Real-Time Tracking of Nuclear and Radioactive Material Packages in Transport*

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ABSTRACT

Real time situation awareness is an important prerequisite for ensuring safety, security, and safeguards of nuclear and radioactive materials in transport. Sponsored by the U.S. Department of Energy, Environmental Management, Office of Packaging and Transportation, Argonne National Laboratory has developed and tested a highly automated, sensor-based system, called ARG-US TransPort, to support this goal. The key elements of ARG-US TransPort consist of a radio frequency identification (RFID) system employing active sensors with long-life (> 10 years) batteries, a vehicle tracking system incorporating global positioning system (GPS) and satellite communication modules, a geodatabase issuing geographic information system (GIS) report, when necessary, for emergency management, and a pilot RFID command center hosting secure local and central databases and web servers at Argonne National Laboratory, IL, USA.

The sensors in the ARG-US RFID tags that are attached to the transport packages can monitor temperature, humidity, seal integrity, shock and battery status. Information is sent from the tags at preset interval, or upon an operator query, to an interrogator (also known as reader) mounted in the cargo bay of the transport vehicle. From the reader, the information, along with other pertinent vehicle data such as GPS locations, is relayed to the Argonne command center via the Qualcomm OmniTRACS satellite communication module. When an alarm state is encountered by any of the sensors in the tag, a notification is promptly sent to the Argonne command center to alert the user and other responsible individuals via automated texted messages. A dedicated secure database server and its backup at the command center can manage the information from a single vehicle to multiple convoys and displays the information on a secured web page for remote access by authorized users. The system also allows the administrator to send commands to the vehicle so certain operations, such as resetting the alarm state or adjusting the alarm thresholds, can be performed remotely, if necessary, without distracting the driver. In case of a transportation incident, a GIS report using data in pre-existing geodatabases can be issued promptly with ARG-US TransPort. Such reports, containing important information on local assets and vulnerabilities, can greatly aid the first responders in emergency management. Extensive testing in multiple transportation platforms has shown that ARG-US TransPort can reliably track and monitor multiple transport packages near real time.

INTRODUCTION

ARG-US is an RFID-based system developed by Argonne National Laboratory for the management of nuclear materials packages in storage and transportation.[1] ARG-US TransPort is a major component of ARG-US that enables real-time tracking and monitoring of nuclear and radioactive materials packages

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during transportation. The system is an integration of multiple cutting-edge technologies, involving radio frequency identification (RFID), global positioning system (GPS), two-way satellite communication, geographic information system (GIS), secured database and web servers, and a pilot RFID command center at Argonne National Laboratory. ARG-US Transport is capable of tracking vehicle location and monitoring "the state of health," i.e., seal integrity, shock, temperature, humidity, and radiation (in the near future), of nuclear and radioactive materials packages in transport. When any sensor in the RFID tags exceeds its preset thresholds, an automatic alert/alarm is triggered and the event will be reported immediately via satellites to the command center so that appropriate actions can be taken to manage the situation. ARG-US TransPort can also issue GIS report using data in the pre-existing geodatabases that contain important information for the first responders in emergency management.

Since 2008 ARG-US TransPort has been tested on multiple package transportation platforms to evaluate system performance and reliability of the various components. Whereas the earlier tests and demonstration evaluated multiple prototypes and subsystems,[2] the latter tests and demonstration focused on contract-manufactured MK-II RFID tags and satellite communication gear widely used by industry.[3] This paper will highlight results obtained in recent testing of ARG-US TransPort on (1) the "Big Bird" truck used by the Los Alamos National Laboratory (LANL) for the Off-site Source Recovery Project (OSRP),[4] and (2) the Sprinter van used by the National Transportation Research Center (NTRC), Oak Ridge National Laboratory (ORNL) for the Transportation Security Technologies Testbed. Both projects are sponsored by the USDOE National Nuclear Security Administration (NNSA). Special attention was paid during testing on establishing 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 TransPort system.

ARG-US TransPort

ARG-US TransPort is designed with the key requirement that the system must be able to continuously monitor the status of packages in a moving vehicle, and report any abnormal event to the command center in "real-time." Other design requirements include allowing access to data and event history by authorized users over a secured webpage on the Internet, and automation of the system in the vehicle so that the driver is not distracted from driving.

Figure 1 is a schematic diagram showing the communication design of ARG-US TransPort. The communication paths, shown in two-way arrows, start from an RFID tag all the way to a remote end user or system administrator, and vice versa. One complete path may involve a tag-initiated alert/alarm when its battery-powered sensors detect a threshold violation; another complete path, in reverse direction, involves instructions issued by the command center to reset the tag after the cause has been determined for clearing the alarm. The communication between the RFID tag and interrogator is achieved via 433 MHz radio waves over the air, and the events are recorded both in the non-volatile memory of the tag and the database server for future references.

Since the interrogator, also known as reader, and the MK-II RFID tag have a known omni-communication range of ≈100 m, a reader installed inside a vehicle has no difficulty in receiving tag-initiated alert/alarm instantly. Under normal operating conditions, however, the reader is also instructed by the control computer to query (or poll) the tags at regular intervals, e.g., minutes, or continuously to ensure that tags are present and functioning. Absence detection of tags, which are attached to packages, and automatic alarm notification is one of the key features of ARG-US TransPort that greatly enhances transportation security of packages containing nuclear and radioactive materials. (Other security features are the shock sensor for detecting excessive package handling and movement, and seal integrity sensor for package tamper indication.)

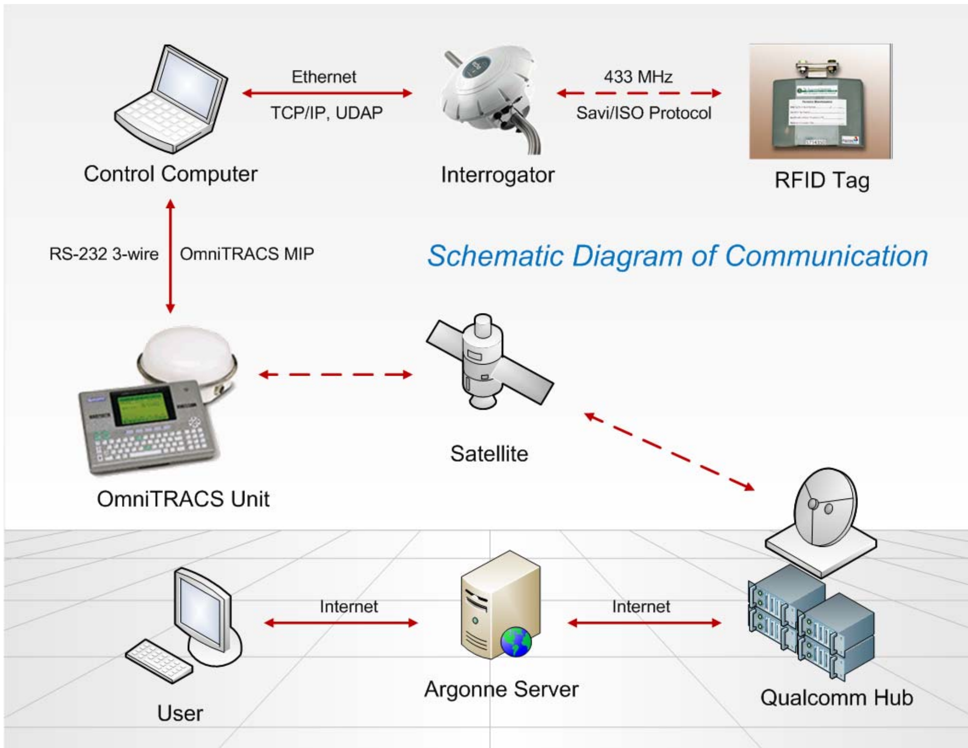

Figure 1. Schematic diagram of communication design of ARG-US TransPort

The control computer runs the Applied Programming Interface (API) in the ARG-US TransPort and interfaces with the interrogator and RFID tags in the vehicle on the one end, and the Qualcomm OmniTRACS[5] satellite communication unit (consisting of a transponder and a tablet) on the other end. The transponder is typically installed on the roof of the vehicle for better antenna performance, whereas the tablet is inside the cab and used by the driver for vehicle tracking and communication. For the current ARG-US TransPort configuration, wired connections are made between the control computer and the tablet/transponder, as well as separate power and Ethernet cable connections to the RFID reader inside the trailer.

The OmniTRACS satellite unit transmits messages and data to the Qualcomm hub that could be instructed to "push" the information to users via Internet, or "pulled" by users, as is currently done by the server at the Argonne command center. The data, including package status, vehicle location, and alarm messages, if any, are stored in a database on the Argonne server that also supports a web page secured by encryption and password protection. Other features of the web page includes a Google map showing the history and current vehicle location, package status and sensor readings, and various other reporting functions and functionalities, including a button for generating instant, event- and location-specific GIS reports for emergency management.[2]

ARG-US TransPort is designed to work in a moving vehicle. The system, except for the RFID tags with its own lithium-ion batteries, is powered by the vehicle battery. Communication throughout the system is achieved by wire and wireless means, both relatively short and long ranges over the air where the inherent communication latency, i.e., delay, is mainly due to satellite transmission. The satellite transmission signals, particularly to and from a moving vehicle, can be affected by weather, nearby trees, bridges, buildings, etc. causing unexpected delay, as can a sharp turn of the vehicle that changes the transponder antenna orientation relative to the satellite. Extensive testing of ARG-US TransPort has been conducted on multiple package transportation platforms and highlights of the recent testing in the Big Bird truck and the Sprinter van are discussed next.

THE “BIG BIRD” TESTS

“Big Bird” is a nickname for a Peterbilt truck used by LANL in the Off-site Source Recovery Project that supports the NNSA’s Global Threat Reduction Initiative. The truck is used for transport of excess, unwanted, abandoned or orphan radioactive sources that pose a potential risk to health, safety, and national security. Because of the positive experience with the ARG-US TransPort system in the earlier demonstrations,[2, 3] LANL decided to install the ARG-US RFID equipment in the Big Bird truck to augment existing capabilities and to better serve OSRP missions. The Big Bird truck, shown in Figure 2 upon arrival at Argonne, is already equipped with a Qualcomm OmniTRACS satellite communication unit.

Figure 2. The "Big Bird" truck with the OmniTRACS satellite communication unit.

Installation of the RFID equipment and its integration with OmniTRACS in the Big Bird truck by the Argonne Vehicle Department were completed in approximately half a day during the week of March 15, 2010. The installation, which consisted of mounting an RFID reader in the trailer, tapping into the vehicle’s 12-V power supply, routing an Ethernet cable from the trailer to the tracker, and connecting the cable to a control computer and the Qualcomm gear, was straightforward.

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.

The three stationary communication tests were conducted with the LANL 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 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, just as 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 is a marked improvement. (The time lags reported by DOE TRANSCOM using comparable Qualcomm OmniTRACS equipment are typically 4–7 minutes.[7]) The main reason for the improved performance was apparently due to the increased internal polling rate at Qualcomm — from every 5 min to every 1 min — made at the request of Argonne.

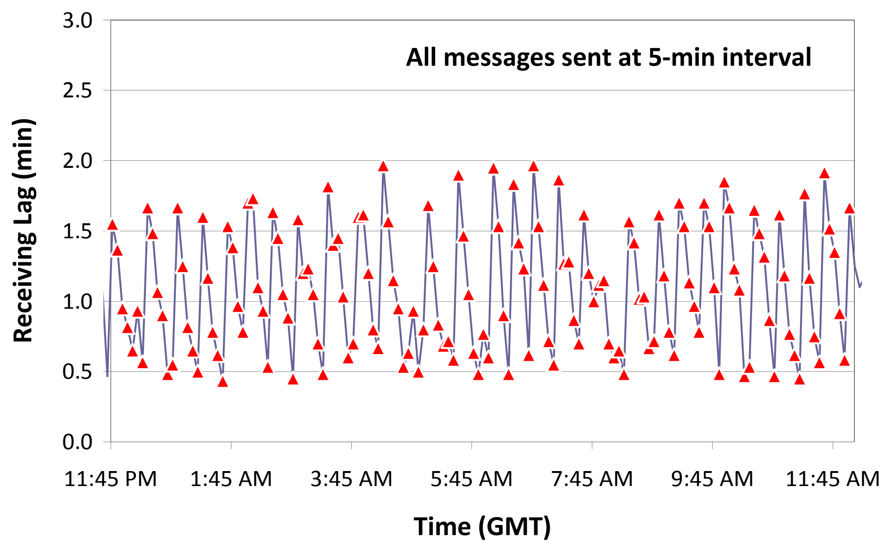

Figure 3. Typical time lags between send and receipt in stationary tests

A road test was conducted on March 24, 2010 during which the LANL truck travelled approximately three hundred (300) miles in about seven (7) hours. The truck stayed on the express ways in the State of Illinois for most of the time. The reader polled a total of ten (10) RFID tags in the trailer every five (5) minutes and sent the status of each tag as messages to the Argonne command center immediately after each poll. The truck stopped four (4) times to trigger staged alerts of the tags. The alerts, two each involving shock and seal sensor violations, simulated incidents which may occur in a real shipment.

The progression of the road test was followed in real time via secured Internet at the command center. Figure 5 shows a screenshot of the ARG-US TransPort web page 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 trailer, along with alarm messages, e.g., Seal Open, of Tag #5714152 that came in at 19:07 GMT and subsequently cleared sometime after 19:13 GMT. The status of other tag sensors all indicated normal readings.

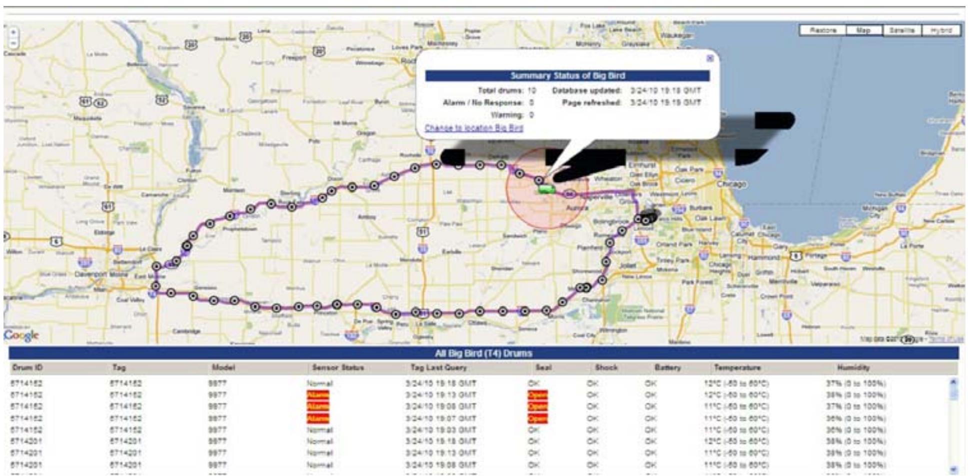

Figure 4. Screenshot of ARG-US TransPort web page during the road test of the LANL truck. Each dot on the map represents a position where the data were sent from the truck.

The time lags between messages during the road test (shown in Figure 5), were, as expected, somewhat longer than those in the stationary tests conducted in an open field, which is near ideal and absent of

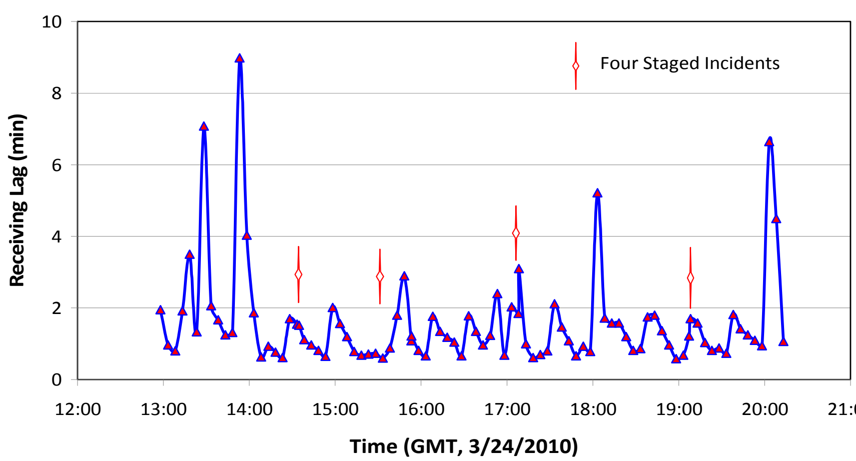

Figure 5. Time lag in receiving messages during the road test of the LANL truck.

obstructions that would have affected the line-of-sight required for clear satellite communication. When an obstruction occurred, 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 command center.

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. The full record of the sensor response during the road test is archived in the report.[4]

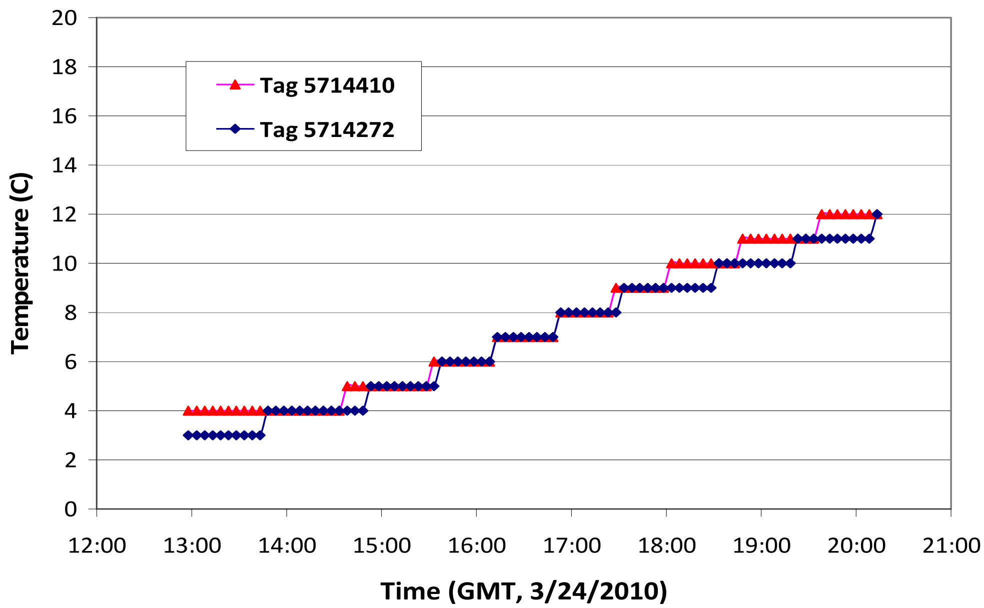

Figure 6. Temperature data from two of the tags in the LANL truck during the road test that started at ≈8 am local time, hence the gradual increase in temperature during the travel.

THE SPRINTER VAN TESTS

The NNSA's Office of Nonproliferation Research and Development and Global Threat Reduction Initiative (GTRI) have jointly established the Safeguards and Transportation Security Technologies Testbed at the NTRC/ORNL to test and demonstrate security technologies and products for deployment in commercial radioactive material shipments. A Dodge Sprinter van with Qualcomm OmniTRACS gear, shown in Figure 7, was acquired as a mobile platform to evaluate security technologies and products currently available on the market. Through a cooperative agreement between NTRC and Argonne, an ARG-US TransPort system that includes a control computer, an RFID reader and several MK-II RFID tags were installed in the Sprinter van in July, 2010. A road test was subsequently conducted on August 16, 2010 by a joint Argonne-NTRC team driving the van from Knoxville, TN to Savannah, GA — about 425 miles (682 km) total distance on interstate and local highways.

Figure 7. Sprinter Van used as a mobile platform for Transportation Security Technologies Testbed (The ARG-US TransPort control computer, RFID reader and MK-II tags are in the van; the OmniTRACS satellite transponder is mounted on the roof and the tablet is in the van.)

The van left Knoxville in the morning of August 16, 2010 and made a stop in Atlanta, GA before continuing to Savannah. The vehicle location and the RFID data were sent every 5 min. from the van, via satellite, to the Argonne command center in the communication paths depicted in Fig. 1. The progression of the road test was monitored on the secured web page via Internet by both Argonne and a DOE gathering in Savannah, GA. Figure 8 shows a screenshot taken from a remote laptop in

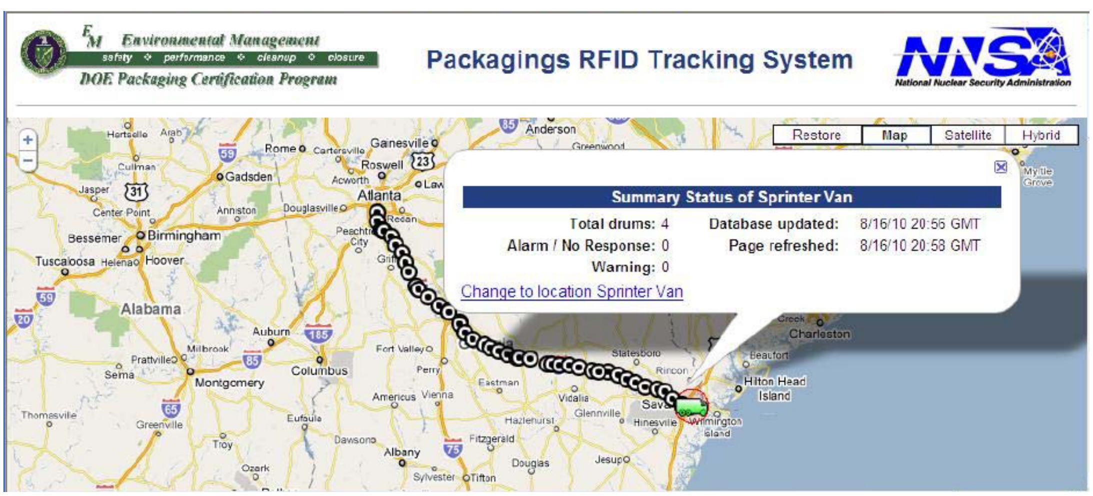

Figure 8. Screenshot of the ARG-US TransPort web page taken from a remote laptop during the road test of Sprinter van from Atlanta, GA to Savannah, GA, August 16, 2010.

Savannah during the DOE meeting when the van was about to arrived at the final destination. The breadcrumbs along the journey indicated the path taken by the van and a popup window, similar to that in Fig. 4, showed a summary status when each breadcrumb is selected by the cursor. This remote tracking and monitoring of the RFID tags inside the moving van hundreds of miles away from Argonne was made possible via a secured web page at https://rfid.dis.anl.gov/pcp-test/Webform1.aspx.

A short demonstration of the capabilities of ARG-US TransPort for real-time tracking and monitoring was also conducted for a large audience on August 18, 2010, during which the van was driven across the city of Savannah and onto express ways 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 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 form 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 is 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.

DISCUSSION

The NNSA's OSRP has been recovering excess and unwanted sealed sources for 10 years, with more than 23,000 sources recovered to date.[7] NNSA has acquired a dedicated vehicle, the Big Bird LANL truck, to enhance transportation security in the OSRP shipments. NNSA and GTRI are also sponsoring the transportation security technologies testbed evaluation using the Sprinter van as a mobile platdorm.[8] Installation of the ARG-US TransPort system to these vehicles, particularly the LANL truck, will significantly enhance transportation security in the OSRP shipments, because "the state of health" of the source containers inside the truck is monitored, in addition to the physical location of the truck, during transportation and near real time.

Installations of the RFID equipment in the LANL truck were simple and straightforward. Once the processes were finalized and the work plan approved, the physical installation took less than half a day to accomplish. No special tools were required, and the overall cost was minimal. There were no compatibility problems between the installed ARG-US TransPort RFID system and the Qualcomm communication unit already in the truck. The integrated system worked at the first attempt. The positive outcome of the tests suggests that other OmniTRACS-equipped vehicles can be enabled with ARG-US TransPort tracking and monitoring capabilities, with minimal effort and cost.

Efforts are currently under way to integrate ARG-US TransPort with TRANSCOM, the USDOE unclassified tracking and communications system used to monitor the progress of various "high visibility" shipments, such as spent nuclear fuel, high-level and transuranic radioactive waste.[6] TRANSCOM currently uses the Qualcomm system, including OmniTRACS, to track vehicles that transport radioactive material packages, but not individual packages in the vehicles — a capability that ARG-US TransPort can uniquely provide. Since both TRANSCOM and ARG-US TransPort use OmniTRACS for communication between the vehicle and the command center, integration of the two systems will allow users of TRANSCOM to track and monitor individual packages during shipment, while users of ARG-US TransPort will benefit from the well-established, nation-wide user base of TRANSCOM.

The integration mainly takes place on the server side. The ARG-US TransPort is linked to the TRANSCOM so that the user will have a choice to go from TRANSCOM to ARG-US TransPort to view the sensor status of the packages. An alert from ARG-US TransPort is displayed on the TRANSCOM web page, along with automatic notification messages sent to the user. A recent test demonstrated that the integration of the two systems is capable of handling multiple shipments or vehicles at the same time. Further tests will be performed to ensure system reliability and the results will be reported in future publications.

So far the testing of current ARG-US TransPort with Qualcomm OmniTRACS satellite communication unit in vehicles showed a "nearness" to real-time capability of ≤ 2 min under optimal conditions, which may be entirely acceptable depending on circumstances, e.g., at a truck stop or overnight stay where the truck is not moving and the time lapses established from the stationary testing should apply. The factors that affect satellite signal transmissions of the OmniTRACS unit and message delay are known, thus the solution, e.g., a hybrid network based on cellular and satellite communication that should work better in the cities and rural areas and minimize the delay of messages.

Further streamlining and automation of ARG-US TransPort is also possible by eliminating the control computer while incorporating its functions into the RFID reader that directly interfaces with the OmniTRACS satellite communication unit, or its next-generation derivatives. Improved performance in real time tracking is certainly possible with advanced satellite technologies that enabled fans around the world to watch the 2010 World Cup Live in Johannesburg, South Africa, or soldiers in the US flying drones in military sorties in Afghanistan. The cost of such implementation, of course, needs to be taken into account.

SUMMARY

Argonne National Laboratory has developed the ARG-US TransPort system for "real-time" tracking and monitoring of nuclear and radioactive materials packages during transportation. Extensive testing of ARG-US TransPort has been conducted on multiple transportation platforms to evaluate system performance and reliability of the various components. The results of the testing demonstrated that the ARG-US TransPort has worked as designed, and will significantly enhance safeguards, security and safety of nuclear and radioactive materials packages during transportation.

Future development of ARG-US TransPort will complete its integration with DOE TRANSCOM, and consider a cellular-satellite hybrid communication device for better overall signal coverage, as well as further automation by eliminating the control computer in the data pathway and incorporating its functions directly into the RFID reader.

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