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TRACKING AND MONITORING OF RADIOACTIVE MATERIALS IN THE COMMERCIAL HAZARDOUS MATERIALS SUPPLY CHAIN

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ABSTRACT[1]

One of the main components of the Environmental Protection Agency's (EPA) Clean Materials Program is to prevent the loss of radioactive materials through the use of tracking technologies. If a source is inadvertently lost or purposely abandoned or stolen, it is critical that the source be recovered before harm to the public or the environment occurs. Radio frequency identification (RFID) tagging on radioactive sources is a technology that can be operated in the active or passive mode, has a variety of frequencies available allowing for flexibility in use, is able to transmit detailed data and is discreet. The purpose of the joint DOE and EPA Radiological Source Tracking and Monitoring (RadSTraM) project is to evaluate the viability, effectiveness and scalability of RFID technology under a variety of transportation scenarios.

The goal of the Phase II was to continue testing integrated RFID tag systems from various vendors for feasibility in tracking radioactive sealed sources which included the following performance objectives:

1. Validate the performance of RFID intelligent systems to monitor express air shipments of medical radioisotopes in the nationwide supply chain,

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2. Quantify the reliability of these tracking systems with regards to probability of tag detection and operational reliability,
3. Determine if the implementation of these systems improves manpower effectiveness, and
4. Demonstrate that RFID tracking and monitoring of radioactive materials is ready for large scale deployment at the National level.

For purposes of analysis, the test scenario employed in this study utilized the real world commerce supply chain process for radioactive medical isotopes to validate the performance of intelligent RFID tags. Three different RFID systems were assessed from a shipping and packaging perspective, included varied environmental conditions, varied commodities on board vehicles, temporary staging in shipping terminals using various commodities and normal transportation handling. We tracked 32 air express (AE) shipments from a medical radioisotope (MR) production facility in Boston, MA to ORNL in Oak Ridge, TN. Each RFID system was individually tested in Type A modified packaging with differing quantities of Phosphorus-32 (1,000 µci, 500 µci and 250 µci) for 16 shipments per system. Three of these shipments per system contained dry ice (9 total). An additional 16 shipments were tested that contained one tag from each system using Type A packaging without Phosphorus-32. Twelve of these shipments contained dry ice. RFID interrogators for each system were installed at four waypoints along the 1,000 mile shipping route from source to designation via air and surface. Each package was expected to be detected by its corresponding interrogator(s) at each waypoint.

System A's overall probability of detection was 77 percent, System B's overall probability of detection was 20 percent and System C's overall probability was 75 percent. The presence of more than one RFID system in a shipment did not appear to have an effect on any of the three systems tested. However, no tests of significance could be performed because group sample sizes did not satisfy the standard binomial test-of-significance between independent samples. Preliminary analysis of the data using pair-wise comparison (in process) is expected to show some (possibly significant) differences due to packaging and the effects of dry ice on the tags.

Phase II of the RadSTraM project verified that RFID tagging can be applied to the tracking and monitoring of medical radioisotope air express shipments. This study demonstrated that active RFID tagging systems can be feasibly integrated and scaled into the nation-wide supply chain to track and monitor medical radioisotopes.

INTRODUCTION

This report focuses on the technical information gained from the Radiological Source Tracking and Monitoring (RadSTraM) Phase II investigation and its implications. The intent of the RadSTraM project was to determine the feasibility of tracking radioactive materials in commerce, particularly International Atomic Energy Agency (IAEA) Category 3 and 4 materials. Specifically, Phase II of the project addressed tracking radiological medical isotopes in commerce. These categories of materials are susceptible to loss or theft but the problem is not being addressed by other agencies. The purpose of the joint DOE and EPA RadSTraM project is to evaluate the viability, effectiveness and scalability of RFID technology under a variety of transportation scenarios.

BACKGROUND

Phase I of the study served as a critical component for addressing procedures and protocols needed to establish an operational system. During the first phase, RFID was used to track radiological commodities under typical "in commerce" shipping conditions. The project tracked

a series of shipments between Oak Ridge National Laboratory (ORNL) and Oak Ridge Associated Universities (ORAU) utilizing commercial Less-than-Truckload service, commercial truckload service and ORAU private fleet. The testing included single and multiple shipments under different loading and shielding scenarios. The scenarios included in transit as well as overnight storage, and they were tracked using bulk radiological monitors at the I-40 Watt Road weigh station. The testing coupled data from two RFID technologies with data collected from radiation portal monitors. This set of tests verified that active RFID tagging can be applied to the tracking of interstate shipments of radioactive material. Furthermore, it was demonstrated that RFID systems are robust and mature enough to be scaled into a nation-wide system with the caveat that there is some central database or network that can present the data to a variety of users. (1)

Phase II implemented the procedures, protocols and lessons learned during Phase I into a real-world environment to test proof-of-concept with a range of tags for large-scale deployment. RFID systems were used to track, locate and identify express air and truck shipments of medical radioisotopes shipped by a commercial air express (AE) service between a medical radioisotope (MR) production facility in Massachusetts and ORNL in Tennessee. An RFID manifest system consisting of a standalone database and web client was developed to manage data from the tags from several different vendors. The RadSTraM project used operational procedures set by the Department of Energy (DOE) Isotopes Group for medical and industrial supply chain shipments of radioactive materials. This initiative was unique because it implemented lessons learned from the previous test phase to evaluate instrument technology in a real world deployment.

Motivation

Highly radioactive sources are used in everyday life to treat cancer patients, as irradiators to preserve food, in industrial radiography to check for welding errors in pipelines and buildings, for thermoelectric generation of electricity in remote locations, and for a variety of other purposes. There are reportedly some ten thousand radiotherapy cancer treatment units worldwide, with many more radioactive sources used throughout industry. Radiological sources are essential to our societies, and there is not practical option to secure and control every item, everywhere.

There is not an accurate figure on how many radioactive sources exist throughout the world. Some of the isotopes of most concern include Cobalt 60, Strontium 90, Cesium 137, and Iridium 192. A huge number of applications of these materials make them inherently difficult to track and control. Many of these sources are lost, stolen, or simply abandoned when no longer required. In the United States, for example, an average of about 300 sources of radioactive material are reported lost or stolen each year (2). Such "orphaned" radioactive sources give cause for immense concern and is most troublesome in countries where civil authority and regulatory oversight are weak. Orphan sources are found worldwide. In early 2002, for example, two canisters containing highly radioactive Strontium 90 were discovered in the former Soviet republic of Georgia. The three Georgian woodsmen who came upon them were severely burned by radiation. The United States, the IAEA, and the Georgian government subsequently worked together to secure these field radioisotope thermoelectric generators, many of which exist in uncontrolled settings. Furthermore, there exist significant quantities of Cesium 137 that has been used to preserve harvested grain in some countries and become orphaned, for example. (3, 4, 5, 6)

RadSTraM and RFID Technologies

The first step in the design and implementation of an RFID intelligent tag system into the supply chain process for radioactive materials is for a validation of this technology to be completed to assess how to best apply it to the in-commerce process. To this end, the RadSTraM Controlled Shipment Test Phase II was conducted to assess the technology in a real-world environment simulated after the DOE Isotopes shipping program at ORNL. Collaborations with the state/federal government agencies and the private sector will prove invaluable as RFID technologies are studied. It is envisioned that RFID technology will serve the primary need of the EPA to reduce the number of orphan sources and identify radioactive materials throughout their life cycle in the supply chain. Additionally, it is hoped that RFID will provide the capability to pre-clear vehicles that might set off radiation detection sensors to avoid further inspection of the vehicle.

PROJECT DESIGN

The experimental design for the RadSTraM study combines off-the-shelf technology into an intelligent system that meets criteria established for successfully implementing and testing the project requirements.

Methodology

On February 23, 2006, RFID interrogators were installed at a medical radioisotope facility and an AE facility in Boston, Mass. The interrogators for AE facility in Knoxville (Alcoa, Tenn.) and ORNL in Oak Ridge, Tenn. were installed on February 28.

The test scenario employed in this project utilized the real world commerce supply chain process for radioactive medical isotopes to validate the performance of RFID intelligent tags. RFID technology was assessed under normal operating conditions, including varied environmental conditions, varied commodities on board vehicles, temporary staging in operating terminals with various commodities and normal transportation handling. The criteria for the test included:

1. U.S. Department of Transportation (DOT) Type A packaged, RFID modified inner containers with electronic inner containers. (The U.S. has four levels of packaging for non-waste radioactive material. Shippers of non-waste radioactive material are affected by three of these packaging levels: strong tight containers (STC), Type A and Type B. STC is used for radioactive materials that have minimal impact on health safety and property should exposure occur. Type A packages are required for transporting material that would have a limited, non-lethal impact on health safety and property. Type B packages are required for transport of radioactive materials that would have a lethal impact on health safety and property should an exposure occur.)
2. Type A quantities of phosphorus (P-32) package in Type A inner containers.
3. Radioactive material shipments from a medical radioisotope production facility in Massachusetts to ORNL in Roane County, Tenn. using a commercial AE service.
4. Packaging configured with active tags provided by three RFID vendors.
5. Configuration and testing of RFID interrogators provided by the three RFID vendors installed at ORNL, the AE facility in Tenn., the AE facility in Mass., and the MR production facility in Mass.
6. Collection of data and documentation of results using ORNL's data collection application.
7. Data analysis and lessons learned reporting.

Thirty-two air express shipments were tested from May 1, 2006 to May 11, 2006. All shipments originated at the medical radioisotope production facility in Boston. The shipments were air expressed to ORNL. From ORNL they were sent back to the medical radioisotope production facility. This round trip route was then repeated. The testing groups were as follows:

1. Three RFID systems: System A, System B and System C.
2. Four tags from each system type were used for the test. Each tag was tested on two roundtrip shipment runs (from medical radioisotope production facility to AE Boston to AE Knoxville to ORNL; ORNL to AE Knoxville to AE Boston to medical radioisotope production facility) for a total of four shipments per tag.
3. RFID readers for each system were installed at each point in the route (ORNL, AE Knoxville, AE Boston and MR production facility). Therefore, each tag tested in a shipment should have been seen by a reader eight times per roundtrip.
4. Two tags from each system were tested individually in Type A boxes containing medical radioisotopes. (There were four isotope quantities used in the testing: P32 1mc, P32 500uc, P32 250uc and no radioactive material. Since the medical radioisotopes are all contained within shielded inner containers and the RFID tags are packaged in the boxes outside of the inner containers, the four quantities will be considered as a group in the analysis of the data.)
5. Two tags from each system were tested in the presence of tags from the other two systems in Type A boxes that did not contain medical radioisotopes. (Two subtypes of Type A boxes were used in the testing: Box Type E (small box with six holes) and Box Type A (medium box with one day supply of dry ice). Box subtype was not considered in the analysis of the data.)
6. Two shipping conditions: ambient air and dry ice.

RESULTS

Table 1displays the overall success rate for each system.

Table 1. The Overall Success Rate

	Ratio of Hits	Percentage of Success
System A	49/64	76.56%
System B	13/64	20.3%
System C	48/64	75%

Two-sample z tests for the significance of the difference between two independent proportions were conducted to determine whether the overall success rates of the RFID systems were significantly different from each other. The overall success rate for each system was 76.56% (49 out of 64 hits) for System A, 20.3% (13 out of 64 hits) for System B and 75% (48 out of 64 hits) for System C. The difference between System A and System B was significant ($z = 6.367$, $p < 0.002$) and the difference between System C and System B was significant ($z = 6.194$, $p < 0.002$). (Sample sizes for the other conditions were too small to satisfy the standard binomial requirement that n(p) and n(1-p) both be greater than or equal to five, where n is the number of observations and p is the proportion. Because of this, no statements of significance can be drawn about between or within groups for the ambient air vs. dry ice condition the presence of other tags condition.) Table 2 displays the results for the success rate of shipments package with dry ice compared to those packaged without dry ice for all tags. Dry ice appears to negatively affect the performance of System C. Table 3 displays success rates of tags package in the presence of other tags. Again, dry ice appears to negatively affect the performance of System C. Table 4 displays success rates for tags packaged individually with medical radioisotopes with and

without dry ice. The results in Table 4 show that performance of System C appears to be negatively affected by dry ice. The success rates for tags packaged individually and the success rates for tags packaged in the presence of other tags appear to be approximately the same, indicating the performance of these systems is not affected by the presence of other systems.

Table 2. Ambient Air vs. Dry Ice Comparison of Success Rates for Each System

	Ratio of Hits Ambient Air	Percentage of Success	Ratio of Hits Dry Ice	Percentage of Hits
System A	30/40	75%	19/24	79.2%
System B	8/40	20%	5/24	20.8%
System C	36/40	90%	12/24	50%

Table 3. Ambient Air vs. Dry Ice Comparison of Success Rates for Each System in the Presence of Other Tags Condition.

	Ratio of Hits Ambient Air	Percentage of Success	Ratio of Hits Dry Ice	Percentage of Hits
System A	13/20	65%	10/12	83.3%
System B	5/20	25%	3/12	25%
System C	18/20	90%	9/12	75%

Table 4. Comparison of Each Systems Success Rates for Shipments Packaged with P32 Medical Radioisotopes.

	1 mc	Percent of Hits	500 µc	Percent of Hits	250 µc	Percent of Hits	All Quantities	Percent of Hits
System A								
Ambient Air			13/16	81.25%	4/4	100%	17/20	85%
Dry Ice					9/12	75%	9/12	75%
System B								
Ambient Air	1/4	25%	2/16	16.67%			3/20	15%
Dry Ice	2/12	16.67%					2/12	16.67%
System C								
Ambient Air	18/20	90%					18/20	90%
Dry Ice	3/12	25%					3/12	25%

Observations

Two incidents occurred during the shipment runs that are important to note.

1. Technical difficulties with system B's server were identified during the first shipment run. The tags were packaged at the medical radioisotope production facility in Boston with all supporting documentation recorded. ORNL's server and System B's server recognized the

tags at the Boston facility. When the shipments arrived at ORNL's facility the tags were not recognized by the readers. The batteries in the tags were still working properly, so battery life was determined not to be the problem. ORNL's server was still reading tags from the other vendors, so ORNL's server was not the problem. (ORNL's server obtained data from System B's server.) Vendor B was able to get their server back on-line, but the reason for the interruption was not identified.

2. During the return shipment of the first run (ORNL to Boston) a package was misplaced. The package contained a tag from Vendor A. The package left the ORNL facility with all the other packages that were part of the shipment. All the appropriate documentation was recorded and ORNL's server registered the tag. When the packages arrived at the AE facility in Knoxville one of the packages was not scanned by the AE company. When the shipment arrived in Boston the AE company did not have a record of the misplaced package leaving Knoxville. We were able look up the tag that was in the missing package using ORNL's API. We found that the package had been shipped and was at the Boston facility.

CONCLUSIONS

This demonstration tracked 32 air express shipments from a medical radioisotope production facility in Boston, Mass. to ORNL in Oak Ridge, Tenn. Three RFID systems were evaluated under a number of conditions. Each RFID system was individually tested in Type A modified boxes with differing quantities of P32 (1 mc, 500 uc and 250 uc) 16 shipments per system. Three of these shipments per system contained dry ice. An additional 16 shipments were tested that contained one tag from each system packaged Type A boxes without P32. Twelve of these shipments contained dry ice. RFID interrogators for each system were installed at four waypoints along the shipping route: the medical radioisotope production facility in Boston, Mass., the AE terminal at Logan International Airport in Boston, Mass., the AE terminal at McGhee Tyson International Airport in Knoxville, Tenn. and ORNL in Oak Ridge, Tenn. Each package was expected to be detected by its corresponding interrogator(s) four times per shipment.

System A's overall probability of detection was 76.56 percent, System B's overall probability of detection was 20.3 percent and System C's overall probability was 75 percent. Results for System A's and System C's overall probability of detection were found to be significantly higher than System B's. The presence of more than one RFID system in a shipment did not appear to have an effect on any the three systems tested. However, no tests of significance could be performed because between and within group sample sizes did not satisfy the standard binomial requirement for the test of significant difference between independent proportions. The presence of dry ice appeared to have a deleterious effect on System C, but again sample sizes did not satisfy the standard binomial requirement for test of significant difference between independent proportions and conclusions cannot be drawn for these results.

Table 5. Implementation of Phase I Lessons Learned in Phase II of Testing

Phase I Lesson Learned	Phase II Implementation
A standard form should be designed that includes all relevant information.	ORNL's web-based RFID manifest system contains a standard form on its user interface.
More attentions should be given to completing forms in their entirety.	A protocol for collecting data was implemented that included completely filling forms.
Shipments should be verified as going through each waypoint.	Collaborating with a national air express shipper provided a secondary check of through the use of their shipment tracking software.
Software should automatically run when a system reboots.	New software designed to automatically reboot.
Data should be handled in electronic form to reduce human error.	ORNL's web-based RFID manifest system was developed to reduce the error seen with hand written test logs.
All data should be copied to a single database for storage and analysis	ORNL's web-base RFID manifest system stores all of the test data in a database.

Phase II of the RadSTraM project successfully implemented the lessons learned from Phase I. Human error seen in data logging in Phase I were eliminated in Phase II by the use of a web-based manifest system to standardized the data entry forms. Implementing a protocol for collecting test data helped to eliminate errors in data logging. Using the web-base manifest system to collect and store data increased the manageability of the data and provided a user-friendly graphical interface that could be accessed by a variety of users. The results of the shipping runs in Phase II indicate that the use of dry ice in shipments of medical radioisotopes does decrease the performance of some types of tags. However, operating tags from multiple vendors in close proximity of each other does not appear to affect their performance.

Phase II of the RadSTraM project verified that RFID tagging can be applied to the tracking and monitoring of medical radioisotope air express shipments. The project demonstrated that active RFID tagging systems are robust and mature enough to be scaled into the nation-wide supply chain for medical radioisotopes. The development of a web-base manifest system by ORNL to handle data eliminated the problems with data handling reported in Phase I of the RadSTraM project.

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