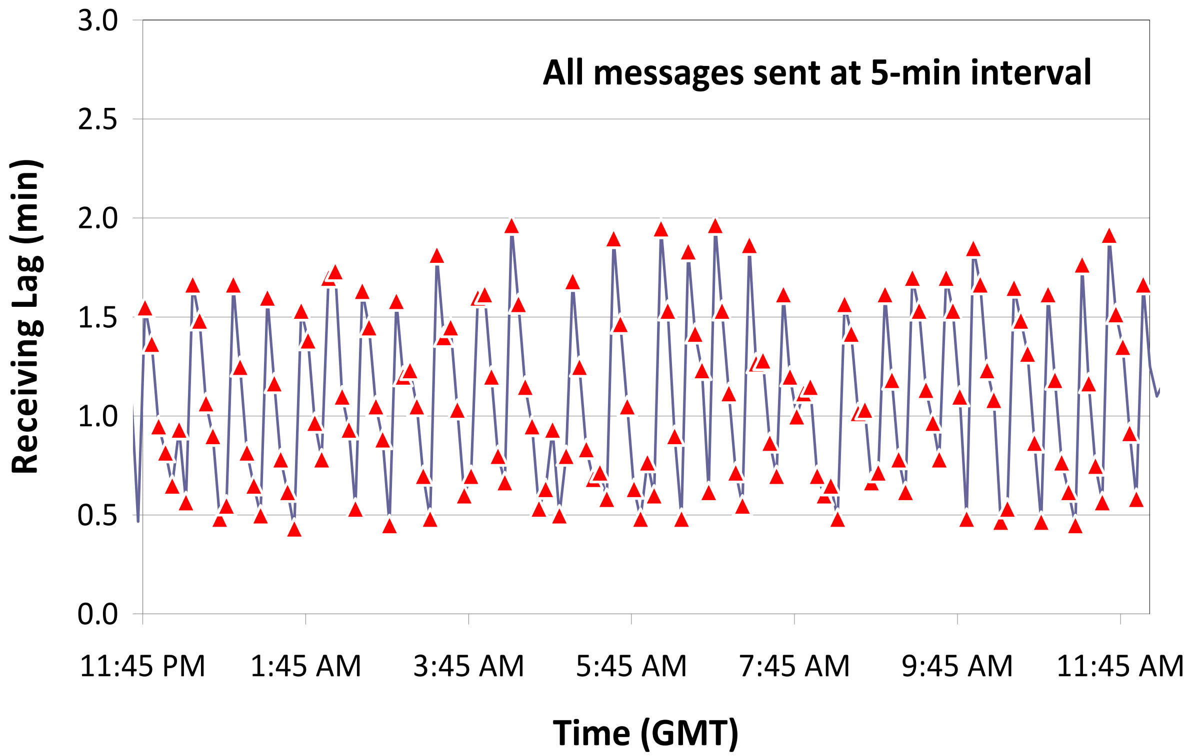

Figure 3. Typical time lags between send and receipt in stationary tests

A road test was conducted on March 24, 2010, during which the truck travelled approximately 300 miles in about 7 hours. The truck stayed on expressways in Illinois for most of the time. The reader polled a total of 10 RFID tags in the truck every 5 minutes and sent the status of each tag as messages to the Argonne RFID Command Center immediately after each poll. The truck stopped four times to trigger staged alerts of the tags. The alerts, two each involving shock and seal sensor violations, simulated incidents which could occur in a real shipment.

The progression of the road test was followed in real time via secured Internet at the Command Center. Figure 4 shows a screenshot of the ARG-US TransPort Webpage at 19:18 Greenwich Mean Time (GMT), or 3:18 pm local time, when the road test was nearly 90% complete. The table beneath the Google map shows a summary of status and recent histories, at 5-min intervals, of the 10 RFID tags in the truck, along with alarm messages. For example, the message of “seal open for Tag 5714152” came in at 19:07 GMT and subsequently cleared sometime after 19:13 GMT. The status of other tag sensors all indicated normal readings.

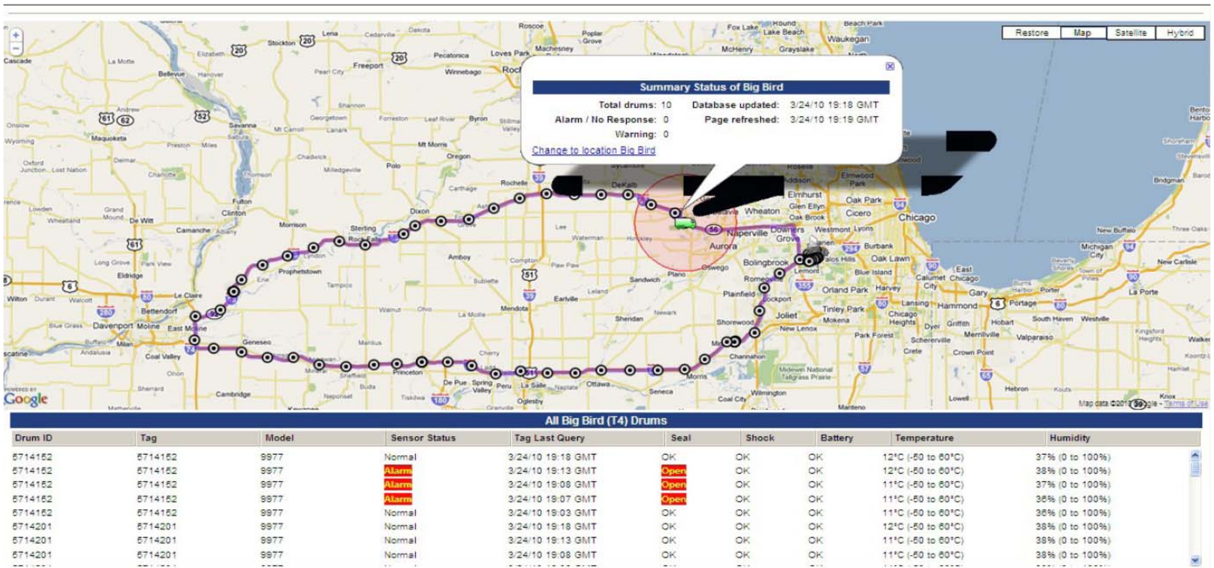

Figure 4. Screenshot of a portion of ARG-US TransPort Webpage during the road test of the truck. Each dot on the map represents a position where the data were sent from the truck.

The time lags between messages during the road test (shown in Figure 5) were, as expected, somewhat longer than those in the stationary tests (see Figure 3) conducted in an open field, since the latter occurred under near ideal conditions and absent of obstructions that would have affected the line-of-sight required for clear satellite communication. When an obstruction occurred in the road test, the data were stored in the queue and resent when the channel became open again, thus contributing to the time lag in message communication. However, even with the occasional interruptions, the lag time for the majority of the messages (83 out of 93) was less than 2 min, which is excellent in real-world operations. Even more significant is the fact that none of the alert messages took more than 2 min to reach the Argonne RFID Command Center.

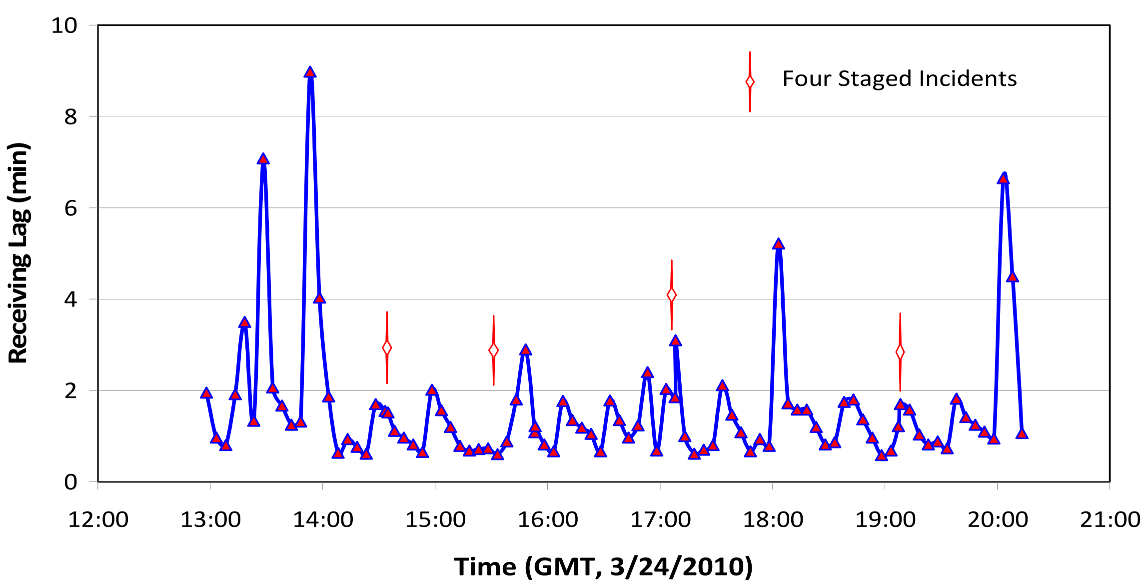

Figure 5. Time lag in receiving messages during the road test of the truck

All 10 tags functioned reliably during the road test, and the sensor readings were accurate the entire time. Figure 6 depicts the recorded temperature data from two of the tags, showing consistent temperature profiles and gradual warm-up during the day. The full record of the sensor response during the road test is archived in the report.[5]

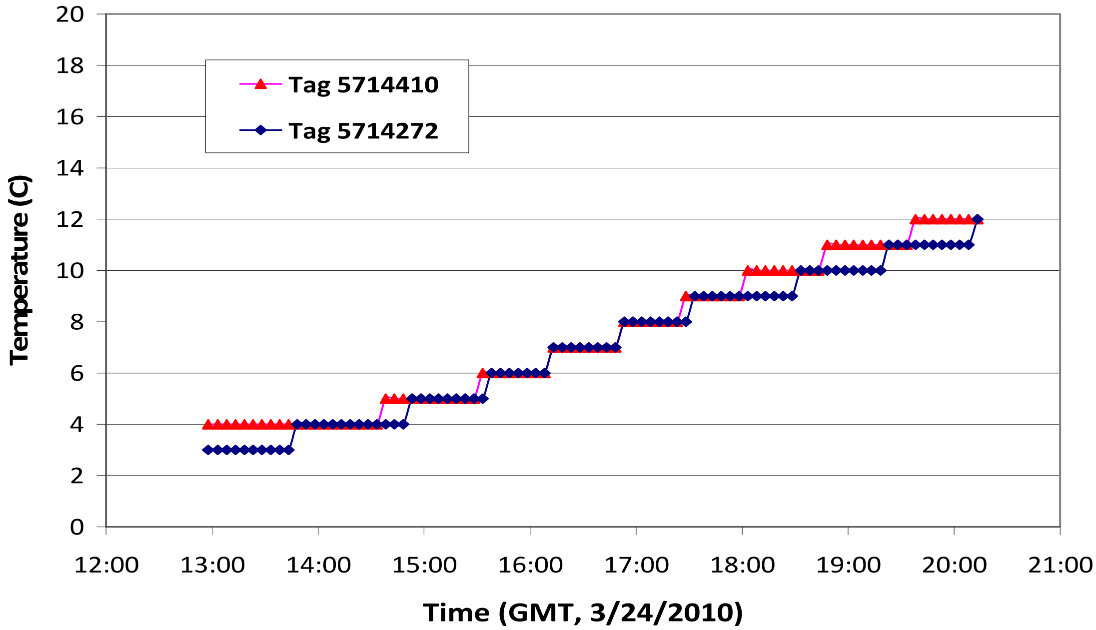

Figure 6. Temperature data from two of the tags in the truck during the road test. The gradual increase in temperature occurred because the test started at ≈8 am local time.

A short demonstration of the capabilities of ARG-US TransPort for real-time tracking and monitoring was also conducted for a large audience in a DOE gathering at Savannah, GA on August 18, 2010, during which the Sprinter van was driven across the city of Savannah and onto expressways for ≈1 hour. The RFID reader in the van polled the four RFID MK-II tags every 2.5 min and the satellite unit was instructed to send messages to the Argonne RFID Command Center immediately after each poll. Two staged incidents were initiated to trigger the seal sensor alarms on the road, without stopping the van. The audience observed the progression of the demonstration "live" on a large screen from a laptop connected via wireless Internet to the Argonne Command Center. The performance of the system was similar to that of the previous tests whenever there was a good satellite signal. A delay in the reporting status of the RFID tags was noted occasionally when the van traversed the city of Savannah.[6]

INTEGRATION AND APPLICATION TESTING

The integration of ARG-US RFID and TRANSCOM took place mainly on the server side. TRANSCOM already had the methods in place to look for messages and pop-up alarms. As part of the planned integration, TRANSCOM would receive the ARG-US RFID data messages and then parse and decode them. If the data message(s) contained an alarm from the ARG-US RFID system, TRANSCOM would send an alert message to the user. The user would then be prompted to navigate to the ARG-US Website and view the shipment in the ARG-US RFID system. The actual effort involved in the integration was minimal — the goal of the integration was met without duplicating functionality between the TRANSCOM and ARG-US RFID systems.

Application testing of the integrated ARG-US RFID/TRANSCOM system continued for about 2 weeks in September-October 2010 and consisted of stationary and road tests monitored at the Argonne RFID

Command Center. Two satellite transponders connected to two ARG-US RFID systems were used in the stationary tests, during which multiple sensor alarms were triggered to test the functionality of the integration. To ensure the robustness of the system integration, alarms were triggered at specified intervals, alternating between the two systems. After the alternating alarm test was completed, the two systems triggered alarms simultaneously to test the ability of the integrated system to handle multiple simultaneous alarms. The stationary testing was a success with the TRANSCOM Webpage displayed correct alarm messages each time the ARG-US RFID systems were tripped.

The application road tests used two vehicles to simulate a fleet operation. Each vehicle carried five or six RFID tags, and the key metrics were real-time tracking by TRANSCOM and the Argonne RFID Command Center, automatic alert/alarm notifications by TRANSCOM, Command Center operation, and two-way communication. Figure 7 is a screen capture of the planned routes and locations of the two vehicles traveling west on I-80 and south on I-57 from Argonne National Laboratory, Argonne, IL. The TRANSCOM map was also on display at the Argonne RFID Command Center, along with the shipment ID, location (latitude, longitude), last position, and time stamps.

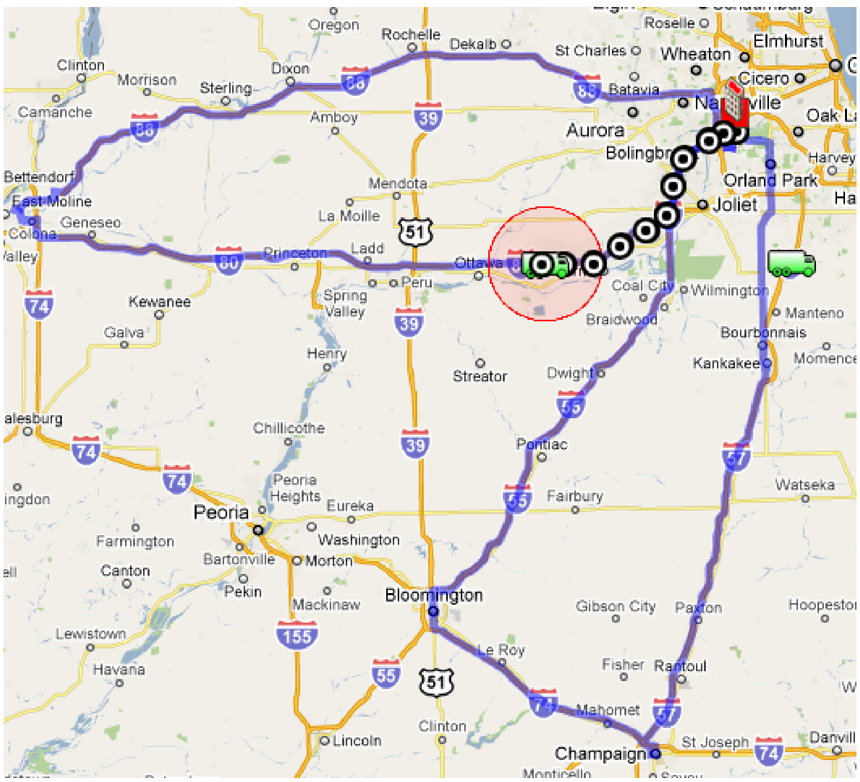

Figure 7.   Planned routes and locations of the two vehicles in the application road test

Figure 8 is a mosaic of responses and displays that occurred after a staged seal alarm from the vehicle traveling south on I-57. The red window popped up from the TRANSCOM Webpage in less than 2 minutes after the incident, showing alarm detection, the RFID tag number, the shipment ID, the incident location, and the nearest city or village. The user was given the option to acknowledge, defer, or go to the ARG-US RFID Website by clicking the center button of the pop-up window. The ARG-US RFID Webpage would then appear showing the tag that was tripped and the nature of the alarm, i.e., seal was open. Figure 8 also shows the GIS report on the emergency management facilities, e.g., hospitals, police stations, etc., within a 10-mile radius of the incident, along with the nature of the incident (i.e., seal violation of the given drum). The GIS report was issued by the Command Center in less than 4 minutes after the staged incident. As the alarm was staged, it was subsequently cleared remotely by the operator at the RFID Command Center.

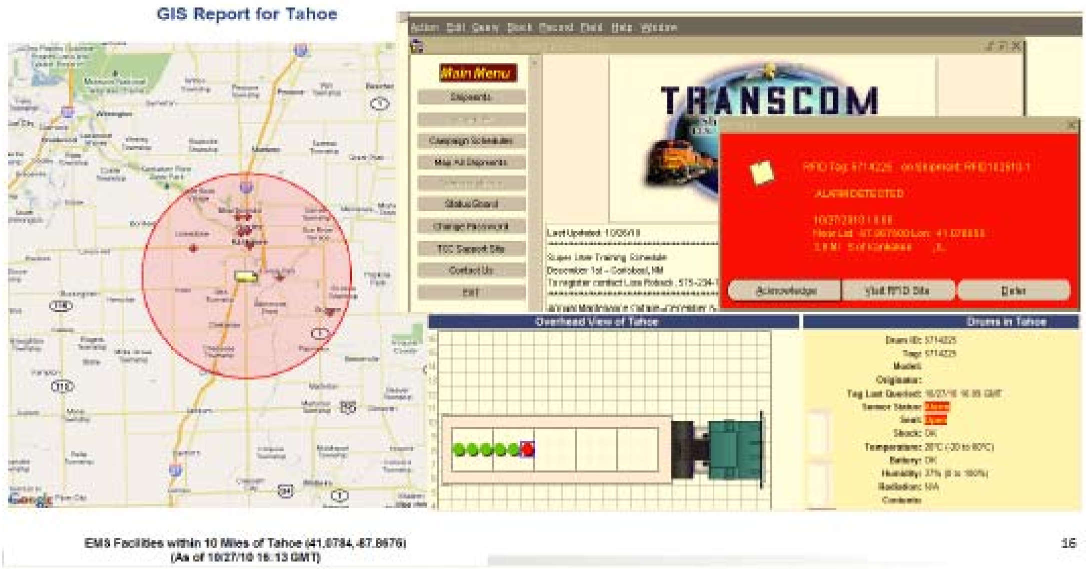

Figure 8. Screens appearing after alarm detected in the TRANSCOM/ARG-US RFID system

DISCUSSION

One of the challenges in tracking and monitoring containers of radioactive and hazardous materials during transport is managing the data messages and communication paths, which vary from short-range radio waves inside the cargo bay of a truck to distant satellites. Weather conditions, obstructions, and sometimes even sharp turns of the vehicle can change the orientation of the transponder relative to the satellite and thus affect the sending and receipt of the messages. The control computer may be programmed to continuously query the state of health of all of the containers in the vehicle, but it can only send the most recent state-of-health information every 5 minutes via the satellite communication link to the central server. The five-minute interval was chosen on the basis of the amount of data transmitted to the satellite and the transfer rate of the satellite communications link. A shorter interval could cause the messages to queue, because the previous message might not have finished transmitting owing to the changing external conditions. One way to shorten the cycle time is to request the satellite communications provider (i.e., Qualcomm) to copy the incoming messages into two separate accounts so that both TRASNCOM and the ARG-US RFID central database servers can retrieve the messages, if necessary. Once the ARG-US RFID server receives the information, it would store the data in the database so that the users can view the status of the containers and shipment via the ARG-US RFID Website. The ARG-US Website allows users to view the current state of health of all containers in the system, as well as generate multiple reports on the detailed history of the containers.

In the event of an alert/alarm, the control computer will send the alarm message immediately over the satellite communication channel. If other messages are queued, the alarm message is moved to the front of the queue to ensure prompt notification. When the ARG-US central database server receives the alarm message, it automatically generates and sends e-mail and short message service (SMS) text message to users regarding the alarm condition. While the ARG-US central database server is receiving the alarm message, the TRANSCOM central server also receives a copy of the same alarm message. The TRANSCOM server will display an alarm message (Fig. 8) and enter the alarm into the shipment history.

Therefore, the integrated system has redundancy of alarms, as well as near-instant, automatic alert/alarm notification capability.

A recent development for the ARG-US RFID Website is the ability to send messages from the Website to the onboard control computer in the vehicle. This development allows the operator at the Argonne RFID Command Center to clear alarms after the cause of the alarm condition has been investigated and resolved. The ability to clear alarms remotely is important so that the driver can concentrate on driving without performing all the hands-on actions. Future enhancement of the system will include additional security measures such as geo-fencing for route deviation, delay elements such as electronic door seals, and overall information assurance and security.

In the U.S. Nuclear Regulatory Commission (NRC) Regulatory Issue Summary 2010-02,[7] NRC provided updated information about the DOE/NNSA's Global Threat Reduction Initiative (GTRI) for voluntary security enhancements, which combined earlier pilot programs and is now being nationally implemented on a voluntary basis. The mission of GTRI is to reduce and protect high-risk nuclear and radiological materials located at civilian sites worldwide. GTRI achieves its mission by converting research reactors and isotope production facilities from the use of highly enriched uranium (HEU) to low enriched uranium (LEU), removing and disposing of excess nuclear and radiological materials, and protecting high priority nuclear and radiological material from theft and sabotage. In the United States, GTRI's objective is to further enhance the protection of these materials through voluntary security enhancement efforts. GTRI's voluntary security enhancements focus on (1) Elimination (unwanted source removal), (2) Detection (remote monitoring, access control, motion detection, and cameras) (3) Delay (in-device delay (IDD) mechanisms, tie downs, and hardened doors/rooms), and (4) Response (equipment, alarm response training, and table top exercises for first responders).

As stated in the RIS 2010-02, the GTRI effort is one way for the NRC licensees to identify best practices beyond regulatory compliance. Under the program, GTRI security experts will provide security assessments, share observations and make recommendations for enhancing material security. When appropriate, NNSA pays for the installation of agreed upon security enhancements. Typical security enhancements include automated access control, motion sensors, radiation sensors, electronic seals, alarm control and display systems, remote monitoring of licensee facilities at off-site response locations, enhanced security force communications and protection equipment, delay elements, and transportation security enhancements, when appropriate. This GTRI program has the support of the NRC and the Agreement State Radiation Control Programs. GTRI's voluntary security enhancements complement and do not replace NRC and Agreement State increased controls requirements. The ARG-US RFID/TRANSCOM system is an excellent candidate to be considered by NRC licensees and others in the GTRI's federally funded voluntary security enhancements for high-risk radiological material.

SUMMARY

Integration of ARG-US RFID container monitoring capability with that of the DOE TRANSCOM for vehicle tracking was successfully completed in October 2010, after nearly 3 years of development and testing for equipment compatibility, systems performance and reliability, and application testing that included multiple stationary and on-the-road tests. Overall, the results confirmed the functionality, performance, and reliability of the integrated system that will greatly enhances the efficacy of the ARG-US RFID and TRANSCOM, especially during shipment of radioactive and hazardous materials. The integrated system is now ready for service.

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