OAK RIDGE NATIONAL LABORATORY
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RadSTraM: Radiological Source Tracking and Monitoring

Interim Final Report

June 3, 2005

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EXECUTIVE SUMMARY

The Radiological Source Tracking and Monitoring (RadSTraM) project was designed to evaluate the feasibility of tracking radiological commodities under typical "in commerce" shipping conditions. The project tracked a series of 28 shipments between Oak Ridge National Laboratory (ORNL) and Oak Ridge Associated Universities (ORAU) utilizing commercial Less-than-Truckload (LTL) service, commercial truckload (TL) service and ORAU private fleet. The shipments traveled less than 50 round trip miles each. 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.

Radio frequency identification (RFID) tags were used as the means of tracking coupled with data collected by radiation portal monitors. The two RFID systems that were evaluated are denoted PT and SN in this report. RFID tags from both systems were embedded into four Type A packages employing tamper-proof electronic seals and containing the following isotopes: Cesium-137, Cobalt-60, Strontium-90 and Californium-252. Since RFID attenuation and reflection are important factors affecting the readability of RFID tags, different loading configurations and trailer types were evaluated. All metal trailers and trailers that were all metal except for wooden floors were used in both TL and LTL configurations. Tag listeners were deployed at four waypoints: ORNL, ORAU, the Watt Road weigh station and a trucking terminal. The Watt Road weigh station was chosen because this location incorporates an independent device (i.e., radiation portal monitors) available to verify the presence of radioactive material in shipment. A figure of merit called the "probability of detection" was calculated for both systems. This is the ratio of the number of times that a tag was seen versus the number of times it was known to be present. The first system, PT, had a probability of detection of 77% while the second system, SN, was shown to have probability of detection of 44%.

A cost analysis of the two systems was also performed. The unit costs of the SN system was, at a minimum, twice that of PT. For this demonstration, there were other costs that made the SN system nearly *four times* more expensive than the PT system, which would have highly significant ramifications in a scaled-up national system. While both systems tested in this demonstration would qualify as candidates for further study concerning use in a nation-wide system, the PT system proved more reliable and cost effective.

It is recommended that a second phase of this study be performed to test proof-of-concept and a wide range of tags for large-scale deployment. Interest has been shown by global transportation and logistics carriers as well as isotope distributors/manufacturers for participation in a second phase. A set of lessons learned are presented at the end of this report, which may provide valuable criteria to consider prior to implementation of any phase two effort.

1 INTRODUCTION[1]

This report focuses on the technical information gained from the Radiological Source Tracking and Monitoring (RadSTraM) investigation and its implications. The intent of the project was to determine the feasibility of tracking radioactive materials in commerce, particularly International Atomic Energy Agency (IAEA) Category 3 and 4 materials. These categories are not being addressed by other agencies, and they are susceptible to loss or theft. A technology solution was sought to help prevent lost radioactive sources, which is one of the main components of the EPA's Clean Materials Program.

1.1 BACKGROUND

The purpose of the EPA and DOE RadSTraM joint study was to investigate radio frequency (RF) technologies (i.e., RF Identification [RFID] tags and listeners) and their usefulness in tracking and monitoring radiological sources in commerce. The study (phase 1) has served as a critical component for addressing procedures and protocols needed to establish an operational system.

ORNL conducted the EPA RadSTraM project using radiological monitors and operating procedures already in place at a bulk radiological monitoring system installed at the Tennessee Department of Safety (TDOS) Commercial Vehicle Enforcement Division's Watt Road/Campbell Station Road Weigh and Inspection Station. Using this already established testbed, ORNL conducted the EPA RadSTraM project using radiological monitors and operating procedures already in place at the Tennessee weigh station. This initiative was unique because it was not limited to instrument technology evaluation, but included most of the typical facets of real world deployment.

The operational requirements of a tagging system will depend on the risk posed by the source to the public and the environment, the risk of the source being lost or stolen, and the needs of the monitoring authority as to type of information and timeliness required. There are a number of available technologies that are used for tagging items; however, there is no information in the available literature about tagging technologies being tested in proximity to radioactive materials.

The goal of this project is to continue testing the integrated RFID tag, developed by Northwest Nuclear, LLC for its feasibility in tracking radioactive sealed sources. This techno1ogy was chosen for a number of reasons, including:

1) the cost of RFID tags has become affordable,
2) the technology has flexibility in frequencies used, which allows detection at varying distances from the reading device,
3) tags may be passive or active and may be combined with other sensors and technologies, such as Global Positioning Satellite tracking,
4) RFlD testing can be combined with ongoing or planned in-commerce projects at the I-40 Weigh Station in Oak Ridge, Tenn.

The integrated tag has been tested with various radioactive isotopes, supplied by the Oak Ridge National Laboratory. These packages, containing strontium, cesium, cobalt and californium isotopes, have been passed by reading devices in various configurations, to determine the optimal operating conditions for the tags.

[1] The mention of brand names does not constitute endorsement by the US Government.

Different truck constructions, different package positioning within the trucks and different mixtures of isotopes have been tested in actual shipping scenarios in and around the Oak Ridge, Tenn. area. The various shipping runs have simulated radioactive source material in-commerce.

The results of this project to date have indicated that this tag works effectively under the limited scenarios tested. The operational parameters necessary to operate this system successfully are being identified based on the test run results utilizing two of the largest commercial isotope distributors/manufacturers. The initial success has been very encouraging and the next phase will test the tagging system under actual medical and industrial supply chain shipping runs by the Department of Energy Isotopes Group, which routinely ships large quantities of radioactive isotopes throughout the United States. Five regular shipments that utilize Less-than-Truckload ground transportation will be equipped with two different RFID tags and interrogators will be installed at chokepoints along the transportation route. Information generated during this domestic ground supply chain test will further refine the operating parameters of the tagging system within the government sector and bring the system closer to imp1ementation by the commercial shipping industry.

1.2 OBJECTIVES

The purpose of the RadSTraM project was to test the use of RFID tags to detect shipments of radiological material while in commerce and transport. The following tasks were performed:

- Established necessary data needed for collection (base line),
- Selected controlled shipment testing,
- Data analysis, and
- Lessons learned reporting.

1.3 STAKEHOLDER ISSUES

The stakeholders identified in this demonstration were the Department of Energy (DOE), Oak Ridge National Laboratory (ORNL), the distributors/manufacturers and commercial freight companies that transport radioactive material, the State of Tennessee, the Environmental Protection Agency (EPA), and the general public. While there were similarities in some of the stakeholders' needs with regards to a successful demonstration, these entities had differing reasons for seeing a successful demonstration.

All of the stakeholders desired the ability to track radioactive material shipments in transit. For ORNL, this desire was based on inquiries by the Nuclear Regulatory Commission requiring ORNL to provide location information of their radioactive material shipments as they traveled along their routes. It is anticipated that the distributors/manufacturers and commercial freight companies that transport radioactive material will desire this same information to reduce risk and potentially reduce insurance premiums. The general public is always desirous of safe roadways as well as the stringent regulation of radioactive materials and their safe shipments.

A more complicated reason arose from the Commercial Vehicle Enforcement Division of the Tennessee Highway Patrol (THP). The weigh station located near the Watt Road exit off I-40 in Knoxville, Tenn. had been equipped with radiological detectors. These detectors alarm whenever radioactive material shipments pass through the station. Trucks are then pulled over and examined in more detail. It was hoped that RFID tagging would allow near-instantaneous verification of the shipping manifest and thus, minimize the requirement and manpower necessary to pull these trucks over and inspect them.

1.4 TECHNOLOGY ASSESSMENT

The instruments and technologies used for the RadSTraM study were chosen based upon their being considered or utilizing the latest off-the-shelf advanced technology. As such, the components used were experimental in nature and with distinct advantages and limitations. These are outlined in detail in Section 2 of this document.

The first phase of the study involved ORNL conducting a technology assessment in association with the requirements for the EPA and DOE Radiological Source Tracking and Monitoring (RadSTraM) study. The assessment recommended two technology candidates. One candidate technology chosen can be described in a generic sense as follows: The system utilizes Gateway Controllers (GCs) placed within 300 feet of the assets being tracked or monitored. The GC communicates with devices called Remote Sensor Interfaces (RSIs), which are affixed to the assets, allowing location and asset condition to be determined. GCs can be mobile, allowing assets in transit to be monitored via a cellular or satellite connection. This system will be called SN in this report. The second off-the-shelf system was selected because of its operational deployment characteristics. This system currently tracks and locates 300 trucks/day on average at ports. This system will be called PT in the report.

2 PROJECT DESIGN

The experimental design for RadSTraM Study combines off-the-shelf technology into a system that meets criteria established for successfully implementing/testing the project requirements. Section 3 covers the demonstration plan as it relates to the real-world facilities used for the study (experiment).

2.1 BACKGROUND

ORNL is providing support to the EPA, Department of Homeland Security (DHS), and DOE in their goal of proving technologies associated with the detection and clearance of radiological materials in-transit. ORNL is also providing support to the Tennessee Department of Safety (TDOS), South Carolina State Transport Police (SCSTP), Mississippi Department of Transportation (MDOT), Washington State Police (WSP) and the Commonwealth of Kentucky Transportation Cabinet (KTC) in their goal of proving technologies associated with the enforcement of commercial vehicle state and federal laws associated with radiological materials and their transport. Bulk radiological monitoring systems have been installed at the TDOS's Knox County Weigh and Inspection Station (see Figure 1), SCSTP Dorchester County Weigh and Inspection Station, and KTC Laurel County Weigh and Inspection Station. Additionally, a mobile unit has been installed in a MDOT vehicle to study data collection procedures and operational procedure protocols during their daily commercial vehicle enforcement operations. WSP plans a more extensive mobile unit utilizing other sensor technologies including RFID capabilities. These initiatives are unique in that they will not be limited to instrument technology evaluation, but include all facets of real world deployment including secure communications, operational protocols, information technologies, cyber security, database development and technical reachback.

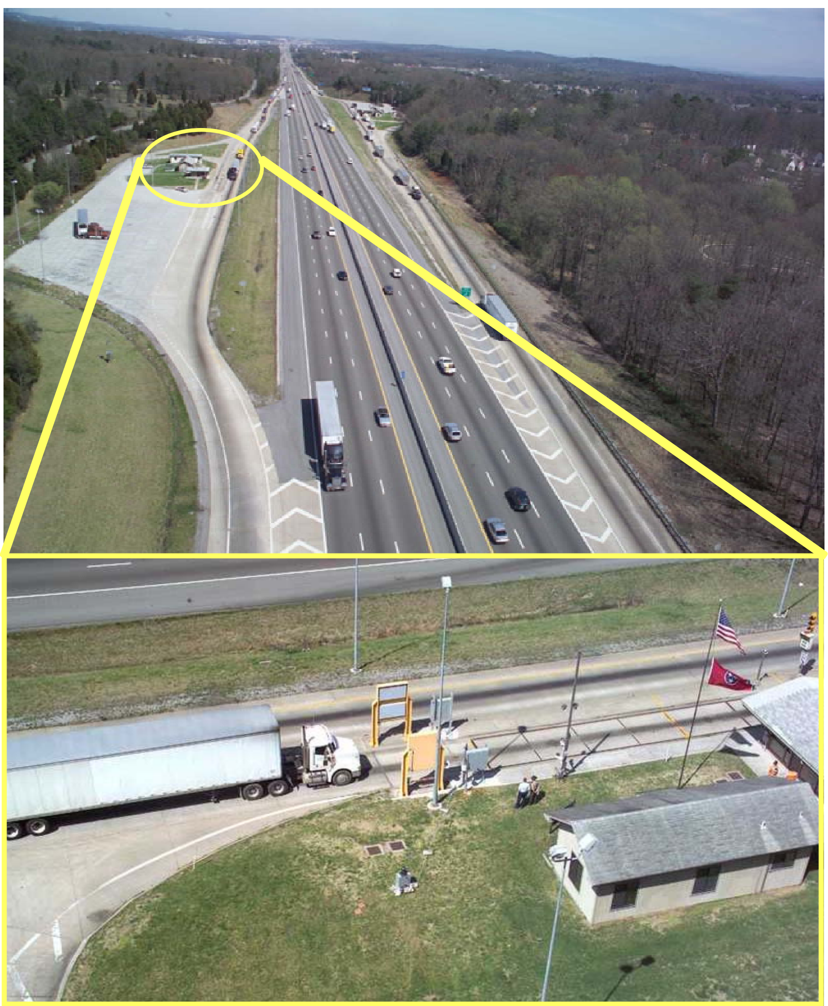

Figure 1. Aerial photographs of Weigh Station test area (reader placement).

The purpose of this EPA and DOE RadSTraM project is to investigate near real-time tracking technologies and their usefulness in tracking and monitoring radiological sources in commerce. This project will serve as a critical component for addressing procedures and protocols needed to establish the goals mentioned previously. Collaborations with the aforementioned State/Federal government agencies will prove invaluable as the RFID component is studied. It is envisioned that RFID will provide the capability to pre-clear vehicles, which might otherwise set off sensors that might cause further inspection of the vehicle. Additionally this same RFID capability would serve the primary need of EPA to reduce the number of orphan sources and identify radioactive materials throughout their life cycle in the supply chain.

To accomplish these goals RFID capabilities must be identified and tested that will be:

- Robust enough to handle at least a five year cycle in the radiological supply chain,
- Integrate with other initiatives conducted by DHS, DOT and the states,
- Powerful enough to be read at distances exceeding 100 meters up to highway speed, in various operational configurations,
- Standardized in a manner where the commercial stakeholders will accept them as value-added, and,
- Reliable enough so that EPA, DOT and DHS can modify policies and regulations to accept their use.

2.2 SITE/FACILITY CHARACTERISTICS

The Oak Ridge National Laboratory (ORNL) is currently prototype testing state-of-the-art sensor technologies associated with detection of radiological materials in-commerce. These technologies are deployed at an Evaluation User Facility at the Weigh and Inspection Station in Knoxville, Tenn. (I-40/I-75), and Dorchester County, S.C. (I-26, outside of Charleston) and are in use at the Watts Bar Lock in the Tennessee Valley Authority (TVA) inland waterways system. This real-world testing addresses radiological and nuclear material detection in commerce and is part of a larger program entitled Performance-Based 21st Century Commercial Vehicle Inspection System.

Tennessee hosts the initial IMRicS (Identification and Monitoring of Radiation (in commerce) Shipments) deployment, which provides unique best available detection capabilities under the auspices of state safety and law enforcement entities. This initiative serves state and federal security, safety, compliance and enforcement needs, and utilizes existing infrastructure. The weigh and inspection infrastructure and TVA's inland waterways lock system are a recognized and accepted infrastructure used by the commercial carrier industry. IMRicS supports decision analysis and is the transportation module of the SensorNet Data Framework (see Appendix B). Safety monitoring includes vehicle operators, vehicle/vessel and cargo addressing safety of shipments in transport, identification of unsafe vehicles/vessels and carriers, and monitoring of domestic and foreign commercial vehicles (NAFTA). Enforcement opportunities address cargo safety, tracking, transport safety regulations, and hazardous materials regulations. Homeland security applications address Radiological Dispersion Devices (RDDs) identification, Weapons of Mass Destruction (WMDs), identification of unsafe or illicit transport of hazardous materials including chemical and radiological materials, and screening shipments for illicit drugs.

Twelve million commercial vehicles pass the Tennessee I-40/I-75 Watt Road Weigh and Inspection Station of the Evaluation User Facility annually (Figure 1). All HAZMAT commercial vehicles are directed to Static Scales. All commercial vehicles are screened for overweight and over-dimension. Current commercial vehicle screening process utilizes:

- A commercial motor carrier pre-screening system utilized in Tennessee
- Weigh-in-Motion, or
- Static Scale.

The criteria for these tests included:

- Type A tested and RFID modified Type A packages. (The U.S. Department of Transportation 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 materials 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. Also see Appendix A for further references.)
- Type A quantities of strontium, cesium, cobalt and californium contained by the Type A packages.
- Ship radioactive material between ORNL and ORAU using commercial Less-than-Truckload (LTL) service, commercial and private truckload (TL) service[2].
- Packaging configured with SN technology provided by Northwest Nuclear, LLC.
- Testing configuration and SN Gateway Controllers (RFID tag interrogators and forward-station PCs containing the necessary software and data archiving capabilities) installed at ORNL, Knox County Weigh and Inspection Station, LTL Truck Terminal in Knoxville, Tenn. and Oak Ridge Associated Universities (ORAU) receiving dock.

[2] LTL service picks up multiple partial loads (any number of packages). Shipping rates for this service are charged on a per package basis. In this scenario the truck is loaded in a random fashion posing a "random" shielding effect. On this basis, our tests simulated worse than average case loading that could potentially attenuate RFID Tag broadcast signals.

3 RadSTraM RFID SYSTEM COMPONENTS

The design for RadSTraM study combines off-the-shelf technology into a system that meets criteria established for successfully implementing/testing of the project requirements. Section 2 covers the various components used for the study (experiment).

Task I consists of two subtasks: (1) system check out and data collection, (2) data logic, collection and reporting. The first subtask addressed: (1) personnel training and equipment familiarization, (2) equipment (checkout) readiness testing, (3) data collection strategy and (4) equipment parameterization (currently set by manufacturer). During this period, the vendor's standard data collection procedures are used to familiarize personnel with the equipment and document the operating conditions in a controlled laboratory environment. ORNL personnel also received training in systems operations and related procedures. In the second subtask of Task I, the process was refined and data collection trending/analysis were initiated to address statistical sampling related to quality, cataloging, trending, presentation format and methodology.

Task II aims to establish a baseline regimen for real world testing of RFID technology (by comparing both SN and PT) performed in five distinct interoperable steps. The steps are designed to simulate real-world shipping and transport scenarios. The following tasks identify the logical sequence to simulate selected in-transit radiological sources in a controlled testing environment:

- DOE controlled staged shipment
- DOE isotope selected supply chain controlled in-commerce shipment
- Private sector selected supply chain controlled in-commerce shipment
- In-commerce infrastructure (e.g., warehouse or port) selected environment
- Selected workplace (e.g., hospital or manufacturing) environment

3.1 SN RFID System Description

SN is an RFID technology which utilizes two unique components: 1) Class Based Asset Tracking (CBAT) algorithm and 2) utilization of Bluetooth®-based radio frequency (RF) standards.

3.1.1 Technology Development and Application

Bluetooth® is a relatively new wireless technology that provides wireless communications between computers and peripheral devices such as printers, fax machines, phones, etc. Because Bluetooth was not primarily designed for communications between users but only between devices, it is rather limited in its data throughput—only 1 Mbps versus other radios using 2.4 GHz (6 Mbps or greater).

The SN CBAT algorithm allows devices to completely turn themselves off and then re-establish themselves into the network. SN claims uniqueness in this area[3]. This feature enables the life of the battery to last from five years to ten years.

As shown in Figure 2, the Asset Commander System enables the wireless Remote Sensor Interface tags (RSI) to transmit their data to a Gateway Controller (GC). GCs are small personal computers that are designed for outdoor/rugged environments. The GCs keep track of the tags in their area and network with the central database. Gateways issue commands to tags to turn on/off and also reformulate the network after such an

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[3] A patent (**6,745,**027) has been granted for the CBAT architecture.

event. GCs are similar in nature to routers used in a TCP/IP network. The biggest difference is that a GC contains not only a TCP/IP port and Bluetooth® or Wi-Fi card but also may contain a cellular modem or a satellite phone.

3.1.2 Advantages and Limitations of Technology

SN claims the following advantages:

1. The ability to turn on/off individual tags.
2. A network using a patented flexible architecture that can re-form itself after each on/off event.
3. Better digital security because tags can be switched on/off to limit tag availability for hacking.

SN has the following limitations:

1. Each piece of the equipment is proprietary in nature. There was no open architecture and SN did not allow ORNL personnel access to the software to encrypt sensitive data.
2. It has a limited data throughput of 1Mbps and slow connection times associated with this.
3. Bluetooth® has a limited radio range.

3.1.3 Factors Affecting Cost and Performance

Factors that affect SN cost and performance include:

1. Area to be covered by the system;
2. Number of items to be tracked;
3. Number of obstructions. These obstructions could be the walls of a building or the number and type (e.g., all metal trailer shell) of tractor-trailers.

3.2 PT RFID System Description

PT is based on the popular IEEE 802.11xx architecture (so-called "Wi-Fi"), which is utilized worldwide.

3.2.1 Technology Development and Application

The backbone of the PT system is composed of tags that use a TCP/IP network. The IEEE 802.11xx ("Wi-Fi") is the name given to any radio that conforms to this IEEE standard. There are several varieties of these standards but the most common ones are 802.11b and 802.11g (802.11i includes additional security protocols). The Wi-Fi tags produced by the manufacturer of the PT system use the 802.11b standard that limits them to 11 Mbps throughput.

The PT system manufacturer has been producing an RFID location system utilizing their tags. However, in the last year, they have joined forces with a supplier of networking equipment in developing applications for asset tracking. This means that a router, once programmed with the PT system tracking software is capable of reading the PT system tag. The tags are only broadcasting at prescribed intervals. This has a positive effect on battery life, increasing the life of the battery up to ten years. For example, a tag operating on a broadcast interval of 10-seconds has a life of nearly two years while a tag operating at a one-minute broadcast interval will have a life of approximately eight years.

The PT system, therefore, uses a tag that is rapidly becoming the standard RFID tag in the market. Also, PT uses TCP/IP networking. TCP/IP is the backbone of the Internet, which, again, means that PT system can be deployed with very few infrastructure modifications.

Figure 2 shows the architecture of the PT system. Since it overlays on existing wireless network infrastructure, it is not as complex as SN. Essentially, a computer with specially designed software "listens" for the tags through the network router. This data is compiled into a database that can be accessed by an authorized user.

3.2.2 Advantages and Limitations of Technology

PT has the following advantages:

1. Relies on commercially available network infrastructure.
2. Utilizes a widely used communication protocol.
3. Results can be easily secured through encryption and user authorization.
4. Tags broadcast intermittently, which increases battery life and decreases probability of detection.

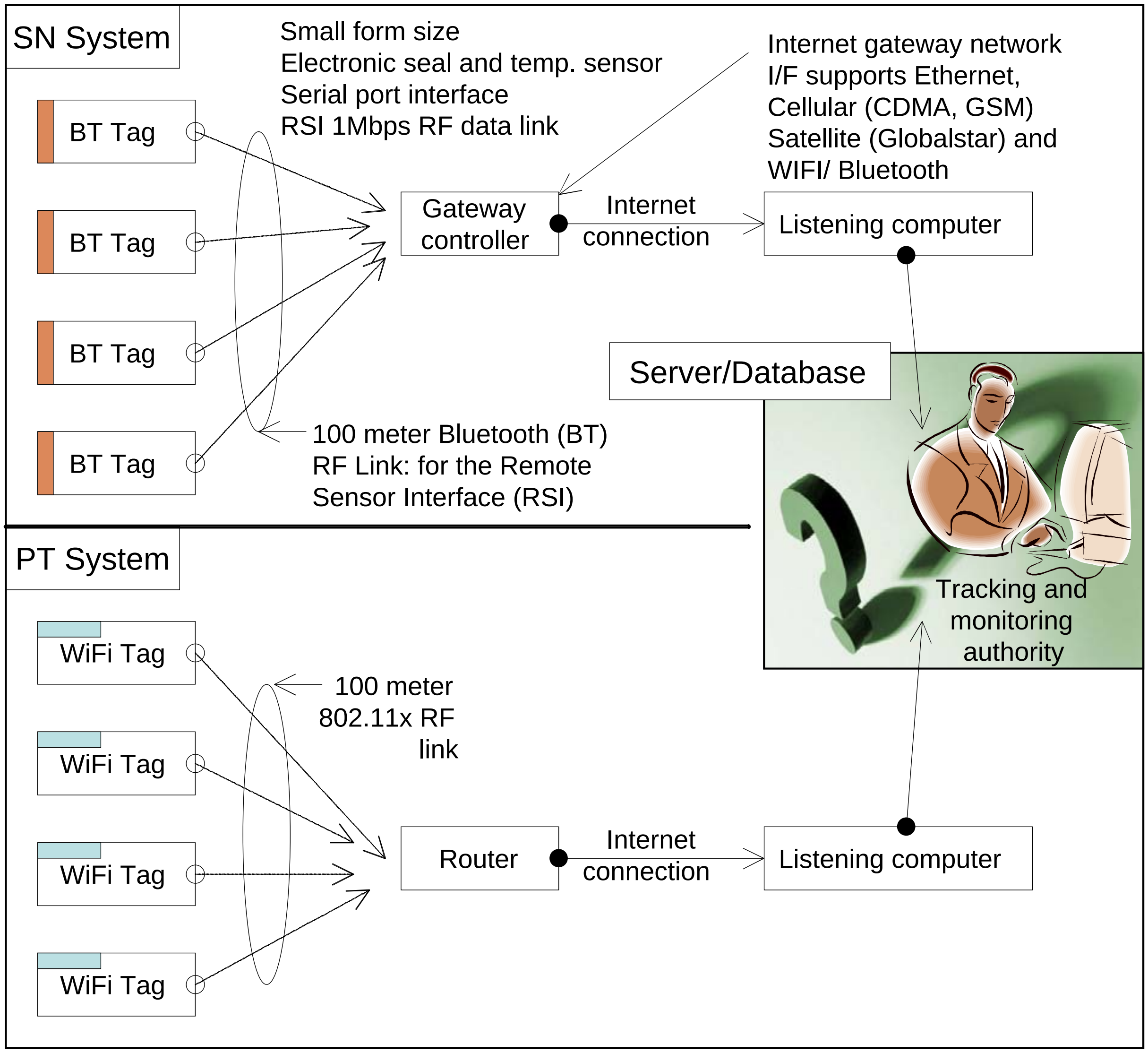

Figure 2. SN and PT Systems showing general architectural characteristics.

5. Software is nearly open source and can be modified quickly.
6. Listeners use high quality, proven Linux-based wireless access points.
7. Tags can be obtained from numerous manufacturers.
8. Tags are one of the smallest available.
9. Up to ten-year battery life, based on broadcast interval.
10. Millions of the Wi-Fi radios have been made and continue to be made (COTS).
11. Easily attachable due to the small size.

PT has the following limitations:

1. Tags broadcast at preset intervals. The package must be in range of the receiver for at least one tag interval.
2. Since it relies on existing network infrastructure, any disruption of the existing network by external sources will cause the system to fail remotely.

3.2.3 Factors Affecting Cost and Performance

Factors that affect PT cost and performance are:

1. area to be covered by the system;
2. number of items to be tracked;
3. number of obstructions. These obstructions could be the walls of a building or the number of tractor-trailers.

4 DEMONSTRATION AND TESTING

Case analysis is the process of evaluating packaging and portal characteristics to determine where to place an RFID tag to achieve optimum tag readability under real operating conditions (compliance requirements, implementation schedule, shipping flow rates, packaging/transport circumstances, etc.). In this section the various RadSTraM in commerce shipping constraints are discussed in the context of testing the feasibility of using an RFID system as a means to effectively reduce orphaned sources.

4.1 BACKGROUND

Questions of concern include: What are the most effective package tag/label and reader placement locations (options, tolerances)? What is the effective read rate and range? How well do these constraints fit with the typical shipping process? What training will be required for packaging, warehousing and distribution workers? What costs are involved with each label application method? What is the most effective antenna configuration and what characteristics of RF affect the read rate and reliability? The hard science of RFID must come to terms with the environment of shipping radiation sources. Most RFID adopters typically experience problems associated with the following issues: materials translucence and/or absorption, shielding, detuning of the tag antennas, reflection and interference when trying to achieve acceptable performance. RadSTraM was designed to illuminate such problems and identify workaround solutions.

Figure 3. Viking shipping container used during this demonstration.

4.2 PERFORMANCE OBJECTIVES

This demonstration had the following performance objectives:

- To demonstrate that the tracking of radioactive material shipments using RFID was possible.
- To quantify the reliability of these tracking systems with regards to probability of tag detection and operational reliability.
- To determine if the implementation of these systems improved manpower effectiveness.
- To demonstrate that RFID tracking of radioactive materials was ready for larger deployment to the national level.

4.3 PHYSICAL SETUP AND OPERATION

The first step in the design and implementation of an effective and deployable intelligent real time locating system (RTLS) is validation. Therefore, our test scenarios were designed to simulate the in commerce supply chain process for radioactive materials (Table 1). To this end, the RadSTraM Controlled Shipment Test Phase II was conducted to assess the technology in a real-world environment simulated to closely emulate the DOE Isotopes Shipping Program at ORNL. The criteria for these tests include:

- U.S. DOT Type A certification tested and RTLS modified package supplied by Viking (see Figure 3).
- Type A quantities of strontium-90, cesium-137, cobalt-60 and californium-252 packaged in the Type A containers.

- Ship radioactive material between ORNL and Oak Ridge Associated Universities (ORAU) using commercial Less-than-Truckload (LTL) service, commercial truckload service (TL) and private fleet (ORAU).
- Acquire packaging configured with RFID technology installed.
- Configuration and testing of Gateway Controllers (RTLS interrogators and forward-station PCs containing the necessary software and data archiving capabilities) installed at ORNL, TDOS Knox County Weigh and Inspection Station, LTL terminal in Knoxville, Tenn. and ORAU.
- Collect data and document results using the ORNL SensorNet backbone, (see Appendix B).
- Data analysis/ refinement to incorporate learned lessons. The RadSTraM project team conducted 20 test shipments of the radioactive materials and their packaging between July 2004–Sept. 2004 using a route that transports materials from Roane to Knox to Anderson County, Tenn. and return to Roane County. Testing included single and multiple shipments to test the ability to track the commodities in commerce, offsite overnight storage, in association with bulk radiological monitors at a weigh station, with an electronic seal, and three types of transportation services. Figure 4 shows the shipment routing. Two different routes were used. The first route used a LTL (Less than Truck Load) service, which ran over a two-three day duration (ORNL → Watt Road Weigh Station → LTL terminal [break bulk] → ORAU and return). The second route used a TL (Truck Load) service, which ran over a four-six hour duration (ORNL → Watt Road Weigh Station → ORAU and return). Table 1 gives the test methods and purpose.

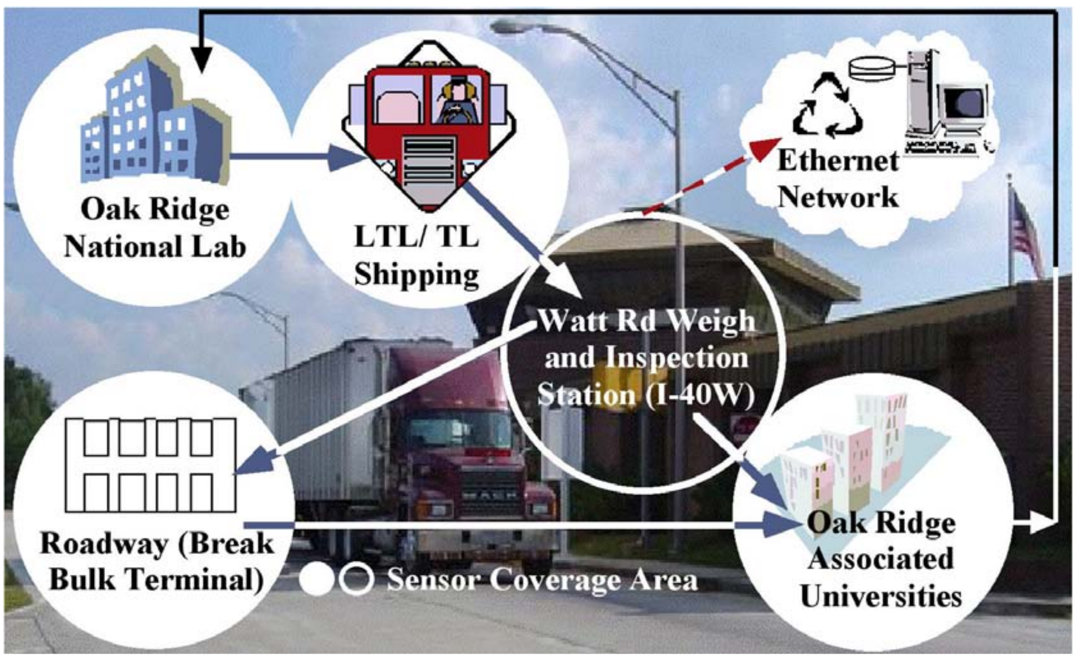

Figure 4. The shipping routes that were used by RadSTraM (proof-of-concept).

Table 1. Three different shipping methods were tested.

Tested Service	Test Purpose/Step
LTL	*Used to validate the performance of an integrated RTLS intelligent system by documenting the following steps:*
	Single isotope (Type A quantities) shipments under normal LTL operating conditions include varied environmental conditions, varied commodities on board vehicle, temporary staging in operating terminals with various commodities & normal transportation handling.
	The integrity of the interrogator system to interference from sources or operating conditions external to the interrogation system.
	The status of the interrogator system during the interrogation process.
	Susceptibility of the RSIs to radiological dose during shipping and warehousing operations.
Commercial TL	*Used to validate the performance of an integrated RTLS intelligent system by documenting the following steps:*
	Single and multiple isotope shipments under normal TL operating conditions including varied environmental conditions and normal TL operating conditions.
	The integrity of the interrogator system to interference from sources or operating conditions external to the interrogation system;
	The status of the interrogator system during the interrogation process.
	Susceptibility of the RSIs to radiological dose during shipping and warehousing operation.
Private Carriage	*Used to validate the performance of an integrated RTLS intelligent system by documenting the following steps:*
	Single and multiple isotope shipments were completed under normal private carriage service operating conditions including varied environmental conditions, temporary staging in shipping operations terminals and normal transportation handling.
	The integrity of the interrogator system to interference from sources or operating conditions external to the interrogation system;
	The status of the interrogator system during the interrogation process.
	Susceptibility of the RSIs to radiological dose during shipping and warehousing operations.

Table 2. Equipment used for the different shipping methods (services) tested.

Equipment Description
Five Gateway Controllers located at TDOS Knox County Weigh and Inspection Station (2), ORNL Building 7001, ORAU Shipping and Receiving and Roadway Express Knox County Terminal.
Five Type A Viking Packages modified and tested with RSIs, each integrated with embedded Bluetooth radio.
Cobalt-60, Cesium-137, Strontium-90 and Californium-252 Source in Type A quantities.
Roadway Express City Pickup and Delivery Equipment.
TAG Transport Incorporated over the road equipment.
ORAU city pickup and delivery equipment.
NucSafe PUMA equipped Bulk Monitor (Gamma and Neutron).
SAIC/Exploranium AT900 Bulk Monitor (Gamma and Neutron).
SensorNet software interface for data collection and storage.

The photographs in Figure 5 show the system installed at TDOS Knox County Weigh and Inspection Station. An exhaustive list of the equipment used for this prototype system is given in Table 2 and the general test procedure used is provided here.

Figure 5. Digital photos of typical truck loading configurations.

Test Procedure:

1. Package all sources in modified Viking Type A packages per ORNL/ DOE procedures.
2. Transport one of each source weekly over twelve weeks by a LTL service from ORNL to ORAU utilizing a route that takes the transport truck through the static scale lane at the TDOS Knox County Weigh and Inspection Station eastbound/ northbound side.
3. ORNL will take digital photo after loading.
4. Periodically packages were opened at ORNL breaking the electronic seal. When the package was next interrogated by the Gateway Controller located at ORNL Shipping and Receiving, the number of times the seal was broken was recorded and archived in the forward-station PC's database.
5. A photo of the shipment is made at ORAU before unloading.
6. Fill out data forms and take digital photo after loading truck at shipping point and before unloading truck at

Figure 6. RFID tracking/ radiation portal monitor systems at Knox County weigh station.

receiving point and attach copy to shipping paper.
7. File hard copy of data forms and photos along with time stamp.
8. Download gateway (listener) data from the five forward-station PCs weekly to the SensorNet database and correlate with data forms and photos collected at ORNL and ORAU.
9. Maintain isotope sources at ORNL Building 7001 when not in shipping process as well as daily radioactive Shipping Vault Log Sheets while materials are present in the ORNL vault.

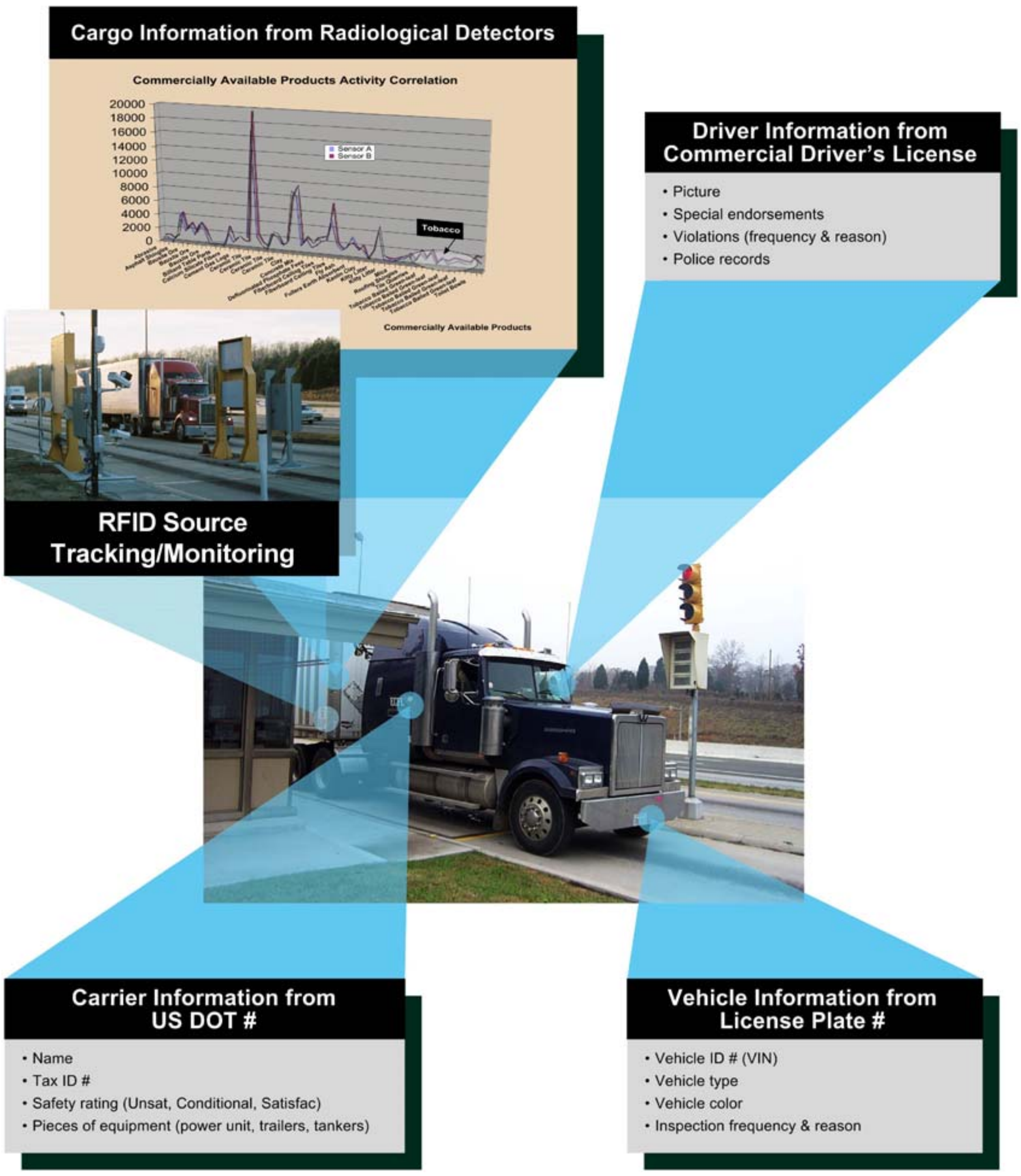

Figure 7. Watt Road weigh station provides ancillary tracking/monitoring capabilities.

5 PERFORMANCE ASSESSMENT

This section describes how the data was analyzed in relation to technologies and facilities that were utilized.

5.1 DATA

The data collected during this demonstration presented some problems for post analysis. Firstly, the shipping information, while initially very detailed, became increasingly vague and had substantial changes in nomenclature as the demonstration continued. While no regulations or requirements were transgressed, it made the task of post-analysis more difficult.

Secondly, due to the manner of the demonstration, the only verifiable positions of the RFID tags at any time were indicated by the data generated at the Watt Road weigh station. There was insufficient information as to when the RFID tags physically left ORNL or ORAU. At the LTL shipping terminal, it was known a priori that certain parking positions were not accessible by the tag listening systems.

The NucSafe radiation detection system at Watt Road gave an independent verification of the presence of the tagged shipments. The NucSafe system verified that radiation was present as well as the shipment number.

5.1.1 Correlating Shipping Data to Tag Data

In Table 3, we show how the RFID tags were assigned to a particular source. Each radioactive source had a unique serial number.

Table 3. Radioisotopes with their activities, serial numbers, and the assigned RFID tags.

Isotope	Activity (GB)	ORNL Serial Number	PT	SN
Cesium 137	0.274	45	PT-229	SN-3414
Strontium 90	1.37	46	PT-228	SN-349E
Californium 252	1.74	47	PT-226	SN-345B
Cobalt 60	0.141	48	PT-223	SN-345D

5.1.2 Raw Tag Data

For completeness, the data collected by tag listeners for both PT and SN are provided in Tables 4-7.

5.2 DATA ASSESSMENT

As explained in the previous section, the only independent monitor of a shipment's position was the NucSafe radiation detection system, located at Watt Road weigh station.

While there were 24 shipments, only 18 of these appeared at the Watt Road weigh station and were observed and recorded by the NucSafe system. The tag listener logs were examined to determine whether or not PT and/or SN detected the tags.

A one-point score was assigned if a given listener saw the tag and a score of zero was assigned if the listener did not see the tag. The sum of the scores was calculated and the ratio of the sum of the scores to the number of shipments (18) was then determined. We refer to this ratio as the probability of detection and we are using this as a figure of merit to evaluate the systems. Table 8 shows the results of this analysis

Table 4. Data Collected by tag listeners at the Watt Road weigh station.

Shipment Date	S/N	PT	SN	Comments
9/22/2004	47	1	1	
9/22/2004	45	1	1	
9/29/2004	48	1	1	
9/29/2004	46	1	1	
10/6/2004	45	1	1	
10/6/2004	46	1	1	Shipping data seems incorrect
10/12/2004	48	0	0	
10/13/2004	46	0	0	
10/20/2004	47	1	0	
10/20/2004	48	1	0	
10/20/2004	46	1	0	
10/20/2004	45	1	0	
11/3/2004	47	0	1	
11/3/2004	46	0	1	Shipping data seems incorrect
11/10/2004	47	1	0	
11/10/2004	46	1	0	
11/9/2004	48	1	0	
11/9/2004	45	1	0	
Total Tags Seen		14	8	
Probability of Detection		77.78%	44.44%	

The most glaring data gap occurs during the shipment dates of October 12 and October 13, 2004. During this week, personnel monitoring the demonstration found both systems off-line. It is suspected that a power failure at the weigh station incapacitated both systems.

The other large data gap is the fact that out of 24 shipments, only 18 of them can be verified by an independent system (i.e., the NucSafe detectors). Future data logging, either by manual or automatic means, would be able to increase the statistical population. Also, utilization of data at all four waypoints would have significantly increased the statistical population.

The RadSTraM forms were filled out incorrectly or incompletely towards the end of the demonstration. While this made the analysis of the data frustrating, there was some redundancy in the system to overcome this limitation. However, future testing must include some method of either generating the data automatically or more rigorous record keeping must be performed. Indeed, large scale future testing must have a better methodology for record keeping.

6 COST ASSESSMENT

This section is provided as a cost assessment and is meant to establish a baseline set of parameters for which to make future comparisons and trade-off analysis for asset ownership performance expectation.

6.1 COST REPORTING

Table 9 shows the unit prices for components of SN and PT.

Table 5. Unit prices for SN and PT

	Unit Price	
Description	**SN**	**PT**
Gateway Controller/Tag Listener	$ 2,907.50	$ 3,400.00
Remote Sensor Interface/Wi-Fi Tag	$ 265.00	$ 85.00
Asset Tracking Software	$ 15,000.00	$ 5,500.00
Software Customization	$ 20,000.00	N/A
Optical Sensor and Reflector	$ 101.25	N/A
Installation Support	$ 5,000.00	$ 4,800.00
Installation Support for Remote Sensor	$ 1,500.00	N/A
TOTAL	**$ 44,773.75**	**$ 13,785.00**

6.2 COST ANALYSIS

This analysis section discusses, in turn, each of the features and quality factors from Table 9.

6.2.1 RFID Tags

While the SN RFID tags were proven under certain conditions to be turned on/off, it is difficult to justify their much higher price. This is further compounded by the fact that after the demonstration, PT announced that they had developed an “on/off” system for their tags.

6.2.2 Gateway Controller (SN) /Tag Listener (PT)

The unit cost of these two devices was nearly identical. However, SN required two Gateway Controllers to cover the weigh station compared to the single Tag Listener unit used by PT. As a result, the SN Gateway Controller cost $2415 more than the PT Tag Listener.

6.2.3 Asset Tracking Software

It is unclear at the time of this writing whether the $20,000 in software modification of SN will be required in other weigh stations or if it is one-time surcharge. However, even without this surcharge, the price of the asset tracking software license from SN is nearly three times larger than the software license from PT.

6.2.4 Installation Costs

PT and SN have nearly identical installation costs. To both systems credit, they have minimal impact on the infrastructure of the weigh station.

SN requires an external sensor to tell the Gateway Controller that the truck is in appropriate position for activation. While the optical sensor and its installation are minimal, there is a large fee associated with "installation support." PT did not charge a similar fee.

7 NATIONWIDE TECHNOLOGY IMPLEMENTATION

7.1 EPA NEEDS/GOALS

The EPA needs a system to track radiological shipments at various waypoints that:

- is minimally invasive to the shippers, shipping companies and the recipients. By "minimally invasive", we mean:
  - low installation cost
  - low cost
  - low maintenance
  - little or no schedule impact to the supply chain process
- does not slow down commerce.

Based on the results of this demonstration, the system should have the following features:

- automated tag listening devices that are easily connected to the Internet (TCP/IP-compatible).
- RFID tags which have long battery lives
- inexpensive RFID tags
- tags which conceal their presence in one of two ways:
  - turning themselves on/off
  - transmitting very infrequently

While the above represents the hardware requirements ("the nuts and bolts"), there must be an overall surveillance network. By network, we mean a set of software that can:

- maintain a database with tags in transit, point of origin, destination and waypoints passed along with manifest information such as cargo, shipper, recipient and shipping agent information.
- provide an output that provides plots of tag vectors displayed on a map. The vectors include:
  - planned route
  - route to-date (using waypoint information)
  - estimated time of arrival at next waypoint or final destination
  - intercept vectors from various emergency agencies, including ETA to current shipment position.
- sort through the manifest and filter for various manifest types. For example, the map should be capable of showing only the cesium shipments or the volatile organic liquids.
- produce alarms on conditions such as missed waypoints, overdue or off-course shipments.
- transmit alarms via all available networks to the (current) responsible personnel.
- possibly include such advanced features as bad weather/road conditions avoidance.

7.2 TRANSITION TO PHASE II TESTING

The nationwide system proposed in section 7.1 is very ambitious. It will take time to convince stakeholders to participate in such a scheme. Also, it will take both funding and time to design a system that satisfies the various desires (and budgets) of the stakeholders and end users. To this end, we suggest a phased approach in which the next project phase is a pilot scale project involving a commercial carrier and a commercial radioisotope company. Furthermore, in the phase II testing, the following objectives should be demonstrated:

1. Standardized procedures and practices with regards to shipping manifest
2. Install tag listening devices at a commercial carrier depot(s) and along designated shipping routes. Listeners would be posted at locations in addition to truck weigh stations (e.g., bridges and overpasses). Suggested routes include Boston to Atlanta along U.S. interstates as well as Oak Ridge (ORNL) to Lexington passing through several truck weigh stations en route.
3. Automate tag listening capabilities into a central database (e.g., ORNL' SensorNet).
4. Increase the number of tagged containers involved in the test.

A shipping company has already been approached and has expressed a keen interest in participating in the pilot project. A commercial radioisotope company needs to be approached to obtain commitment to phase II testing.

7.3 LABORATORY RADIATION TESTING OF RFID TAGS (optional)

One possible scenario would test ten tags: five different manufacturer's one/two passive tag types and three/four active tag types (e.g., Symbol, Intermec, Motorola, Phillips, Printronics, GE, etc.). The testing of tags should consider these questions:

(1) What parameters will be measured at the beginning, during and at the end of the testing (i.e., what is the test procedure)?

(2) Will these be qualitative/quantitative/functional/non-functional tests? Identify the parameters being tested in each of those categories.

(3) After subjecting the tags to an effective one, five and ten year dosage, what will be measured (besides radiation and shielding)? Part of this answer comes from item 2 above.

(4) Will there be visual coarse grain inspection or fine grain (e.g., light/electron microscopy) inspection? There should be some physical descriptive characterization.

(5) What comparisons will be made? And,

(6) How will tag testing be evaluated? One possible way to evaluate using in-vitro laboratory testing would use the DOT Type A specification and limit the tests to less than 200mR/hr (Type A Limit). Thus, a ten year model would require an effective dose rate of 200 mR/hr x 24 /hr/day x 365 days/yr x 10 yrs or 17,520R. It would be necessary to decide the mix of gamma and neutron to make the testing more affordable (i.e., gamma only, neutron only and a mix) instead of doing three different tests. For every tag we test, we will need a control tag.

8 SUMMARY, LESSONS LEARNED, AND CONCLUSIONS

This section contains summary conclusions and lessons learned for the first phase of the RadSTraM study.

8.1 SUMMARY

This demonstration tracked a series of 28 shipments originating from Oak Ridge National Laboratory to Oak Ridge Associated Universities that were then shipped back to the point of origin. One of the focus areas was to evaluate RFID tracking systems. Two systems, PT and SN were evaluated. RFID tags from both systems were placed on four Type A containers that held the following isotopes: Cesium-137, Cobalt-60, Strontium-90, and Californium-252. Tag listeners were set up at four waypoints: ORNL, ORAU, the Watt Road weigh station, and at a commercial freight company terminal.

In this report, we evaluated the data at the Watt Road weigh station because this location incorporated an independent device available to verify the presence of the shipment. A figure of merit called the "probability of detection" was calculated for both systems. This is the ratio of the number of times that a tag was seen versus the number of times it was known to be present there.

PT had a probability of detection of 77% while SN probability of detection of 44%.

A cost analysis of the two systems was also performed. The unit costs of the SN system was, at a minimum, twice that of PT. For this demonstration, there were other costs that placed the SN system nearly four times that of the PT system.

A description of a nationwide system was developed as part of this demonstration. The systems tested in this demonstration would qualify for use in a nation-wide system.

8.2 LESSONS LEARNED

Procedural Lessons:

1. A standard form should be designed that includes all relevant information.
2. More attention should be given to completing forms in their entirety.
3. Shipments should be verified as going through each station.
4. Preferably, data should be handled in electronic form to reduce human error.
5. System computers should have an uninterruptible power supply and software should be designed to automatically run whenever the system reboots.
6. Copies of all data should be sent to a single place for storage and correlation.

Technical Lessons:

1. Tags utilizing the 802.11xx protocol can be detected by external tag listening devices even when inserted into a Type A shipping container that is located in metal tractor-trailer with the doors closed.
2. Tags utilizing the 802.11xx protocol can be detected by external tag listening devices even at highway speeds in the opposite lane of the interstate.
3. PT RFID tags' operation was unaffected by close proximity to a 1.74 GBq (47 mCi) neutron source (^{252}Cf).

8.3 CONCLUSIONS

The following conclusions can be drawn from this project:

- We have verified that active RFID tagging can be applied to the tracking of interstate shipments of radioactive material.
- We have demonstrated that these types of 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.
- We have determined that there are deficiencies in our approach to data logging and there is strong suggestion of the automatic generation of forms. Because DOT requires certain information about the shipment be given to the shipper, such deficiencies could be addressed during the pickup transaction by requiring the shipper to routinely record/generate the (potentially) missing data.
- While neither system detected tags one hundred percent of the time, the PT system was demonstrably superior at detecting tags than its SN counterpart. However, in fairness to SN, its tags were only active after being queried by the Gateway Controller whereas PT tags were broadcasting every 10 to 30 seconds. The requirement for the GC to awaken the tag and then detect it may have also contributed to a lower probability of detection.
- A cost analysis of PT versus SN demonstrated that PT was more cost-effective than its counterpart. Thus, in a cost-benefit analysis of the two systems wherein both cost and performance are considered there can be little doubt that, unless SN re-structures its pricing, the PT outperforms its counterpart by a significant margin. Again, we must note that SN claims to be a more secure device based on the fact that it performs tag turn on/off but we did not perform any test to confirm or deny this claim.
- With a sufficiently large number of tags, the tag listener may be overwhelmed with data, particularly if the interval between broadcasts is short. Thus, the soundness of turning the tags on and off for this reason cannot be denied. A possible question to be answered in Phase II is the maximum number of tags which can be placed in a location before the tag listener is saturated with data and can no longer accurately track all of the tags.
- At a more elemental level, both PT and SN are similar technologies that utilize different radio standards. Both systems suffered failures during the week of October 12, 2004. This is due to the fact neither was placed on an uninterruptible power supply. Future designs of the systems must account for this type of problem.
- The probability of tag detection by the PT system was nearly double that of the SN system. Two possible scenarios are offered to explain the difference. First, the tags may have failed to wake up properly (i.e., the tag did not detect the wake up signal). Second, the listener did not hear the signal transmitted by the awakened tag due to signal attenuation (e.g., mitigated by distance and/or shielding).
- One plausible reason that the PT system had a higher probability of detection is that the tags broadcast intermittently with some pre-determined interval (i.e., every 10 seconds) between broadcasts. Further, the broadcast power allowed under IEEE 802.11 allows for greater range compared to Bluetooth. For example, PT tags were detected during the PT system set-up testing when carried in passenger cars driven past the listeners (on the far side of the freeway, in the westbound lane of I-40) at highway speed. This scenario demonstrates several "high-efficiency" possibilities for deploying a tracking system covering a much larger area than the one where shippers must pull off the main freeway into a weigh station to comply with technology limitations.

9 REFERENCES

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ORNL, "QUALITY ASSURANCE PROJECT PLAN EPA and DOE Radiological Source Tracking and Monitoring (RadSTraM), Revision 2, September 28, 2004.

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APPENDIX A. PACKAGING AND WEIGH STATION RFID SPECIFICATIONS

Packaging: The category of industrial package required for transport of a radiological material is related to the potential radiological hazard of the material. Type A packaging refers to DOT-7A packaging qualifications stipulated in the 65 pages of the HNF-SD-TP-TI-006, Rev. 1 regulations. Type A packaging requirements are identified in Title 49 of the Code of Federal Regulations (49 CFR) 173.415(a) which state, "Each offeror of a Specification 7A package must maintain on file for at least one year after the latest shipment, and shall provide to DOT on request, complete documentation of tests and an engineering evaluation or comparative data showing that the construction methods, packaging design, and materials of construction comply with that specification." Requirements for hazardous materials shippers are established in 49 CFR 173.22. Those requirements direct a shipper to offer radioactive material for transportation in a packaging meeting the requirements identified in 49 CFR 173, Subpart I. The package must be prepared for shipment by classing and describing the hazardous material in accordance with 49 CFR 172 and 173. In addition, the shipper must determine that the packaging is an authorized packaging per the applicable requirements identified in 49 CFR 173 and must ensure that the package has been manufactured, assembled, and marked in accordance with the applicable requirements identified within 49 CFR 173, 178, and 179. Moreover, the material being shipped must be properly characterized and is limited by quantity in accordance with Type A packaging limitations. Viking supplied the packages used in this project. The packaging was modified and tested with both *SN (http://www.seekernetinc.com/home.html)* tags (so-called Remote Sensor Interface (RSIs)) and PT tags. See DOE-HDBK-1122-99 for more details[4].

Weigh Station RFID Specifications
Tags
Up to 10 year battery life
Have range up to ¼ mile

PHYSICAL AND MECHANICAL
Standard dimensions: 66mm x 66mm x 28mm
Weight: 85g (3oz)
Mounting options include adhesive tape or Velcro and a mounting kit for mounting with screws or straps

RADIO
Transmission power: up to +17dBm, 50mW
"Smart" transmission feature avoids interference with wireless networks

PROGRAMMABILITY
Transmission interval programmable between 1 second and 3.5 hours
Transmit mode, channel and power level programmable on-site

ENVIRONMENTAL SPECIFICATIONS

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[4] In general, content posing greater radiological risk must be transported in a more durable package. In 1995, DOT published a final rule which added a new "Industrial Packaging" (IP) category of packaging to the Hazardous Materials Regulations. Three categories of IPs were established (IP-1, IP-2, and IP-3) for use in certain shipments of low specific activity (LSA) materials. An IP-1 package must meet the general design requirements now specified in 49 CFR 173 Subparts A and B and in 49 CFR 173.410. Except for this specific requirement, IP-1 packaging is essentially equivalent to the "strong tight packaging" formerly approved in 49 CFR for LSA materials. Strong tight packaging has no performance specifications. Its only requirement is to meet the general design requirements in 40 CFR 173.410 and 173.24. NOTE: Strong tight packaging is still authorized by 49 CFR 173.427 for exclusive-use shipments of certain LSA materials. The IP designated is used for containment of waste material and typically poses a lower risk (hazard) than material shipped according to the Type A packaging requirements. However, the reader is cautioned to consult the CFR for specific requirements and regulations.

Temperature: -30°C to +65°C (-22°F to 149°F)
Humidity: 0 to 95%, non-condensing
Housing is water and dust resistant and includes a rubber lining

ELECTRICAL (Standard)
3.6V Lithium AA battery (replaceable)
Typical battery life: up to 5 years (dependent on transmission rate)

COMPLIANCE
Fully compliant with Wi-Fi (IEEE 802.11b/g)

CERTIFICATION
Radio: FCC Part 15 class B, ETSI 300-328
Safety: UL60950, CE certified

RFID Reader

SECURITY
Location Receivers do not accept any Wi-Fi client associations, so they need not be placed on secure Ethernet ports and pose no security risks. In addition, together with appropriate security software, Location Receivers may be used as wireless intrusion-detection devices to detect and locate unauthorized use of access points and/or client devices. Can be placed on a secure Ethernet and pose no security risk.

LOCATION
Typical outdoor range: 200m
Typical indoor range: 60m
Over 10 measurements processed per second
Patent-pending signal-processing algorithms
Supports standard Wi-Fi (802.11b/g) clients and AeroScout Tags

PHYSICAL AND MECHANICAL
Dimensions: 254mm x 254mm x 80mm
Must add for local storage

RADIO
2.4GHz direct sequence spread spectrum radio
Supports all worldwide Wi-Fi channels (1-14)
Detachable antenna

INTERFACES
Ethernet: 10/100 base-T Ethernet (RJ-45)
External antenna: Antenna connector to enable customized area coverage and system topology
Compatible with standard wireless bridges to enable wireless backhaul

MANAGEMENT
Static IP support and DHCP could be supported under certain conditions.

ENVIRONMENTAL SPECIFICATIONS
Temperature: -20°C to +50°C (-4°F to 122°F); Humidity: 0 to 95%, non-condensing
Optional NEMA housing available for outdoor and rugged environments

POWER SUPPLY
Wall unit: auto-sensing 100/240 VAC
Power-over-Ethernet: 802.3af compliant

COMPLIANCE
Wi-Fi (IEEE 802.11b)
IEEE 802.3u
CERTIFICATION
UL60950/CE
Radio: FCC Part 15 B&C, ETSI ETS 300 328 & ETS 300 826, CISPR 22, Class B

WARRANTY
One year limited warranty

APPENDIX B. SENSORNET

SensorNet is a framework to tie together sensor data from all over the country to create a real-time detection, alert and tracking system for various threats, whether they are chemical, radiological, biological, nuclear, or explosive.

SensorNet is a vendor-neutral interoperability framework for Web-based discovery, access, control, integration, analysis, and visualization of online sensors, sensor-derived data repositories, and sensor-related processing capabilities. In other words, SensorNet attempts to create a wide-area system to collect and analyze data from sensors all over the country to monitor and detect threats, and then alert agencies, emergency responders, and others as necessary. It is being designed and developed by the Computational Sciences and Engineering Division at the Oak Ridge National Laboratory (ORNL), in collaboration with the National Oceanic and Atmospheric Administration (NOAA), the Open Geospatial Consortium (OGC), the National Institute for Standards and Technology (NIST), the Department of Defense, and numerous universities and private-sector partners. The purpose of SensorNet is to provide building blocks for a comprehensive nationwide system for real-time detection, identification, and assessment of chemical, biological, radiological, nuclear, and explosive hazards.

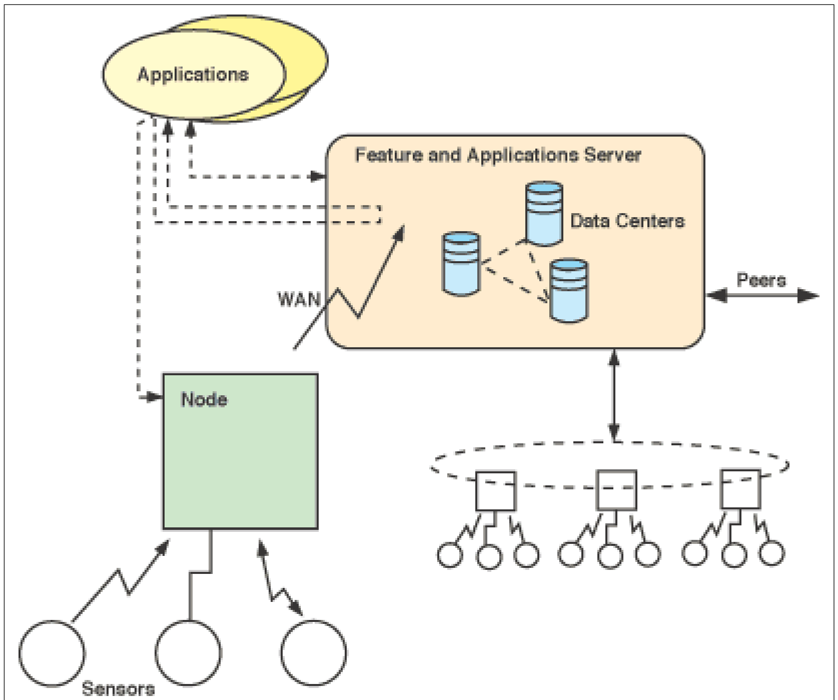

Figure 8. SensorNet node-related architecture components showing how nodes act as gateways to sensors. Data are stored in similarly configured servers to enable information sharing.

The SensorNet team is developing prototypes to network a variety of sensors for strategic test beds at military installations, traffic control points, and truck weighing stations. The sensor networks are connected by secure and redundant communication channels to local, regional, and national operations centers.

From a national security perspective, SensorNet addresses the problem of isolated, custom-designed, single-application sensor networks, incompatible sensor standards, lack of real-time availability of data, and lack of common and consistent schemas for sensor description, control, and data.

In developing an open standards framework for interoperable sensor networks, there needs to be a universal way to connect two basic interface types-transducer interfaces and application interfaces. Operational specifications for sensor interfaces generally mirror hardware constraints, while specifications for service interfaces are closer to application requirements. The sensor interfaces and application services need to work together and thus may need to be bridged at any of the various locations in the deployment hierarchy.

For the transducer interfaces, SensorNet adopts the methodology advocated by the IEEE 1451 working groups that are developing plug-and-play standards for smart transducers. A transducer is "smart" when it includes sufficient descriptive information to allow control software to automatically determine the transducer's operating parameters, decode its electronic data sheet, and issue commands to read and actuate the transducer. The IEEE 1451 standard data sheet encoding scheme is critical. In the past, when each transducer had a separate and nonstandard data sheet, it was necessary to write custom software to talk to each transducer.

For application interfaces, SensorNet builds on Web services. Although control granularity and latency constraints preclude the use of Web services for some end-to-end control tasks, SensorNet uses them for most interactions including user-directed control. Web-resident service directories and data dictionaries provide consistent terminology so application services can work together.

The Geospatial Component

For a system such as this, it is important to know the location of every sensor and measurement, so geospatial standards are an integral part of the interoperability framework. The SensorNet team has adopted service specifications developed by the OGC because OGC's sensor interface standards approach is compatible with ORNL's service-oriented national architecture. In 2004 ORNL joined the OGC to support its Sensor Web Enablement (SWE) interoperability standards effort to ensure that SWE standards align with SensorNet requirements. SWE envisions Web-accessible sensors with discoverable sensors and sensor data; sensors will be self-describing to humans and software (using a standard encoding), and most sensor observations will be easily accessible in a timely fashion over the Web. The SWE framework involves several OGC encoding and service specifications designed for general geospatial uses as well as schema and service specifications that are specifically sensor related.

For example, OGC's SensorML describes models and schema for describing sensor characteristics, and OGC's Observations & Measurements (O&M) provides models and schema for encoding sensor observations. The Sensor Observation Service specifies access to sensor information encoded in SensorML and sensor observations encoded in O&M, while Sensor Planning Service specifies a service to task sensors or sensor systems. (None of these standards has yet been completed or adopted by the OGC membership.)

ORNL is serving as the catalyst for bridging the SensorML and IEEE P1451 standards, as well as helping develop an OGC Sensor Alert Service through the use of existing standards, particularly the OASIS Common Alerting Protocol (CAP).

The SensorNet Node

SensorNet developers placed the implementation middleware for bridging and interoperability in the SensorNet node to ensure localized sensor control while at the same time providing remote users and applications access to lower-frequency application-level messages.

Since it often doesn't make sense to connect a transducer directly to the Internet, the SensorNet node addresses the common situation where a computer must manage those higher-layer services that provide remote access to a locality's sensors and actuators; this situation can be due to cost, size, legacy proprietary interfaces, or real-time latency constraints. The node provides the last-mile intelligence functions (e.g., control, cache, management) needed in a wide-area sensor network. The ORNL team prototyped the node using commercially available products. Figure 1 shows how nodes fit into the SensorNet architecture.

APPENDIX C. PROJECT PARTICIPANTS

The key personnel responsible for the implementation of this program are listed below:

- Deborah Kopsick, EPA Project Lead
- ORNL:
    - Randy M. Walker and Robert K. Abercrombie, ORNL Project Leads
    - David E. Hill, Engineering Technician
    - Frederick T. Sheldon, Project Analyst
- DOE Isotopes Program:
    - R. L. Cline, Isotope Specialist
- Oak Ridge Associated Universities (ORAU):
    - Randy Dillon, Project Shipping Receiver
- Northwest Nuclear, LLC (NWN):
    - Jon Paschal, Senior Applications Engineer, designed the PT system, oversaw installation and software control
    - Dudley Pinson, President of NWN, Senior Wireless Development Engineer, designed the PT system and conducted troubleshooting efforts.
    - Frederick J. Schultz, Vice President, NWN Project Lead

APPENDIX D. GENERAL RFID SYSTEM OVERVIEW

Let's consider the market place. A typical RFID system consists of four main components: tags, an encoder, readers and a host computer (not including the Internet). The last three components can be configured as independent units or combined in one total package (portable or fixed). The RFID tag is made up of a microchip and a flexible antenna encased in a plastic-coated inlay (or wrapper). The encoder is used to write information to the tag. In coming years expect to find RFID tags built into products and product packaging. The most common format is a shipping label with a built-in tag, or smart label. Smart labels can be printed and placed on any unit to be tracked. Tags for supply chain use come in a few basic types. One distinguishing characteristic is whether a tag is active or passive. Active RFID tags broadcast under their own power. An on-board battery runs the tag's microchip circuitry and transmitter. Active tags are capable of receiving and transmitting signals the distance of 100 yards. They are well suited to applications where they can be permanently mounted and maintained such as on trucks, railroad cars or shipping containers (possibly sea borne), and on high-value military items stored in outdoor supply depots or bases (to give a few examples). Passive tags, in contrast, have no battery and draw their power from the reader (or listener). Electromagnetic waves transmitted from the reader induce a current in the tag's antenna. The tag uses that energy to talk back to the reader (i.e., known as backscatter reflection). The phenomenon is similar to radar. Whereas radar backscatter is more like an echo, the tiny circuit in an RFID tag can power itself with the induced current, and its backscatter is an amplitude modulated (AM) response (i.e., the AM signal can be interpreted as a digital signal of ones and zeros). When these tags are not in the presence of a reader signal directed at them, passive tags are just that: passive –not capable of any radio signal by themselves. They do not add unnecessary electromagnetic noise to the surroundings. Another type of tag is the so-called semi-passive tag. It has many of the characteristics of a passive tag (small, lightweight, limited memory), but with a battery backup to extend the answer range. Semi-passive tags are becoming more popular for parts kitting and just in time manufacturing applications.

The distance within which a reader can communicate with a tag is called the read range. Communications between readers and tags are governed by protocols and emerging standards, such as the EPC UHF Class 1 standard for supply chain applications. The properties of radio waves are frequency dependent. At low frequencies, radio waves pass through obstacles well, but the power falls off sharply with distance from the source. At high frequencies, radio waves tend to travel in straight lines and bounce off obstacles. They diffract at corners, sharp edges, and openings. They are also subject to interference from a variety of sources, from sunspots to other electrical equipment. Radio communications have uses in all sorts of applications, but only if interference between users can be kept at a minimum. For this reason, governments tightly license users of radio transmitters, with the exception of the industrial, scientific and medical (ISM) bands. Transmitters using these bands do not require government licensing. One band is allocated worldwide: 2.400-2.484 GHz. In addition, in the USA and Canada, bands also exist at 866-956 MHz and 5.725-5.850 GHz. These bands are used for cordless telephones, garage door openers, wireless hi-fi speakers, security gates, etc.

Adopters of RFID systems must protect their investments during implementation by seeking out upgradeable devices that will retain their usefulness through the lab, pilot and production phases of an implementation. Devices that are engineered for rugged use in a production environment from suppliers with a proven industry experience and a commitment to helping bootstrap their customer base will certainly be the most desirable. This is especially important as compliance requirements shift to the UHF Gen 2 standard in 2005. Device vendors should provide (software) migration tools that support the conversion of the current state of practice over to the use of RFID systems. Furthermore, as the single biggest cost item, users need flexibility in sourcing tags (labels). Vendors who offer tag/label compliance and certification services, and professional service teams who will help users to achieve compliance are the most desirable. Vendor teams who have RFID and supply chain experience working together on similar projects offer the best assurance of success for the move toward volume production with respect to system integration and success. It will be important to find teams who have the ability to work with both legacy systems and open-source languages and protocols to ensure against having to scrap a system and start over. Finally, smart labels with bar coding offer the best way to identify and disaster recover from RFID problems. Users should look for ways to stream RFID into the current bar coding processes, and partners that will help retain the integrity of both systems for the foreseeable future.

APPENDIX E. DATA COLLECTED BY TAG LISTENERS

Table 6. Data collected by tag listeners at ORNL Bldg 7001

	SN – 34-5B		PT – 226		SN – 34-5D		223		SN - 34-9E		228		SN - 34-14		PT - 229		
DATE	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**DATE**
9/20/2004			8:17a	8:53a			11:41a	11:44a									
9/21/2004	4:33p		9/22 OUT	12:54p									4:33p				9/21/2004
9/22/2004			3:11p		7:33a	8:18a	7:56a	8:21a						2:18p	7:56a	2:22p	9/22/2004
9/23/2004				9:31a													9/23/2004
9/24/2004													9:48a				9/24/2004
9/28/2004			1:23p												1:23p		9/28/2004
9/29/2004		4:33a		10:27a										4:33a		10:27a	9/29/2004
9/30/2004																	9/30/2004
10/1/2004																	10/1/2004
10/6/2004																	10/6/2004
10/7/2004																	10/7/2004
10/8/2004																	10/8/2004
10/12/2004																	10/12/2004
10/13/2004																	10/13/2004
10/14/2004																	10/14/2004
10/26/2004																	10/26/2004
10/27/2004																	10/27/2004
10/28/2004	2:20p				2:20p				2:20p				2:20p				10/28/2004
11/2/2004						1:50p								1:50p			11/2/2004
11/3/2004																	11/3/2004
11/4/2004					3:35p								3:35p				11/4/2004
11/8/2004		8:06p				11:36p											11/8/2004
11/9/2004	12:06a													1:51p			11/9/2004
11/10/2004																	11/10/2004
11/11/2004													11:21a				11/11/2004
11/12/2004					7:06p												11/12/2004
11/16/2004			7:34a			7:21a	7:33a	12:09p			7:33a			7:36a	7:33a	12:09p	11/16/2004
11/17/2004																	11/17/2004
11/18/2004				12:43p	10:06a							12:45p	10:06a				11/18/2004

Table 7. Data collected by tag listeners at the Roadway Terminal

	SN - 34-5B		PT – 226		SN - 34-5D		223		SN - 34-9E		228		SN - 34-14		PT - 229		
DATE	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**DATE**
9/20/2004							1:42a	1:48p									
9/21/2004							5:09p	5:10p									9/21/2004
9/22/2004													4:31p		4:31p		9/22/2004
9/23/2004														9:46a		9:16a	9/23/2004
9/24/2004																	9/24/2004
9/28/2004																	9/28/2004
9/29/2004					7:01p		6:53p								12:00p	9:16a	9/29/2004
9/30/2004						9:46a		10:38a									9/30/2004
10/1/2004																	10/1/2004
10/6/2004									12:47p								10/6/2004
10/7/2004										8:47a							10/7/2004
10/8/2004																	10/8/2004
10/12/2004									6:32p								10/12/2004
10/13/2004										8:47a							10/13/2004
10/14/2004																	10/14/2004
10/26/2004	8:33p		5:44p		8:33p		5:44p		8:33p		5:44p		8/33p		5:44p		10/26/2004
10/27/2004		3:18a		9:14a		3:18a		9:14a		3:18a		9:14p		3:18a		4:40a	10/27/2004
10/28/2004																	10/28/2004
11/2/2004					6:48p								7:03p				11/2/2004
11/3/2004						8:18a								8:18a			11/3/2004
11/4/2004																	11/4/2004
11/8/2004																	11/8/2004
11/9/2004													9:04p				11/9/2004
11/10/2004														6:04a			11/10/2004
11/11/2004																	11/11/2004
11/12/2004																	11/12/2004
11/16/2004																	11/16/2004
11/17/2004							7:11a	9:38a							7:07a	9:38p	11/17/2004
11/18/2004																	11/18/2004

Table 8. Data collected by tag listeners at ORAU.

	SN - 34-5B		PT - 226		SN - 34-5D		223		SN - 34-9E		228		SN - 34-14		PT - 229		
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	DATE
9/20/2004							12:08p	12:12p									
9/21/2004																	9/21/2004
9/22/2004			2:21p	2:46p													9/22/2004
9/23/2004													3:39p		3:22p		9/23/2004
9/24/2004														9:09a		9:13a	9/24/2004
9/28/2004																	9/28/2004
9/29/2004									2:40p	2:40p	2:35p	2:50p					9/29/2004
9/30/2004					11:40a		11:21a										9/30/2004
10/1/2004						9:10a		9:32a									10/1/2004
10/6/2004																	10/6/2004
10/7/2004									10:40a								10/7/2004
10/8/2004										8:40a							10/8/2004
10/12/2004																	10/12/2004
10/13/2004								10:44a	10:56a		10:42a						10/13/2004
10/14/2004										9:41a		9:45a					10/14/2004
10/20/2004			1:48p	1:58p			1:47p	2:00p			1:48p	1:58p			1:48p	1:58p	10/20/2004
10/26/2004																	10/26/2004
10/27/2004	12:46p				12:46p				12:46p				12:46p				10/27/2004
10/28/2004		1:31p				1:31p				1:31p				1:16p			10/28/2004
11/2/2004																	11/2/2004
11/3/2004					12:17p								12:17p				11/3/2004
11/4/2004						2:02p								2:02p			11/4/2004
11/8/2004																	11/8/2004
11/9/2004																	11/9/2004
11/10/2004													11:17a				11/10/2004
11/11/2004														10:17a			11/11/2004
11/12/2004																	11/12/2004
11/16/2004																	11/16/2004
11/17/2004					1:32p		11:21a						1:32p		11:21a		11/17/2004
11/18/2004			1:33p	1:42p		9:18a		9:33a			1:33p	1:42p		9:18a		9:33a	11/18/2004

Table 9. Data collected by tag listeners at the Watt Road weigh station.

	SN - 34-5B		PT - 226		SN - 34-5D		223		SN - 34-9E		228		SN - 34-14		PT - 229		
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	DATE
9/20/2004							9:29a	9:55a									
9/21/2004							9:20a	11:16a									9/21/2004
9/22/2004	1:31p	1:51p	1:19p	1:52p			6:36a	6:52a					4:06p	4:06p	4:06p	4:16p	9/22/2004
9/23/2004																	9/23/2004
9/24/2004																	9/24/2004
9/28/2004	8:51a	9:18a	8:51a	9:20a													9/28/2004
9/29/2004					4:16p	4:16p	4:12p	4:22p	2:09p	2:14p	1:45p	2:09p					9/29/2004
9/30/2004																	9/30/2004
10/1/2004																	10/1/2004
10/6/2004									12:08p	12:10p	12:03p	12:18p	9:34a	10:14a	9:34a	10:06a	10/6/2004
10/7/2004																	10/7/2004
10/8/2004																	10/8/2004
10/12/2004																	10/12/2004
10/13/2004																	10/13/2004
10/14/2004																	10/14/2004
10/20/2004			1:14 P	1:27p			1:13p	1:27p			1:14p	1:27p			1:14p	1:27p	10/20/2004
10/26/2004																	10/26/2004
10/27/2004																	10/27/2004
10/28/2004																	10/28/2004
11/2/2004					5:38p	5:47p							5:38p	5:47p			11/2/2004
11/3/2004	12:47p	12:54p							12:47p	12:54p							11/3/2004
11/4/2004																	11/4/2004
11/8/2004																	11/8/2004
11/9/2004							6:26p	6:29p							6:27p	6:29p	11/9/2004
11/10/2004			10:33a	10:37a							10:33a	10:37a					11/10/2004
11/11/2004																	11/11/2004
11/12/2004																	11/12/2004
11/16/2004							4:31p	4:31p							4:31p	4:31p	11/16/2004
11/17/2004																	11/17/2004
11/18/2004			1:03p	1:14p							1:03p	1:13p					11/18/2004

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