ARG-US Remote Monitoring Systems for Enhancing Security of Radioactive Material

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Abstract
In this paper, we briefly describe Argonne's ARG-US (meaning *watchful guardian*) remote monitoring systems technology for enhancing security of radioactive material during storage and transportation. Over the past 10 years, Argonne has developed, demonstrated, and deployed two patented technology systems with the goal of enhancing the safety, security, and safeguards of nuclear and other radioactive materials, including spent nuclear fuel and high-level waste in the commercial nuclear industry. Recent applications of the ARG-US remote monitoring systems in a radiological facility are demonstrated by combining sensor data and video images from the radiofrequency identification system and the Remote Area Modular Monitoring system. Highlights are also provided for recent development and applications of the ARG-US TRAVELER for tracking and monitoring cargo conveyance of mock vehicle and rail shipments, along with a summary of a training course on transport security and a brief discussion of future directions.

Key Words: ARG-US radiofrequency identification (RFID), remote area modular monitoring (RAMM), TRAVELER, radioactive material security

1. INTRODUCTION

Argonne National Laboratory (Argonne) is a pioneer in using radiofrequency identification (RFID) technology for the life-cycle management of radioactive material (RAM) packaging [1, 2]. Over the past 10 years, researchers at Argonne—with the support of the U.S. Department of Energy (DOE) Packaging Certification Program (PCP), Office of Packaging and Transportation, Office of Environmental Management—have developed, demonstrated, and deployed the ARG-US remote monitoring technology that consists of two patented systems: The first includes battery-powered RFID surveillance tags and fixed readers to monitor tagged RAM packages in facilities during storage, along with a portable CommBox to monitor tagged RAM packages in vehicles during transportation [2]. The second consists of a network of wired and wireless sensors that form the basis of Remote Area Modular Monitoring (RAMM) for critical fuel cycle facilities and a battery-powered TRAVELER to track and monitor RAM cargo conveyances during transportation [3]. Recently, Argonne researchers also developed a compact Type-B packaging design for end-of-life management of disused radiological sources, which includes an attached ARG-US monitoring device to enhance security during storage, transport, and disposal [4].

This paper briefly describes the two ARG-US remote monitoring systems, as well as highlights of their application in a Category-III radiological facility that is currently undergoing decommissioning and decontamination at Argonne. Our purpose is to illustrate how these systems can help enhance the security of RAM in a facility by combining sensor data and video images in real time with automatic alarms. We then briefly describe the TRAVELER, followed by highlights of its recent performance in tracking and monitoring conveyances in mock rail and vehicle shipments—which demonstrate how the TRAVELER can help enhance the security of RAM during transport. Finally, we summarize the international transport security course that Argonne has been conducting for DOE since 2015, as part of the University of Nevada's Graduate Certificate in Nuclear Packaging (GCNP) program.

2. ARG-US REMOTE MONITORING SYSTEMS

2.1 Radiofrequency Identification (RFID) System

Figure 1 schematically shows ARG-US RFID monitoring and tracking drum-type packages of radioactive material (RAM) during storage and transportation. A battery-powered RFID tag is attached to a drum-type package containing RAM. Each RFID tag contains a suite of sensors (e.g., temperature, humidity, shock, radiation [gamma, neutron], tactile seal) to monitor environmental exposure and the package's "state of health." Field testing and applications of ARG-US RFID systems in storage facilities began in 2010 at selected DOE sites and have continued at Argonne through the present [5]. Demonstrations and field testing of ARG-US RFID in transportation applications began even earlier, in 2008, and continued through the years, as we developed and incorporated additional sensors, multiple communication platforms, and a secured database and webpages to improve the overall performance of the system. The latest development and applications of the ARG-US RFID system can be found in Reference [6] and will not be repeated here.

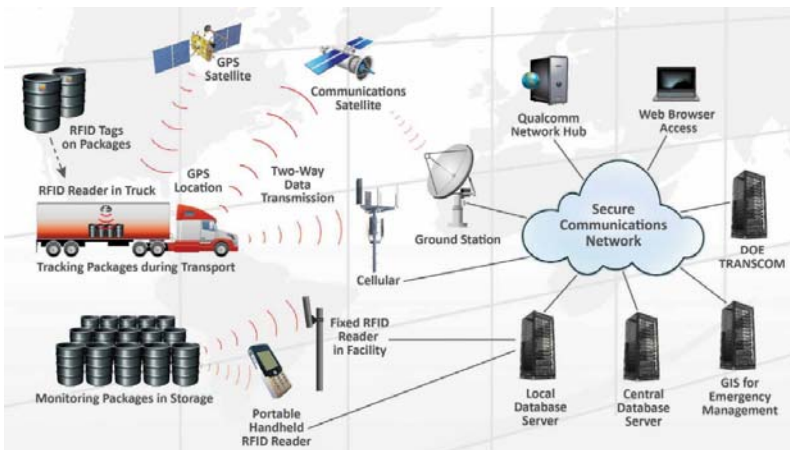


Figure 1. ARG-US RFID monitoring and tracking drum-type packages of radioactive materials during storage and transport

2.2 Remote Area Modular Monitoring (RAMM) System

The ARG-US RAMM system is designed to mitigate the deficiencies in situational awareness noted after the Japanese Fukushima accident when landline-based surveillance assets were lost [7]. Leveraging the ARG-US RFID sensor technology, Argonne researchers designed RAMM with a two-layered architecture: a wired Ethernet base layer and a wireless sensor network (WSN) overlay. The WSN links multiple RAMM units, each with its unique sensory and communication provisions in the application environment [8]. Figure 2 schematically illustrates facility monitoring using WSN of RAMM units, designated "infrastructure nodes," which are preconfigured and prepositioned in a facility and linked by wired Ethernet (not depicted in Fig. 2). Overlaying the wired network is a WSN formed by the wireless transceivers in the RAMM units. The wired network, which provides normal, baseline data collection and communication, also keeps the RAMM batteries charged via power over Ethernet (PoE). Each RAMM unit carries a suite of sensors that can be customized for the application environment, and multiple communication modules that are also functionally dependent; for example, cellular and satellite modems are installed only in those RAMM units that are "gateways" to the outside world. A RAMM system is scalable—the monitoring area and communication distance of the system can be extended by adding additional RAMM units—a feature that is often described as multi-hop "self-forming" or "self-healing," because a RAMM unit will find its neighbors in the WSN to relay data communication to the gateway RAMM. Blink sensors, shown in Figure 2, are wireless sensors that communicate only upstream with the RAMM infrastructure nodes, which enables their deployment and fast connection to the existing WSN. A digital video camera, or optical sensor, is the specialty sensor most recently incorporated into the RAMM platform, in 2017. Three RAMM units with digital cameras have been installed in a radiological facility at Argonne since January 2018 [9]. The ARG-US RFID system in the Argonne radiological facility was first installed in 2013, and has continued operation in that facility ever since [10].

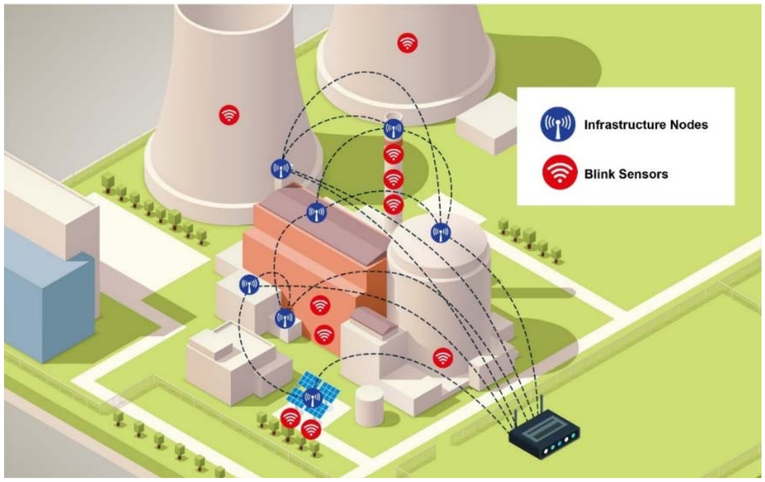


Figure 2. Schematic illustrating facility monitoring using wireless sensors network of RAMM (infrastructure nodes) and blink sensors

3. HOW DOES ARG-US RFID/RAMM ENHANCE SECURITY OF RAM IN A FACILITY?

Figure 3 shows floor views of Argonne's radiological facility, along with (a) locations and coverage areas of RAMM units (numbers 1101, 1102, and 1114) with digital video cameras, and (b) the RFID surveillance tags (circles) and readers (stars). RAMM unit 1114 (orange shaded area) monitors the glovebox and the connecting pathway between the facility's radiation buffer area and radiation controlled area; unit 1101 (blue shaded area) monitors the entry/exit and the work area of the facility; unit 1102 (green shaded area) monitors the clean transfer area (CTA), where packaging of RAM waste takes place during normal operation. All three RAMM units are connected to building IT via Power of Ethernet (PoE); the digital video cameras were programmed to acquire images at 2-minute intervals, thus accumulating 720 frames of images over a 24-hour period. The camera images are displayed on a webpage at 2-minute intervals, archived, and compressed into videos and saved on a secured server for future reference.

(a) (b)

Figure 3. Floor views of Argonne's radiological facility showing locations and coverage areas of (a) RAMM units (1101, 1102, and 1114) with digital video cameras, and (b) RFID surveillance tags (circles) and readers (stars).

The RFID surveillance tags 5101 and 5210, shown in Figure 3(b), are of particular interest here because they are located, respectively, near the glovebox and inside the CTA, where RAM waste is packaged for off-loading. These RFID tags have gamma and neutron radiation sensors with thresholds that can be adjusted to trigger automatic alarms. For example, the status of sensors in RFID tag 5101 displayed in Figure 3(b) is all green (indicating normal); the gamma dose rate and neutron count rate, 2 mR/h and 115 counts/h, respectively, were consistent with the radiation background and recent activities near the glovebox of the facility. However, should there be a radiation alarm in the facility, the toolbar on the webpage for the RFID tags in Figure 3(b) has a button labelled “Multiple Cameras View” that, when clicked, displays the latest images of the three digital cameras in the facility and another camera in an office, as shown in Figure 4.

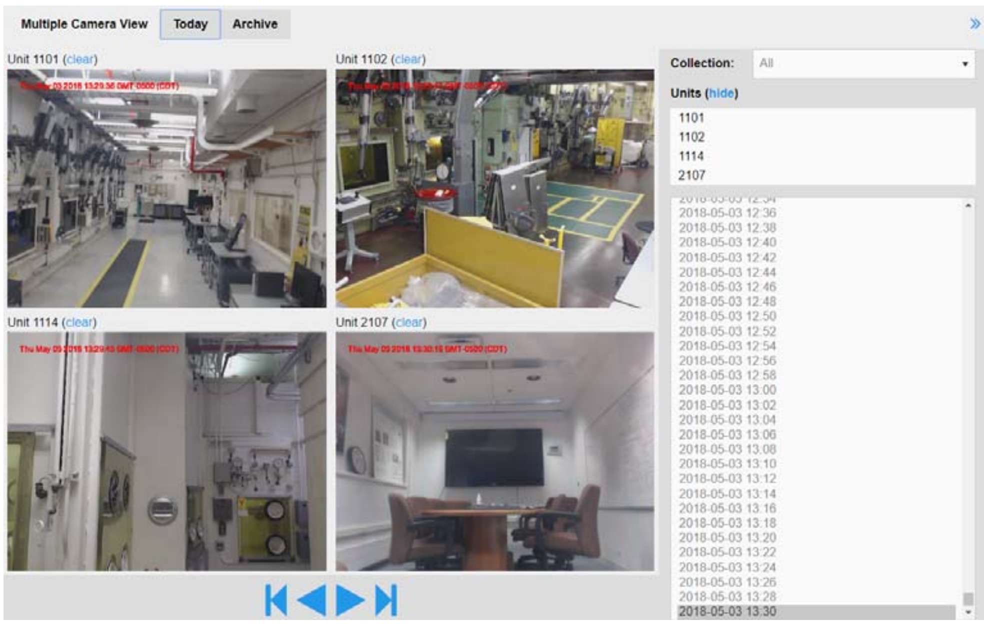
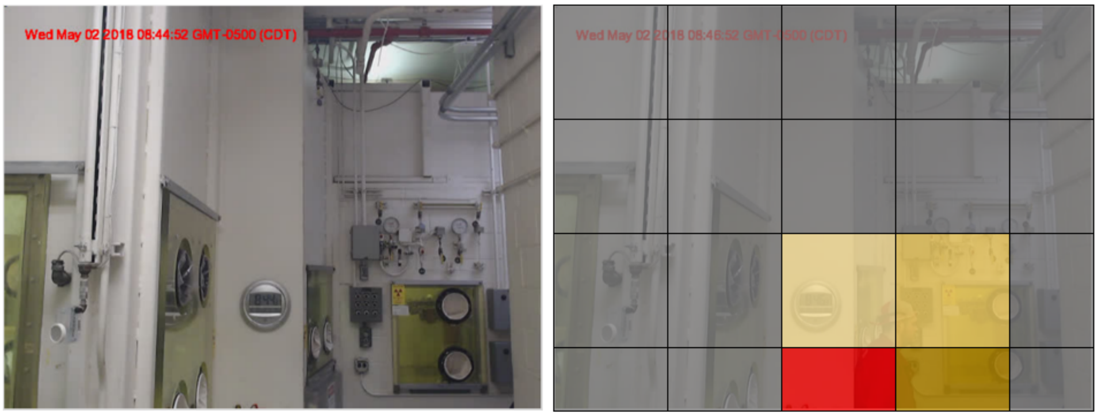


Figure 4. Quad view displaying the “**Today**” tab (Thursday, May 3, 2018) images of multiple cameras in the RAMM units (1101, 1102, and 1114) in the radiological facility, and unit 2107 at another building. The current time (shaded in gray) is 2018-05-03 13:30 GMT.

The arrows located at the bottom of the quad view in Figure 4 allow backward searches of images taken at earlier times of “Today” *for all camera units*. This is a particularly useful feature because it can help determine the cause of a sensor alarm quickly after receiving the automatic alarm. Moreover, the multiple camera images are synchronized, as are their corresponding compressed videos (under the **Archive** tool bar in Figure 4), which provides not only a global facility view in real time, but also synchronized histories down to dates, hours, and minutes in the playbacks. The speed of the video playback can be accelerated up to 16 times, and the videos can be paused at any time for close examination of the images in high resolution.

To enhance security during off-hours of facility operation, including weekends and holidays, detection of motion or event based on changes of intensity in camera images may be used for alarm annunciation. Figure 5 illustrates an event detection by RAMM unit 1114, which covers the glovebox and connecting pathway in the facility. Algorithms and weights are being developed to process successive video images to determine whether a new captured image contained “significant” changes in intensities. Using colors to indicate changes in image intensity, Figure 5(b) shows four different colored pixel tiles (clockwise from top left: beige, yellow, orange, and red) surrounded by background pixel tiles that are all shaded grey. The timestamps on the video images in Figures 5(a) and 5(b) show that the event can be detected within 2 minutes after its occurrence.



(a) (b)

Figure 5. (a) Camera image from unit 1114 before motion (event) detection on May 2, 2018, 08:44:52 GMT and (b) pixel-frame-based motion (event) detection on May 2, 2018, 08:46:52 GMT. (Colors indicate differences in changes of image intensities in successive images.)

4. HOW DOES ARG-US TRAVELER ENHANCE SECURITY OF RAM DURING TRANSPORTATION?

The TRAVELER is the latest innovative product of the ARG-US remote monitoring system technology. It was designed to monitor RAM in cargo conveyances during transportation by truck, rail, or ship. Development, testing, and demonstration of TRAVELER's performance have been described elsewhere [11], and will not be repeated here. Similar to ARG-US RFID and RAMM, the TRAVELER's modular platform allows sensors to be added or removed (i.e., customized) with relative ease. For example, the TRAVELER's modular suite of sensors may include temperature, humidity, and radiation (gamma and neutron) sensors, as well as a three-axis digital accelerometer, an electronic loop seal, and a digital camera, depending on monitoring needs. The TRAVELER uses redundant methods (i.e., cellular and satellite) to transmit sensor data, alarm annunciation when sensor thresholds are violated, and remote clearance of alarms from a command center. Powered by rechargeable lithium-ion batteries, the TRAVELER in its current configurations can support continuous tracking and monitoring of RAM cargo conveyance for up to 6 days.

4.1 Rail Shipment

Figure 6 shows the path marked by an Iridium satellite tracking the ENSA/DOE transport cask as it is shipped by rail from Baltimore, Maryland, to Pueblo, Colorado, from July 28 to August 3, 2017 [11]. The TRAVELER, shown in the insert image in Figure 6, was inside a weatherproof enclosure welded to the railcar behind the transport cask. The map insert in Figure 6 shows the Global Positioning System (GPS) location (latitude, longitude) of the railcar with a timestamp shortly after the TRAVELER was activated ~4:15 PM (20:10 45 GMT) on July 28, 2017. (The train did not leave the CSX Bayview railyard until the evening of July 28.) Shortly after the train left the railyard, a password-controlled, public-accessible webpage was made available to monitors who followed the rail shipment in real time from various locations across the United States and in Europe. The total number of satellite transmissions, represented by the sum of aggregated breadcrumbs, is 1,108.

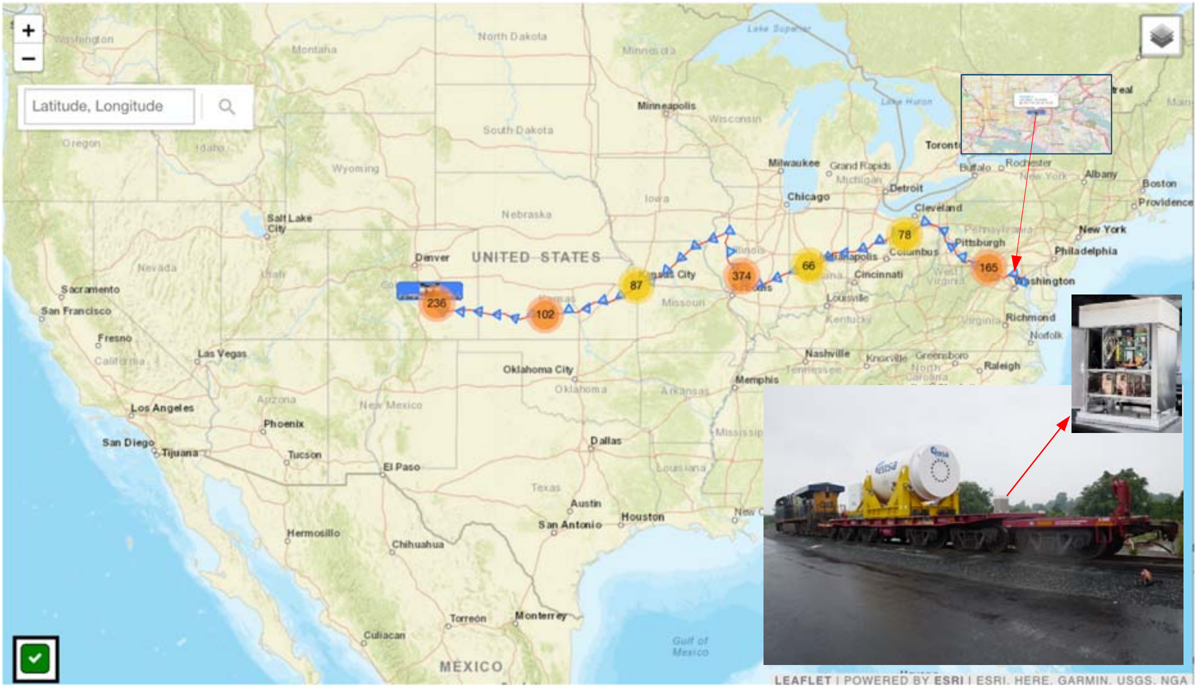


Figure 6. Iridium satellite tracking the ENSA/DOE transport cask as it is shipped by rail from Baltimore, Maryland, to Pueblo, Colorado, from July 28 to August 3, 2017.

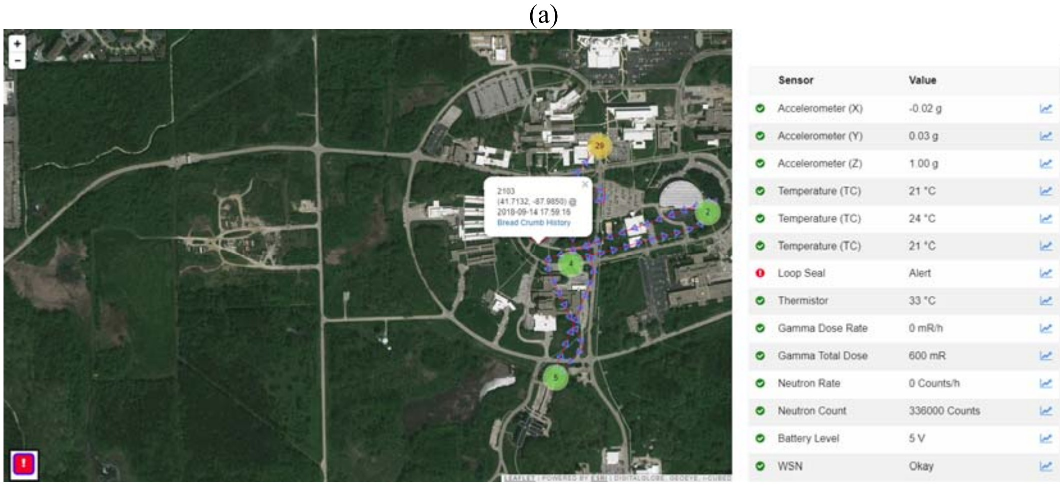
The TRAVELER accumulated large amounts of sensor data with each satellite transmission, including data from a three-axis digital accelerometer, ambient temperature, background radiation, battery status, and the loop seal, which remained engaged throughout the journey. Similar to the sensor alarms discussed earlier for the ARG-US RFID and RAMM, the TRAVELER will transmit an automatic alarm via the Iridium satellite link if any sensor thresholds are violated during the rail shipment.

4.2 Vehicle Testing of Electronic Loop Seal

The electronic loop seal is a specialty sensor incorporated into the TRAVELER that provides robust physical security as well as continuous, real-time monitoring of assets and secured cargo during both transportation and in-transit storage. The multi-strand wire and embedded sensors prevent any attempt at detaching, bypassing, or tampering with the seal, the sealing wire diameter of which is only 6 mm (10mm sealing wire plug diameter); the wire lengths can vary between 110 cm and 40 m. The relatively small diameter of the sealing wire and its long length enables wire looping of many items in a cargo conveyance, which offers a very effective, low-cost means to enhance transport security of RAM.

Figure 7 shows a "staged" loop seal alarm during a recent TRAVELER's vehicle road test inside the Argonne campus on September 14, 2018. The arrows in Figure 7 show the traveling direction of the vehicle during the road test. The loop seal was manually disengaged after the vehicle stopped in a parking lot to activate the alarm. That alarm message was transmitted from the TRAVELER's cellular modem to the cell tower and then to the Argonne server, which turned the webpage vehicle icon red. The entire process took ~2 minutes. After the red icon near the lower left corner of Figure 7(a) was clicked, the panel of sensors appeared on the right side of Figure 7(b) showing red "Loop Seal Alert" text. The pop-up box covering the vehicle icon showed the geographical location (latitude, longitude) and a timestamp (2018-09-14 17 59:16 GMT) when the TRAVELER's loop seal alarm status had not yet been cleared. (The alarm cause needs to be assessed before taking any follow-up action. The status of the electronic loop seal should turn green only after it is manually re-engaged, which requires action in the field, communication to the Command Center, and verification.)

(a)



(b)

Figure 7. Loop seal alarm via cellular communication during TRAVELER's vehicle road test on the Argonne campus, September 14, 2018

5. DISCUSSION AND FUTURE DIRECTIONS

The IAEA General Conference resolution on nuclear security (GC[61]/RES/9) calls upon all Member States, within their responsibility, "to achieve and maintain highly effective nuclear security, including physical protection, of nuclear and other radioactive material during use, storage and transport and of the associated facilities at all stages in their life cycle." Resolution GC(61)/RES/9 also calls upon all States "to improve and sustain, based on national security threat assessments, their national capabilities to **prevent, detect, deter and respond** to illicit trafficking and other unauthorized activities and events involving nuclear and other radioactive material." The resolution further calls upon States "to enhance international partnerships and capacity building in this regard" and encourages States to continue efforts "to recover and secure nuclear and other radioactive material that has fallen out of regulatory control."

Despite efforts to prevent and deter malicious acts to breach the security of RAM, the management of such an act needs to have three components: (1) detection/assessment, (2) delay, and (3) response. Figure 8 shows the overall timeline for a security event. The goal "Deter Actions" begins with the adversary's step "Begin Action." The "Delay" step begins at the "First Alarm" and continues until "Task Complete."

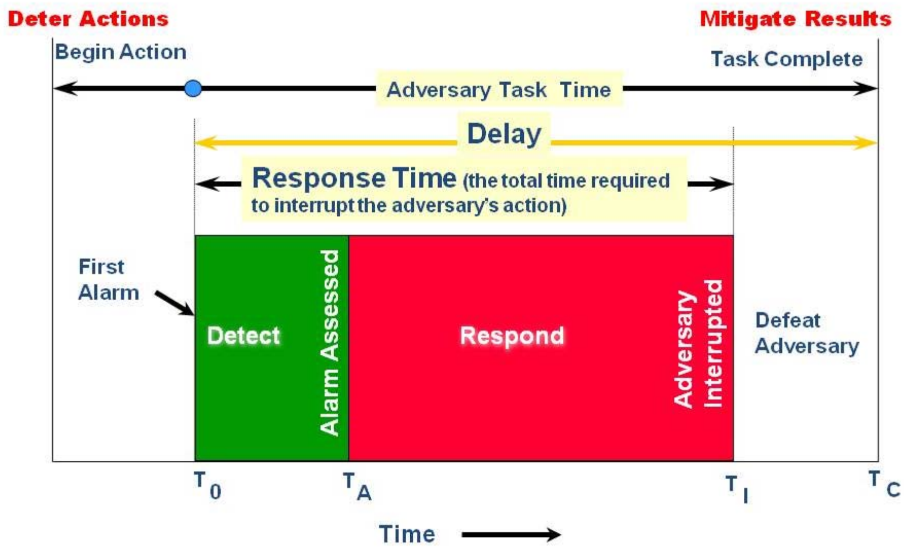


Figure 8. Overall timeline for a security event

Together, these actions constitute the "Adversary Task Time." To ensure security of RAM in any security event, the "Response Time" (i.e., the total time required to interrupt the adversary's action), must be shorter than the "Adversary Task Time" (T_C) to "Mitigate Results" of the malicious act (i.e., $T_I - T_0 < T_C$). The "Response Time" consists of "Detect" and "Respond," and the "First Alarm," T_0, is critical, as is the amount of time that passes before "Alarm Assessed," because only after correct assessment can the response be appropriate to effectively interrupt and defeat the adversary. The sensors in the ARG-US RFID surveillance tags, RAMM, and TRAVELER have all been tested extensively in facility environments and during transportation; all of them have thresholds that can be adjusted in accordance with the threat environment—thus rendering detection of a security event and first alarm literally within minutes of its occurrence. Augmented by digital video cameras in the RAMM units and TRAVELER, visual assessment of the cause of alarm becomes feasible, even remotely, which should reduce the assessment time T_A and enable faster response to the security event.

The efficiency of video image processing can be further enhanced by selecting "regions of interest" where activities are likely to occur and by eliminating comparisons of background images of walls and ceiling that do not change with the sequence of frames. The ability to control digital cameras in the RAMM units directly from the web application's user interface is highly desirable, for example, by increasing the frame rate of the camera, or changing to live streaming when the situation warrants it. Another example is using the pan, tilt, and zoom (PTZ) of cameras. Sounds picked up by the webcam's microphones could be used to trigger alarms with an indicator icon on the webpage, along with concurrent alarm annunciation by automated text messages and phone calls. Finally, the image processing can be further enhanced by incorporating machine learning to allow for visual accounting of assets in the vision space, a capability similar to using computer vision for facial recognition. Advanced imaging devices, such as a silicon retina imager, are being considered for efficient, asynchronous event-based monitoring that could complement the existing ARG-US RAMM units in enhancing the security of RAM in facilities.

The Nuclear Security Summit 2016 Action Plan in Support of the IAEA Global Partnership advocates increased attention to nuclear transport, including "producing guidance documents and facilitating associated exercises, training, and capacity building activities; organizing and sharing of good practices and lessons learned from transporting nuclear and other radioactive material." Since 2013, Argonne has been conducting weeklong, annual training courses on the security of nuclear and other RAM during transport, with guest lecturers from IAEA, the World Nuclear Transport Institute (WNTI), and the World Institute for Nuclear Security (WINS) [12, 13]. This course includes a review of applicable security-related regulations stipulated by U.S. government agencies; relevant international modal regulatory documents; and requirements, guidance documents, and IAEA recommendations related to transport security of nuclear and other RAM. The training course incorporates lectures and in-class discussion, tabletop and field exercises, homework, and exams, as well as hands-on exercises associated with developing a transport security plan and applying it through readiness review and corrective action. Hands-on exercises also included a mock shipment in vehicles and application of the ARG-US RFID/RAMM systems and TRAVELER to track, monitor, and communicate security alarms about RAM during transport and in-transit storage. The transport security course was included in the curriculum in the GCNP program at the University of Nevada, Reno in 2016. Thirty students have taken the international transport security courses over the last two years and obtained credits toward the GCNP program. Discussion is underway with the WNTI to host a shortened, purpose- and/or audience-specific course on transport security of RAM in Europe in 2019.

6. SUMMARY AND CONCLUSION

Nuclear and radiological terrorism continues to be a worldwide concern as the nature of security threats evolves. As stated in the Nuclear Security Summit (NSS) 2016 Communiqué, “The threat of nuclear and radiological terrorism remains one of the greatest challenges to international security, and the threat is constantly evolving.” Furthermore, the White House factsheet for the NSS noted that “nuclear material is most vulnerable while in transit and therefore additional measures are required to mitigate against these risks.” The NSS 2016 Joint Statement on Nuclear Terrorism Preparedness and Response stated, “Nuclear terrorism response requires a range of technical, operational, and communications capabilities to provide coordination and resolution of the incident, as well as mitigating its consequences.” In particular, the NSS 2016 Action Plan in Support of the Global Partnership against the Spread of Weapons and Materials of Mass Destruction identified enhancements, including national nuclear security regimes to “provide assistance to and coordinate programs and activities on strengthening measures of transportation security.” In addition, the NSS 2016 Action Plan in Support of the IAEA advocates increased attention to nuclear transport, including “producing guidance documents and facilitating associated exercises, training, and capacity building activities; organizing and sharing of good practices and lessons learned from transporting nuclear and other radioactive material.”

Continuous surveillance using the ARG-US remote monitoring systems with a suite of sensors (e.g., temperature, shock, radiation, seal, digital video cameras) and their automatic alarms capabilities should help prevent, detect, deter, and respond to unauthorized activities and security events involving RAM in facilities and during transportation.

7. ACKNOWLEDGMENT

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