TRACKING RADIOACTIVE SOURCES IN COMMERCE

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ABSTRACT

The Environmental Protection Agency (EPA) Office of Air and Radiation and Department of Energy (DOE) Oak Ridge National Laboratory (ORNL) are investigating technologies that will assist in the improvement of the tracking and monitoring of high-level radiological sources while in commerce. This real-world testing of the EPA and DOE Radiological Source Tracking and Monitoring (RadSTraM) system addresses radiological and nuclear material tracking and monitoring in commerce and is part of a larger program entitled the Integrated Safety and Security Enforcement and Interdiction System (ISSEIS).

The Nuclear Regulatory Commission (NRC) reports over 300 missing radioactive sealed sources a year[2]. Missing sealed sources can pose a significant environmental and health risk through direct exposure, co-mingling in the metal recycling stream, use in contaminated consumer products, and use in terrorist activities. An effective tracking and monitoring system will increase security on radioactive shipments and help prevent inadvertent or illegal loss of radioactive sealed sources. There are a number of available technologies that are used for tagging items; however, there is very little information in the literature about technologies being tested in proximity to radioactive materials. Current candidate technologies include, (1) Satellite, (2) Radio Frequency Identification (Passive and Active), (3) Real-Time Location Systems (RTLS), and (4) Integrated Technology Solutions. Therefore, the primary goal of this project was to demonstrate the feasibility of a particular RTLS technology that combines wireless radio asset tracking and sensor monitoring technologies to track in commerce radioactive materials throughout the supply chain (both in transit and in storage).

The RadSTraM system provides for the earliest possible identification of radiological (in commerce) sources and the monitoring of these radiological sources as they proceed through the supply chain. To accomplish this, the following tasks have been completed and/or are being performed:

- Base-line data collection to establish nominal/off-nominal conditions,
- Pseudo-random (i.e., controlled) shipment testing,
- Data analysis, and
- Lessons learned reporting (e.g., radiation impact from Radio Frequency Identification [RFID] tags).

Preliminary pseudo-random testing results have been very positive. Once we have determined a successful proof of concept for all phases, RadSTraM will ready for integration into selected commercial transportation supply chains, which include: (1) enforcement, (2) shippers, (3) carriers, and (4) homeland security[3].

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[2] According to the Director General of IAEA, orphan sources are a widespread phenomenon, and 34 of the 49 countries responding to the GAO survey indicated that orphan sources pose problems in their country. Survey respondents reported that 612 sources had been lost or stolen since 1995. Of the 612 reported orphan sources, 254 had not yet been recovered [14].
[3] Data storage and authorized dissemination will use the national SensorNet (http://computing.ornl.gov/cse_home/sensornet/) standards.

Figure 1. Radioactive material package RFID equipped/monitored.

Introduction

Radiation has existed everywhere in the environment since the Earth's formation - in rocks, soil, water, and plants. The mining and processing of naturally occurring radioactive materials for use in medicine, power generation, consumer products, and industry inevitably generate emissions and waste. Recognizing the potential hazards of these activities, Congress designated the EPA as the primary federal agency charged with protecting people and the environment from harmful and avoidable exposure to radiation. Essentially, the number of unwanted radioactive sources in the US is not known, as no records of this type are kept, but the IAEA (International Atomic Energy Agency) estimates 18-38 Million packages of radioactive materials are shipped each year worldwide[4]. The Nuclear Regulatory Commission (NRC) *receives* approximately 300 reports of lost, stolen or abandoned radioactive sources a year. The U.S. Department of Energy (DOE) estimates it will recover over 14,000 greater-than-Class-C sealed sources by 2010 [DOE03]**.** Understanding the extent and nature of a radiological emergency is essential for limiting its adverse effects. In an emergency, the DOE and EPA establish a Federal Radiological Monitoring and Assessment Center (FRMAC) to define and monitor the radiological impact.

Specifically, EPA is the designated Lead Federal Agency in a multi-agency response to releases from accidents in commerce of unknown radiological materials, not licensed, owned or operated by a Federal agency or an Agreement State. In this capacity EPA coordinates with the DOE, since DOE has the lead responsibility for coordinating the FRMAC, during the early phase of a radiological emergency. The earliest identification of radiological (in commerce) sources is paramount in this process.

ORNL provides support to the EPA, Department of Homeland Security (DHS), and DOE in their goal of proving technologies for the detection and clearance of radiological materials in-transit. ORNL is provides support to the Tennessee Department of Safety (TDOS), South Carolina State Transport Police (SCSTP), and the Commonwealth of Kentucky Transportation Cabinet (KTC) in their goal of proving technologies for the enforcement of commercial vehicle state and federal laws for radiological materials and their transport. Bulk radiological monitoring systems have been installed at the TDOS’s Knox County Weigh and Inspection Station, SCSTP Dorchester County Weigh and Inspection Station, and at KTC Laurel County Weigh and Inspection Station. This innovative initiative will not be limited to instrument technology evaluation, but includes all facets of real world deployment including improved: 1) screening for safety and security of non-compliant drivers, vehicles and cargos (e.g., make better the detection/inspection ratio by reducing the frequency of false positives and missing alarms), 2) inspection

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[4] IAEA, Training Course Series Number one, Safe Transport of Radioactive Materials, 3rd edition, IAEA, Vienna Austria (estimate is based on a 1987 study).

process, and thus 3) the productivity of inspection personnel. There are fifty thousand hazardous materials shipment events/yr in the US according to the US Department of Transportation (DOT).

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 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. Such "orphaned" radioactive sources give cause for immense concern and is most 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. [4, 6, 8, 14]

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 an operational system which leverages a significant investment in Neutron-Sensitive Scintillating Glass-Fiber Panel detectors installed at the Watt Road Weigh Station (Knoxville, TN) [5, 11-13]. Collaborations with other interested State/Federal government agencies will be identified and explored where feasible. ORNL has conducted a technology investigation in association with the applications for the EPA and RadSTraM project. From the investigation, two advanced technology candidates comprising three separate Vendor s were selected for further investigation. To mitigate the risk associated with the conditions outlined above, the application of emerging technologies and commercial-off-the-shelf products should be demonstrated and tested [1-3, 7, 9-10].

DESCRIPTION OF THE TWO TECHNOLOGIES EVALUATED

The technologies that were investigated and tested employ a Remote Sensor Interface (RSI), Figure 1. The RSI can be read from a distance to alert enforcement personnel that radioactive items are present (or being received) and if the container has been breached. This technology application is especially relevant in light of the fact that many radiological monitoring and detection systems are in various stages of deployment throughout the world at transportation chokepoints, ports-of-entry, and inter-modal facilities.

AB-system: The first system, so-called the AB-system, uses two different vendors. One, Vendor-A, for the RFID tag (attached to the container, see Figure 1) and another (Vendor-B) for the stationary listening device (installed at all waypoints, see Figure 2). This system has therefore, two main components, the tag and the listener. The RFID tag transmits a packet every 10 seconds using the 802.11 protocol. This packet only transmits it Mac address, and the rest is broken information, therefore the packet is not detectable by normal 802.11 devices (i.e. computers, sniffers, and other wireless devices). It is has one-way communication and therefore only transmits. A new device just recently released, can turn the tag completely off via a wireless signal within a 3 foot range. The battery has a life of about 2 years when the tag is in the 10-second transmitting mode. Another important feature of the tag is that its range is in a ½ mile bubble. The device was detectable in a 4” x 18” schedule 80 pipe 100’ away, and within the confines of a fully metal trailer. Further, the tag was detectable at the same distance moving 70mph along the highway (i.e., I75/40 in front of the weigh station). The listener was custom built by Vendor-B, and is a small Windows XP based computer with custom developed software. The software allows the capture and storage of the Vendor B RFID tags to be correlated with other sensor data (image data, radioactive dose, count and isotope identification). The Vendor-B Listener can be configured to listen for specific tags or all tags, and can transmit the data over an Intranet/Internet.

C-system: The second technology solution, so-called the C-system, has two main components as well, the RSI (i.e., compared to a RFID tag) and the Gateway (or listener). The C-system RSI touts a Bluetooth enabled radio, which does not use the normal Bluetooth protocol. Normal Bluetooth devices do not detect the modified Bluetooth. A distinct feature of this device is that it goes completely asleep. It is awoken by a signal from the gateway, which establishes 2-way communication within 5 to 10 seconds. One limitation is the short range needed to transfer enough energy to wake the device as well as knowing when to transmit the wake up signal. Normally, the gateway is activated via proximity sensors or time, but its difficult to know and it may be necessary to blindly issue the wake-up command for every passing vehicle. Testing revealed that an all steel container prevents the wake-up signal from activating the RSI to wake. The C-system gateway is a Linux based device with a Bluetooth enabled radio. The radio performs 2-way communication to the RSI, including wakeup and data logging of any and all proximal RSIs. The C-system System had a severely limited range and must be in a standstill situation for detection.

VALIDATION OF TESTING SCENARIOS

The first step in the design and implementation of an effective and deployable RTLS intelligent system is validation. Therefore, our test scenarios were designed to simulate the in commerce supply chain process for radioactive materials (Table 2). 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.
- 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 (Roadway Express), commercial truckload service (T.A.G. Transport, Inc.) 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, Roadway Express Terminal in Knoxville, TN and ORAU.
- Collect data and document results using the ORNL SensorNet backbone.
- Data analysis/ refinement to incorporate learned lessons.

The RadSTraM project team conducted 20 test shipments of the radioactive materials and their packaging between July–Sept. 2004 using a route that transports materials from Roane to Knox to Anderson County, TN and return to Roane County. Testing included single and multiple shipments to test the ability to track the

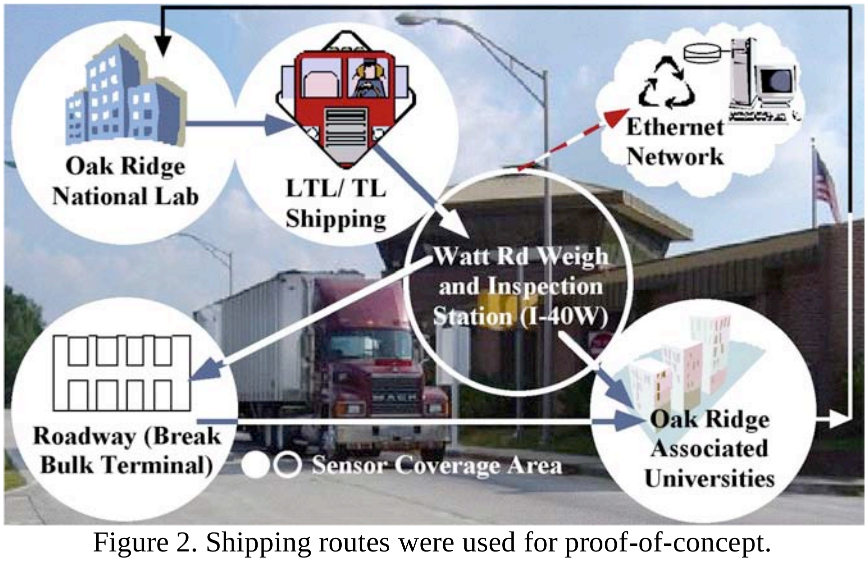

Figure 2. Shipping routes were used for proof-of-concept.

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 2 shows the shipment routing. Two different routes were used. The first used Roadway LTL (Less than Truck Load) service over a two-three day duration (ORNL → Watt Road Weigh Station → Roadway Terminal [break bulk] → ORAU and return). The second route used TAG Transport TL (Truck Load) service over a four-six hour duration (ORNL → Watt Road Weigh Station → ORAU and return). Table 1 gives the test methods and purpose.

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.
T.A.G. 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 3 exemplify 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 3. Asset tracking radiation systems at Knox county weigh station.

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 Roadway Express 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 is 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 (shown in Figure 4) and take digital photo after loading truck at shipping point and before unloading truck at 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.
10. Analyze data and file report.

RESULTS, ISSUES AND CONCLUSION

The data collected at the various waypoints shown in Figure 2 are presented in the Appendix. After filtering the data and upon inspection several issues were discovered in three broad categories: (1) technology hardware (i.e., for physical tracking) and software (i.e., to manage data/information for collection, filtering, and storage), (2) development/codification of Standard Operating Procedures (SOPs)/ automation/ training and (3) data analysis (i.e., tailored data mining tools) for the purpose of tracking/monitoring, forensics and compliance with SOPs. In category one, the Vendor C system provided ID broadcasting at 15-minute intervals (to conserved battery energy) and therefore shipments could pass through the monitoring station without detection. Further, forensic analysis of transit times would also be less accurate. Large gaps in the data were found due to unreliability of the forward-station PC's. When tracking radioactive material in commerce the need for high availability/dependability of automation technology (i.e., tags, listeners, network, and detectors) is tantamount to obtaining timely and reliable tracking/monitoring forensics. By solving the issues and problems (e.g., complete and consistent data reporting correlated with known tracking events) encountered in this pilot, we expect to establish an effective set of goals to implement for the second phase of the RadSTraM project. One especially important goal is to develop a fully networked data collection, filtering, 24x7 secure database availability as well as (automated) procedures to facilitate analysis, incident response policies and timely reporting.

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APPENDIX A RADSTRAM DATA FROM 'RFID' TRACKING SIGNATURES

The two vendor systems are compared in the tables provide here (Tables 4-7). Two different radioisotopes were shipped: Cesium 137 and Californium 252. Each container was fitted with one RFID Tag from the two vendors (i.e., two Tags per container) as described below (see Table 3):

The Cesium 137 shipments (ORNL Containers numbered 45 and 46) for Vendor AB used the serial numbers PT-228 (ORNL#46) and PT-229 (ORNL#45), columns 6 and 8 in the tables below (respectively); for Vendor C used the serial numbers SN-349E (ORNL#46) and SN-3414 (ORNL#45), columns 5 and 7 in the tables below (respectively).

The Californium 252 shipments (ORNL Containers numbered 47 and 48) for Vendor AB used serial numbers PT-226 (ORNL#47) and PT-223 (ORNL#48), columns 2 and 4 in the tables below (respectively); for Vendor C used the serial numbers SN-345B (ORNL#47) and SN-345D (ORNL#48), columns 1 and 3 in the tables below (respectively).

Table 3. Mapping Containers to Isotope Shipments.

Isotope	**Container and Serial Numbers**		
	ORNL	**Vendor AB / Column #**	**Vendor C / Column #**
Cesium 137	45	PT-229 / 8	SN-3414 / 7
	46	PT-228 / 6	SN-349E / 5
Californium 252	47	PT-226 / 2	SN-345B / 1
	48	PT-223 / 4	SN-345D / 3

RadSTraM Data Form
Circle One: Outbound(ORNL) Inbound(ORAU)
Shipment#:
Package Serial #:
Isotope:
Container Breaches:
Date:
Carrier:
Picture #:
Physical Characteristics of Trailer:
Physical Characteristics of Other Freight in Trailer:
Package Conditions:
Weather Conditions:

Figure 4. Data collected as shown.

Table 4. Starting Point: ORNL - BLDG 7001 (route-1:waypoint-1, route-2:waypoint-1)

2004	1. SN-345B		2. PT-226		3. SN-345D		4. PT-223		5. SN-349E		6. PT-228		7. SN-3414		8. PT-229	
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
9/20			8:17	8:53			11:41	11:44								
9/21	16:33		9:22	12:54									16:33			
9/22			15:11		7:33	8:18	7:56	8:21						14:18	7:56	14:22
9/23				9:31												
9/24													9:48			
9/28			13:23												13:23	
9/29		4:33		10:27										4:33		10:27
9/30																
10/1																
10/6																
10/7																
10/8																
10/12																
10/13																
10/14																
10/26																
10/27																
10/28	14:20				14:20				14:20				14:20			
11/2						13:50								13:50		
11/3																
11/4					15:35								15:35			
11/8		20:06				23:36										
11/9	0:06													13:51		
11/10																
11/11													11:21			
11/12					19:06											
11/16			7:34			7:21	7:33	12:09			7:33			7:36	7:33	12:09
11/17																
11/18				12:43	10:06							12:45	10:06			

Table 5. WATT ROAD WEIGH STATION (route-1:waypoint-2, route-2:waypoint-2)

2004	1. SN-345B		2. PT-226		3. SN-345D		4. PT-223		5. SN-349E		6. PT-228		7. SN-3414		8. PT-229	
9/20							9:29	9:55								
9/21							9:20	11:16								
9/22	13:31	13:51	13:19	13:52			6:36	6:52					16:06	16:06	16:06	16:16
9/23																
9/24																
9/28	8:51	9:18	8:51	9:20												
9/29					16:16	16:16	16:12	16:22	14:09	14:14	13:45	14:09				
9/30																
10/1																
10/6									12:08	12:10	12:03	12:18	9:34	10:14	9:34	10:06
10/7																
10/8																
10/12																
10/13																
10/14																
10/20			13:14	13:27			13:13	13:27			13:14	13:27			13:14	13:27
10/26																
10/27																
10/28																
11/2					17:38	17:47							17:38	17:47		
11/3	12:47	12:54							12:47	12:54						
11/4																
11/8																
11/9							18:26	18:29							18:27	18:29
11/10			10:33	10:37							10:33	10:37				
11/11																
11/12																
11/16							16:31	16:31							16:31	16:31
11/17																
11/18			13:03	13:14							13:03	13:13				

Table 6. ROADWAY (route-2:waypoint-3)

2004	1. SN-345B		2. PT-226		3. SN-345D		4. PT-223		5. SN-349E		6. PT-228		7. SN-3414		8. PT-229	
DATE	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
9/20							1:42	13:48								
9/21							17:09	17:10								
9/22													16:31		16:31	
9/23														9:46		9:16
9/24																
9/28																
9/29					19:01		18:53								12:00	9:16
9/30						9:46		10:38								
10/1																
10/6									12:47							
10/7										8:47						
10/8																
10/12									18:32							
10/13										8:47						
10/14																
10/26	20:33		17:44		20:33		17:44		20:33		17:44		20:33		17:44	
10/27		3:18		9:14		3:18		9:14		3:18		21:14		3:18		4:40
10/28																
11/2					18:48								19:03			
11/3						8:18								8:18		
11/4																
11/8																
11/9													21:04			
11/10														6:04		
11/11																
11/12																
11/16																
11/17							7:11	9:38							7:07	21:38
11/18																

Table 7. ORAU (route-1:waypoint-3, route-2:waypoint-4) Endpoint

2004	1. SN-345B		2. PT-226		3. SN-345D		4. PT-223		5. SN-349E		6. PT-228		7. SN-3414		8. PT-229	
9/20							12:08	12:12								
9/21																
9/22			14:21	14:46												
9/23													15:39		15:22	
9/24														9:09		9:13
9/28																
9/29									14:40	14:40	14:35	14:50				
9/30					11:40		11:21									
10/1						9:10		9:32								
10/6																
10/7									10:40							
10/8										8:40						
10/12																
10/13								10:44	10:56		10:42					
10/14										9:41		9:45				
10/20			13:48	13:58			13:47	14:00			13:48	13:58			13:48	13:58
10/26																
10/27	12:46				12:46				12:46				12:46			
10/28		13:31				13:31				13:31				13:16		
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11/17					13:32		11:21						13:32		11:21	
11/18			13:33	13:42		9:18		9:33			13:33	13:42		9:18		9:33

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