Remote Area Modular Monitoring for Nuclear Facilities

B. Craig,[1] K. Byrne,[1] Y.Y. Liu[1] and M. Hoover[2]

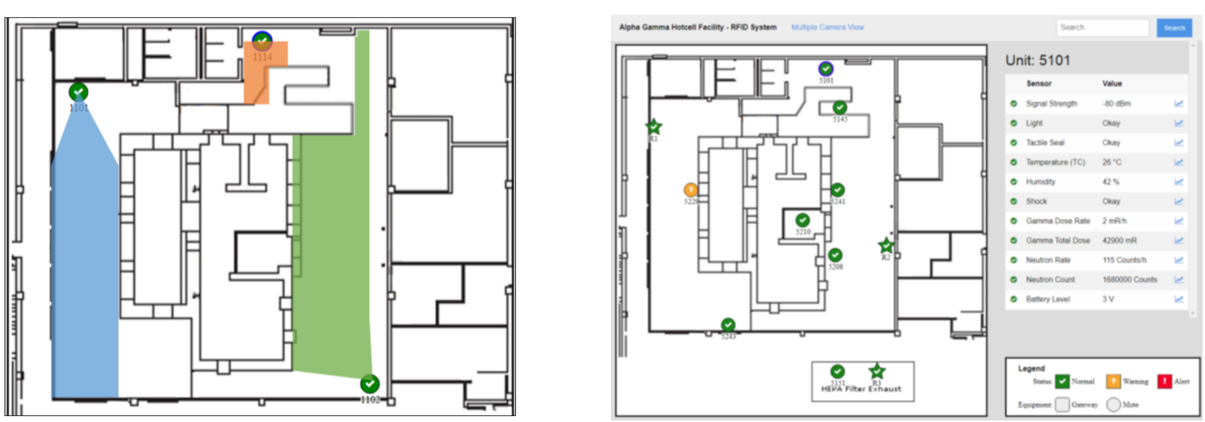
[1]*Argonne National Laboratory, 9700 South Cass Avenue, Lemont, IL 60439*
[2]*Embedded Planet, Inc, Solon, OH. 44139*

INTRODUCTION

The ARG-US Remote Area Modular Monitoring (RAMM) system is designed to mitigate the deficiencies in situational awareness noted after the Fukushima accident in Japan when landline-based surveillance assets were lost. [1-4] Leveraging the ARG-US radiofrequency identification (RFID) sensor technology, researchers at Argonne National Laboratory (Argonne) designed RAMM with a two-layered architecture: a wired Ethernet base layer and a wireless sensor network (WSN) overlay. 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 more RAMM units; this feature 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. A digital video camera, an electronic loop seal, and type K thermocouples are among the specialty sensors incorporated into the RAMM unit. [5] An embedded multi-media controller chipset with onboard flash and dynamic random-access memories has also been incorporated in the single-board computer to enable local data processing and storage in each RAMM unit as part of a distributed sensing system. In this paper, we describe the performance of RAMM in nuclear facilities through use cases in a radiological facility and two accelerator facilities at Argonne, followed by discussion of future applications of RAMM at other DOE and industrial nuclear facilities, including spent-fuel dry cask storage systems in the U.S. and abroad.

Radiological Facility

The Alpha Gamma Hot Cell Facility (AGHCF) at Argonne is a Category 3 radiological facility currently under decommissioning and decontamination. Figures 1(a) and 1(b) are floor views of AGHCF showing (1a) locations of three RAMM Units (#1101, #1102, and #1114) with digital video cameras deployed since 2018, and (1b) seven RFID surveillance tags (circles) and three readers (stars) deployed since 2013. The shaded areas in Fig. 1(a) show the views of three cameras, which together cover nearly 100% of the accessible area



(a) (b)

Figure 1. Floor views of Argonne's radiological facility (AGHCF), showing locations of (a) three RAMM Units (#1101, #1102 and #1114) with digital video cameras, and (b) seven RFID surveillance tags (circles) and three readers (stars)

of the facility. 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 entry/exit and work area of the facility, whereas Unit #1102 (green shaded area) monitors the Clean Transfer Area (CTA), where packaging of radioactive waste took place during normal operation. All three RAMM units are connected to building IT via PoE; the digital video cameras were programmed to acquire images at 2-min intervals, thus accumulating 720 image frames over a 24-h period. The camera images are displayed on a web page at 2-min intervals, archived, and compressed into videos and saved on a secured server for future reference and playback, if necessary.

The RFID surveillance tags #5101 and #5210 shown in Fig. 1(b) are located near the glovebox and inside the CTA, where radioactive waste was packaged for off-loading. These RFID tags have gamma and neutron radiation sensors with thresholds set to trigger automatic alarms, which help to ensure operational safety of personnel. For example, the status of sensors in RFID Tag #5101 displayed in Fig. 1(b) is all green for normal; and the latest gamma dose rate and neutron counts, 2 mR/h and 115 counts/h, respectively, were consistent with the radiation background and recent activities of the facility. The tool bar on the web page for the RFID tags in Fig. 1(b) has a "Multiple Cameras View" button that, when clicked, displays the latest images from the three digital cameras in the AGHCF and one camera in another building, as shown in Fig. 2. The arrows located at the bottom of the Quad view in Fig. 2 allow users backward search of images at earlier times of Today *for all camera units*, which are useful for investigation of probable causes after receiving any automatic sensor alarms. These multiple camera images are synchronized, as are their corresponding compressed videos under the Archive tool bar of the web page (Fig. 2), thus providing not only a global facility view in near-real time, but also synchronized histories down to dates, hours, and minutes in the playbacks, with a maximum playback speed of 16X.

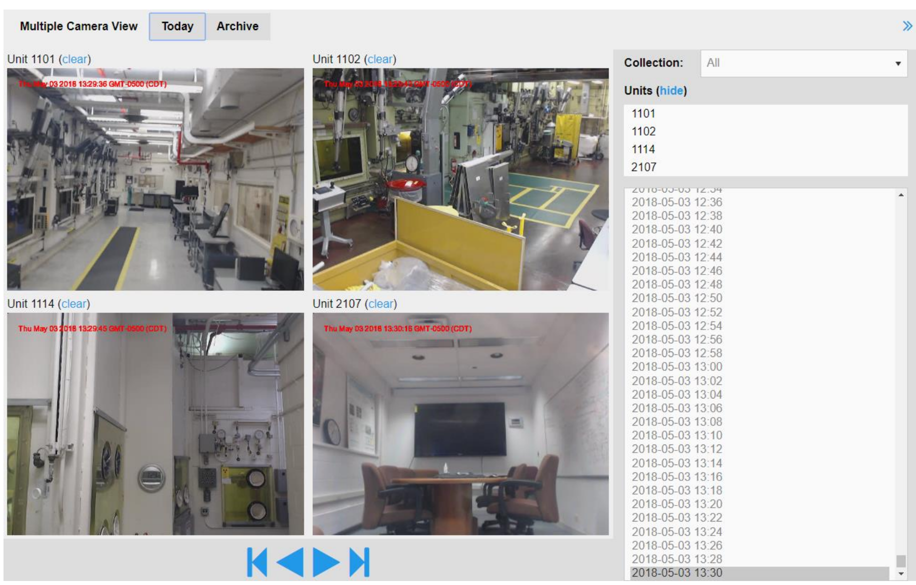


Figure 2. Multiple cameras' images of RAMM units in AGHCF. The current time (shaded in gray) is 2018-05-03 13:30 GMT.

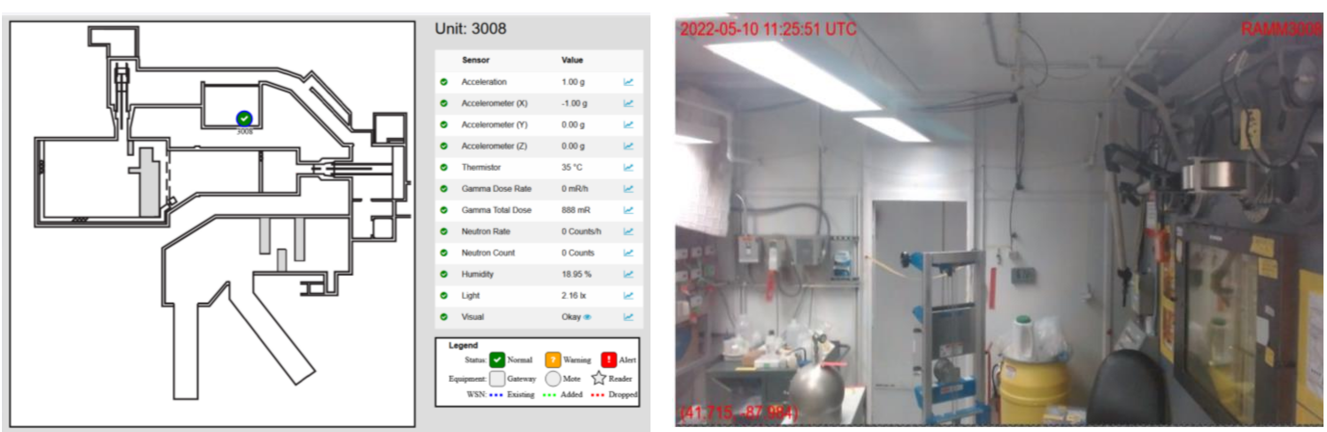
To enhance security during off-hours facility operation, including weekends and holidays, detection of motion or events based on changes of intensity in camera images may be used for alarm annunciation. Figure 3 illustrates an event detection by RAMM Unit #1114, which covers the glovebox and connecting pathway in the facility. Algorithms and weights were being developed to process successive video images to determine if a new captured image contains "significant" changes in intensities. Using colors as an indication of changes in image intensity, Fig. 3(b) shows four different-colored pixel tiles (clockwise from upper left: beige, yellow, orange, and red) surrounded by the background pixel tiles, which are all shaded gray. The time stamps on the video images in Figs. 3(a) and 3(b) show that the event can be detected within 2 minutes after its occurrence.

(a) (b)

Figure 3. (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.)

Accelerator Facilities

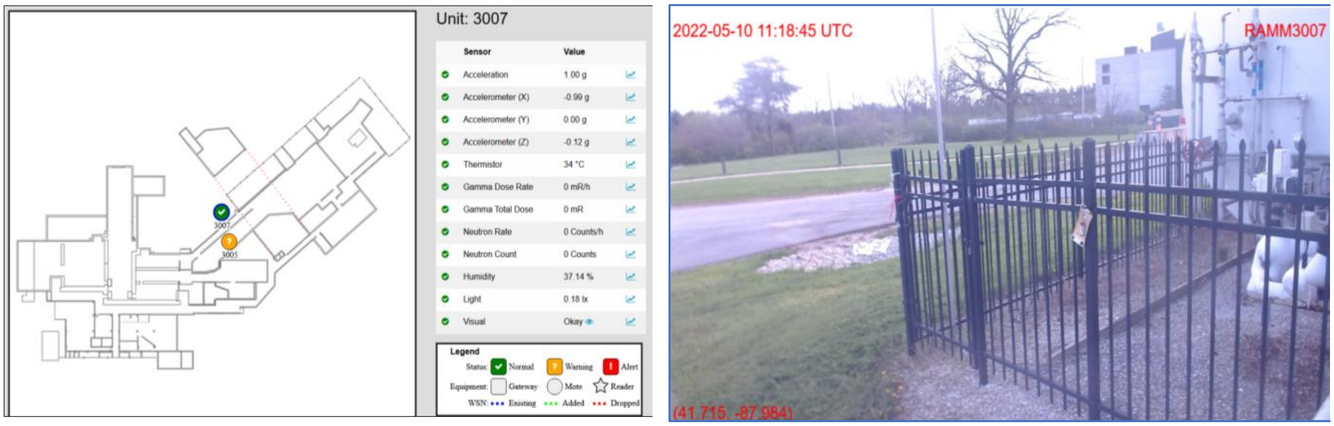
Three RAMM units have been installed since January 2022 in Argonne's two accelerator facilities: two in the Argonne Tandem Linear Accelerator System (ATLAS) and one in the Low Energy Accelerator Facility (LEAF). ATLAS is a DOE National User Facility supporting research in high energy physics, whereas LEAF can produce a wide range of useful radioisotopes for medical, national security, basic science, and industrial applications. The main criteria for selection of locations for installation of the RAMM units were monitoring needs, accessibility, and proximity to existing facility instrumentation for validation of sensor data, particularly gamma and neutron. The location of the first installed RAMM unit (#3008) is in the sample preparation room in LEAF. Figure 4(a) shows the room location in LEAF; all sensor values are normal (green). Figure 4(b) is a screen capture of the camera's live-streaming image with labels on the corners showing date and time (2022-05-10 1202.23 UTC), unit number (RAMM3008), and its geographic location, i.e., latitude, longitude (41.715, -87.984).



(a) (b)

Figure 4. (a) Location of RAMM unit #3008 in LEAF and sensor values, and (b) camera streaming image of the radioisotope handling room.

Figure 5(a) shows the locations of two RAMM units: #3005, near the control room of ATLAS, and #3007, outdoors with the camera monitoring the liquid nitrogen tank in the delivery area outside the ATLAS building. The screen capture of the camera's live-streaming image was taken in the morning of May 10, 2022. The status of all sensors in #3007 is normal (green) in Fig. 5(a) and both gamma and neutron sensors register zero. A thermoluminescent dosimeter (TLD) film badge is hung on the center post of the fence to provide monthly data on radiation exposure.)



(a) (b)

Figure 5. (a) Location of RAMM unit #3007 in ATLAS and sensor values, and (b) camera streaming image of the liquid nitrogen tank.

DISCUSSION

The ability to monitor critical parameters in nuclear facilities during normal operation, and during and after a disruptive incident, is vital for the safety of facility personnel, emergency responders, recovery crews, and residents of the surrounding communities. Conventional hard-wired assets that depend on supplied power may be decimated by natural disasters or by malicious acts of attackers, either physical or cyber. Remote monitoring of nuclear facilities with 24 hours a day, 7 days a week (24/7) surveillance and automatic sensor alarms is analogous to the use of home security systems, which provide assurance that family and property are always protected, because incidents and accidents will be addressed immediately by appropriate emergency response actions.

With its versatile and modular design architecture incorporating multiple sensors, power supplies, and communication media options, RAMM should fulfill most monitoring needs of nuclear facilities during normal operation and disruptive incidents/accidents. Because RAMM is modular by design, upgrading sensors and/or adding sensors for other applications can be achieved with relative ease. One example is the RAMM for temperature measurement (TM), or RAMM-TM, which is a customized, innovative device developed by Argonne researchers for detection of gas leakage from canisters containing spent nuclear fuel. There are over 3,000 spent-fuel canisters in dry cask storage systems emplaced at Independent Spent Fuel Storage Installations in 34 States in the U.S. Two Consolidated Interim Storage Facilities (CISFs), in New Mexico and Texas, submitted license applications to the Nuclear Regulatory Commission in 2016 and 2017, respectively. Each CISF can store thousands of spent fuel canisters in several dry cask storage systems. The RAMM-TM methodology has been demonstrated in a series of canister gas-leakage experiments conducted by using a 1/4.5-scale model cask at the Central Research Institute of Electrical Power Industry, Japan. Both helium and air gas leakages from the model canister, caused by a small, simulated chloride-induced stress corrosion cracking canister breach, were detected within hours after the start of the leakage. The change between canister surface temperatures at the top and bottom center (ΔTBT) during gas leakage (depressurization) triggered automatic alarms, providing a sound basis for early detection of gas leakage from the canister. This methodology would allow the implementation of necessary mitigatory actions to reduce risks to public safety and health and protect the environment. [6-8]

The outdoor RAMM unit #3007 monitoring the delivery area for the liquid nitrogen tank outside ATLAS is another example of remote monitoring of the environment 24/7, in near-real time. Other kinds of environmental monitoring can be implemented relatively straightforwardly, for example, at the periphery of nuclear facilities and nearby public institutions such as village town halls, libraries, hospitals, and schools. In addition to remote monitoring of radiation levels, airborne particulates and/or contaminants in underground water or waste storage tanks can be monitored in real time, even in remote locations, by incorporating appropriate sensors into RAMM and by harvesting energy using solar panels or other means.

SUMMARY AND FUTURE PLAN

The performance of RAMM in nuclear facilities has been demonstrated through use cases in a radiological facility (AGHCF) and two accelerator facilities (ATLAS and LEAF) at Argonne National Laboratory. Investigation is underway to identify facilities for RAMM installation at the Idaho National Laboratory. [9] Development of RAMM will continue with a focus on sensors, energy harvesting, environmental monitoring, information security and human-machine interfaces. The RAMM systems technology is patented, and licensing for commercialization is in progress.

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REFERENCES

1. H-C Tsai, B. Craig, Y.Y. Liu, and J.M. Shuler, “Remote Area Modular Monitoring (RAMM) for Nuclear and Radiological Facilities,” ANS Annual Meeting, San Antonio, TX, June 7–11, 2015.
2. Y.Y. Liu, J.D. Hlotke, and J.M. Shuler, “ARG-US Technology for Decommissioning and Decontamination,” 18th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2016, Kobe, Japan, September 18–23, 2016.
3. B. Craig, K. Byrne, L. Vander Wal, Y.Y. Liu, and J.M. Shuler, “ARG-US Remote Area Modular Monitoring: Digital Cameras Enhancing Safety and Security,” Institute of Nuclear Materials Management (INMM) 59th Annual Meeting, Baltimore, MD, July 22–26, 2018.
4. Y.Y. Liu, B. Craig, and J.M. Shuler, “ARG-US Remote Monitoring Systems for Enhancing Security of Radioactive Material,” IAEA International Conference on the Security of Radioactive Material, The Way Forward for Prevention and Detection, Vienna, Austria, December 3–7, 2018.
5. B. Craig, L. Vander Wal, K. Byrne, Y.Y. Liu, and J.M. Shuler, “ARG-US Wireless Sensor Network for Critical Facilities,” 19th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2019, New Orleans, LA, August 4–9, 2019.
6. Yung Liu, Brian Craig, Zenghu Han, Kevin Byrne, Hirofumi Takeda, and Toshiari Saegusa, “RAMM-TM for detection of gas leakage from canisters containing spent nuclear fuel,” Nuclear Engineering & Design 385 (2021) 111534.
7. Toshiari Saegusa, Hirofumi Takeda, and Yung Liu. “Monitoring of helium gas leakage from canister storing spent nuclear fuel: Radiological consequences and management,” Nuclear Engineering & Design 382 (2021) 111391.
8. Y.Y. Liu and H. Takeda, “RAMM-TM for Detection of Gas Leakage from Canisters,” ANS Winter Meeting, DESD-RRSD Embedded Topical, Nov 30–Dec. 4, 2021.
9. Sam Trost, “Investigation of INL Site Implementation of ARG-US,” Status Report, INL/RPT-22-67104, April 2022.