Tracking and Monitoring with Dosimeter-Enabled ARG-US RFID System* - 12009

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ABSTRACT

Automated monitoring and tracking of materials with radio frequency identification (RFID) technology can significantly improve both the operating efficiency of radiological facilities and the application of the ALARA (as low as reasonably achievable) principle in them. One such system, called ARG-US, has been developed by Argonne National Laboratory for the U.S. Department of Energy (DOE) Packaging and Certification Program to use in managing sensitive nuclear and radioactive materials. Several ARG-US systems are in various stages of deployment and advanced testing across DOE sites. ARG-US utilizes sensors in the tags to continuously monitor the state of health of the packaging and promptly disseminates alarms to authorized users. In conjunction with global positioning system (GPS) tracking provided by TRANSCOM, the system can also monitor and track packages during transport.

A compact dosimeter has been incorporated in the ARG-US tags via an onboard universal asynchronous receiver/transmitter interface. The detector has a wide measurement range for gamma radiation – from 0.1 mSv/h to 8 Sv/h. The detector is able to generate alarms for both high and low radiation and for a high cumulative dose. In a large installation, strategically located dosimeter-enabled tags can yield an accurate, real-time, 2D or 3D dose field map that can be used to enhance facility safety, security, and safeguards. This implementation can also lead to a reduced need for manned surveillance and reduced exposure of personnel to radiation, consistent with the ALARA principle at workplaces.

INTRODUCTION

Environmental remediation and radioactive waste management entail the collection, storage, processing, and disposal of a variety of materials, ranging from legacy weapons stocks, fuel cycle products and by-products, and medical and industrial radioisotopes to radioactive wastes. The packages holding these materials, governed by International Atomic Energy Agency (IAEA) regulations for international transport activities [1,2], are classified as Excepted, Industrial, Type A, Type B, and Type C, with Type C being the most stringently regulated. Many of the IAEA member states adopt the same standards for their domestic transport and handling as well.

In addition to regulations on packaging, IAEA also mandates physical protection against tampering or unauthorized removal of materials [3,4]. The physical protection measures consist of a combination of hardware (security devices), procedures, and facility design fortifications. On

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the basis of the types and quantities of materials, the degree of protection is classified as Category I, II, or III, with Category I being the most tightly guarded.

Radio frequency identification (RFID) [5–9] is a technology that can augment the existing safeguards and security measures and further enhance the protection of both the materials and personnel. It is particularly well-suited for some of the more difficult and monotonic tasks and can greatly assist in the surveillance and verification processes.

An RFID system consists of three components [5,7,8]: tags that are mounted on the packages, readers that interrogate the tags, and software that manages the flow of data and instructions between the tags and readers. With RFID, unlike many other tagging methods, a line of sight is not required between the tags and the readers. Battery-powered tags may have an effective work range of >100 m from the readers. The system tracks the tagged objects and queries their state of health autonomously and continuously. It triggers an alarm when the threshold of any sensor in the tag is exceeded. The control computer, in conjunction with a secure network, can send real-time information thousands of kilometers away. In transportation, the information, including event location, can be relayed via cellular or satellite communication networks and be shared by multiple users remotely in near real time.

ARG-US RFID System

The unit name, ARG-US, is derived from ARGUS, which means a watchful guardian. The system was developed by Argonne National Laboratory under the auspices of the U.S. Department of Energy (DOE) Packaging Certification Program (PCP) (DOE Office of Environmental Management [EM], Office of Packaging and Transportation). The system [10,11,12,13], which consists of tags, readers, and software for local and web-based applications, can continuously monitor and track nuclear and radioactive materials during storage, processing, and transportation.

The tags for the ARG-US RFID system are battery powered with built-in sensors for temperature, shock, humidity, seal, radiation (gamma), and battery strength. The front of the tag is covered by plastic to facilitate radio frequency transmission, and the back is sealed with a strong metal plate with a flange for attachment. Figure 1 shows the construction of an ARG-US tag. Because both the plastic cover and metal back plate are inexpensive and can be readily modified, the form factor of the ARG-US tags is versatile and can accommodate multiple packages. Figure 2 shows ARG-US tags mounted on several types of approved drums for nuclear materials.

For nuclear applications, the tag electronics must adequately resist radiation damage. In gamma irradiation tests performed with a Cs-137 source, the tags were verified to function at a dose beyond 31 krad. This dose level corresponds to about 17 years of service in a field of 200 mR/h, the regulatory dose rate limit on the surfaces of Type B packaging. Since the actual surface dose rates are often significantly lower than the statutory limit, the life span of the tags would be proportionally longer.

The radio wave transceiver in ARG-US tags operates at 433 MHz and complies, for the most part, with the ISO 18000-7 standard [14]. This frequency is globally accepted and widely used. Of particular significance is its suitability for use near metallic objects, such as metal drums or containers. Other components on the tag's mother board (Figure 1) include nonvolatile memories, a temperature sensor, a humidity sensor, a cantilever piezoelectric shock sensor, and the circuitry for processing the signals from the piezoresistive seal sensor (not shown). The nonvolatile memories can be programmed to store encrypted user data (e.g., contents manifest), sensor data, and event histories. When the stored information is programmed, it may be used as the basis for an automated tickler system that addresses compliance with processing or maintenance requirements and schedules.

Fig. 1. Interior view of ARG-US RFID tags, with the metal back plate and seal sensor removed

Fig. 2. Versatile form factor, which allows ARG-US RFID tags to be mounted on various types of drums

Low-self-drain, high-capacity lithium thionyl chloride (Li-$SOCl_2$) primary cells are used in the tags. To further extend battery service life, a smart battery management board is incorporated (right compartment in Figure 1). Although up to four batteries may be loaded, auto-switching keeps only one battery on duty at any time. When the last battery is nearly depleted, an alert to call for replacement is automatically issued. It is projected that under normal usage, this method provides up to 10 years of service without requiring the battery to be changed.

To communicate with the tags via radio frequency, one or more interrogators (readers) are used. The communication is two-way: The readers can receive signals from the tags, and they can send instructions to the tags. The readers may be permanently mounted on a building structure or on mobile carts. The reading range can be >100 m, and no line of sight is required. Mobile handheld readers may also be used when the need arises.

Software provides the vital link between the technology and the end user and is a key component in implementing ARG-US. The ARG-US software package consists of a program called ARG-US OnSite, local and central databases, and web applications for storage, processing, and transportation. ARG-US OnSite is the basic building block; it controls the readers via the control computer and provides a graphical user interface (GUI) to operate the hardware. The design philosophy is to present all relevant information on the console screen in a manner that can be intuitively understood by the user, so that by using pull-down menus, he or she can efficiently obtain information and issue commands. Within the secure Internet, information from multiple rooms, buildings, or sites can be linked together by using the ARG-US web applications. The information can be accessed by authorized users located anywhere at any time. ARG-US TransPort (a subset of the ARG-US system) can monitor and track nuclear or radioactive materials in transport. It incorporates mapping and a global positioning system (GPS) and uses mobile communication equipment in the transport vehicle. Sample displays of the ARG-US OnSite screen and web page are shown in Figures 3 and 4, respectively.

Benefits of Dosimeter-Enabled RFID System

To further extend the functionality of the ARG-US RFID system, a gamma dosimeter has been incorporated into the tags to augment the existing sensors (temperature, humidity, seal, shock, and battery strength). The dosimeter regularly samples the dose rate and accumulates a total dose estimate that is stored in nonvolatile memory. In facilities with a large number of packages, dose rate readings from the tags can be collected to precisely map the radiation field — any significant perturbation from the norm can be used to generate alarms, thereby enhancing the safety, security, and safeguards posture of the operation. Because the radiation field data are constantly available, the number of routine manned inspections with hand-held detectors (particularly those over local areas with high radioactivity) may be curtailed, thus reducing the exposure of personnel to radiation. The dosimeter expansion is designed to facilitate the future development and integration of other types of sensors beyond gamma dosimeters.

In addition to storage vaults and processing facilities, other installations with radioactivity present (e.g., nuclear power plants, hospitals, research and development laboratories, research and test reactors, and nuclear fuel cycle facilities) can also benefit from the system's remote and continuous radiation-monitoring capabilities.

INTEGRATION WITH ARG-US RFID TAG HARDWARE

The detector modules selected for incorporation into the ARG-US tags are modified compact personal dosimeters available off the shelf. The principal features considered in selecting them were their size, power consumption, operating dose-rate range, reliability, and cost.

The selected detector is sensitive to x-ray and gamma radiation in an energy range of 50 keV to 6 MeV and has a wide dynamic measurement range — from 0.1 mSv/h to 8 Sv/h. A carrier board is used to mount the detector module and facilitate the tag integration (see Figure 1). The module carrier board is easily detachable should dosimetry be unnecessary for an application.

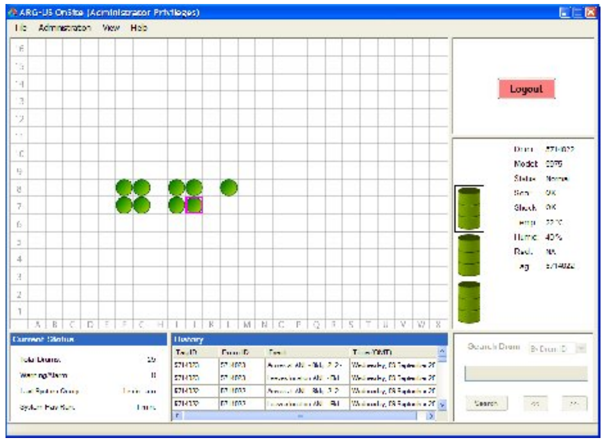

Fig. 3. Sample screen display of ARG-US

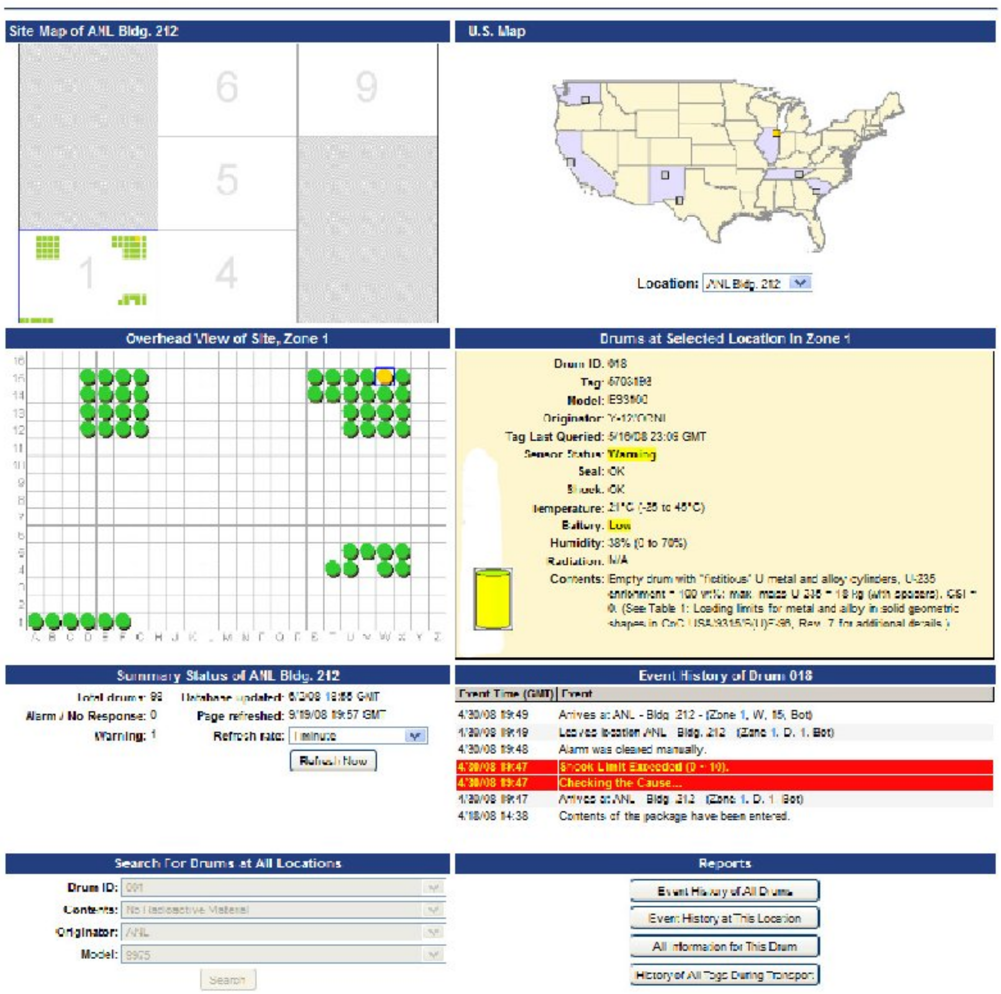

Fig. 4. Sample web screen display of ARG-US for multiple sites

The data from the dosimeter are collected by a low-power micro-controller unit (MCU) on the carrier board. The nonvolatile memory implemented within the MCU allows the accumulated dose rate information to be retained when the power is off. Careful power management and a judicious selection of components resulted in the impact of the dosimeter on battery performance being only minor. In the low-power mode of the carrier board, the MCU is set, at regular programmable intervals, to wake up the dosimeter and read the instantaneous dose rate. The data are passed along through the tag to the reader network whenever those values are requested. The requested data are then displayed at the operator terminal and stored in the system database. Data on alarm events that have resulted from high or low dose rates or a high accumulated dose are stored in both the MCU and the database. To allow the tags to be used in discrete processing or shipping campaigns, the cumulative dose can be reset by the user via the radio frequency link and ARG-US GUI. Figure 5 shows a simplified block diagram of the dosimeter integration in the tag structure and a photo of the carrier board itself, sans dosimeter. The MCU provides additional possibilities for interfacing to facilitate the development of new sensor features, and the carrier board is designed with an internal separation to allow modular expansion capabilities.

The communications protocol between the carrier MCU and the ARG-US RFID tag is designed to be independent of the number and type of sensors attached to the carrier board. This flexible interface allows the MCU of the carrier board to simply identify the amount of data present. The RFID tag firmware design is independent of the number and kinds of sensors that are attached to the carrier. In addition to its data processing, tag interface, alarm initiation, and power management features, the custom-built carrier board has provisions to accept additional sensors, including external ones, through its versatile mix of interfaces. The additional sensors being considered include specialty gas sensors, enhanced seal and tamper indicators, and neutron detectors. A variety of interface methodologies are available, including universal asynchronous receiver/transmitter (UART), inter-integrated circuit (I2C), serial peripheral interface (SPI), universal serial bus (USB), plus direct analog voltage and digital signal interface. The micro-controller used in the carrier provides SMBus [14] master and slave capability.

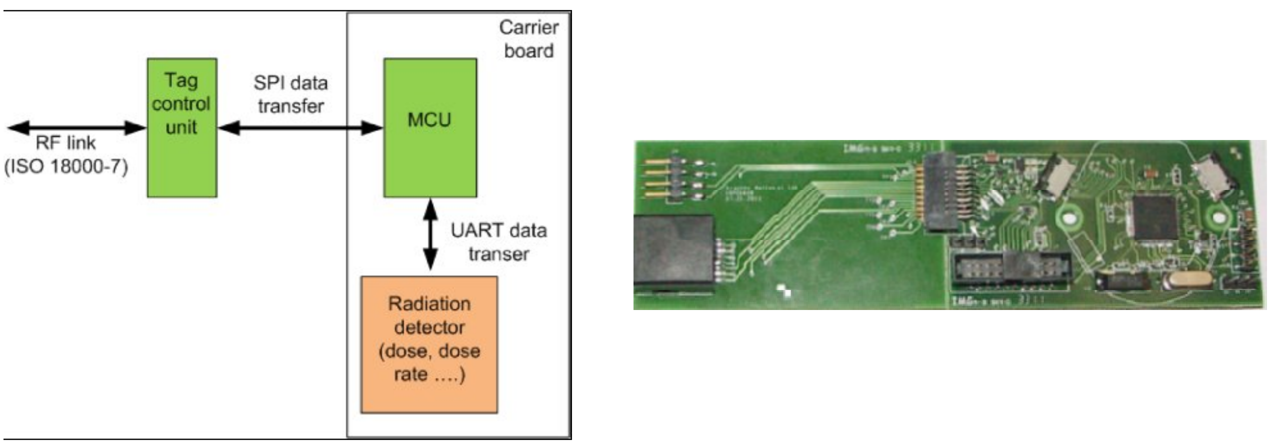

Fig. 5. Sketch of interconnections, plus photo of dosimeter carrier PC board

BENCHMARK TESTING OF INTGRATED DOSIMETERS

Benchmark testing (Figure 6) with a certified Cs-137 source was performed for the lead tags to verify that the integrated dosimeters are functional. The testing was performed at six dose rates (10, 50, 100, 150, 200, and 1000 mR/h), with the longest exposure being 24 hours. The reported dose rates are from the most up-to-date, facility-published exposure rate table traceable to the NIST (National Institute of Standards and Technology) standard.

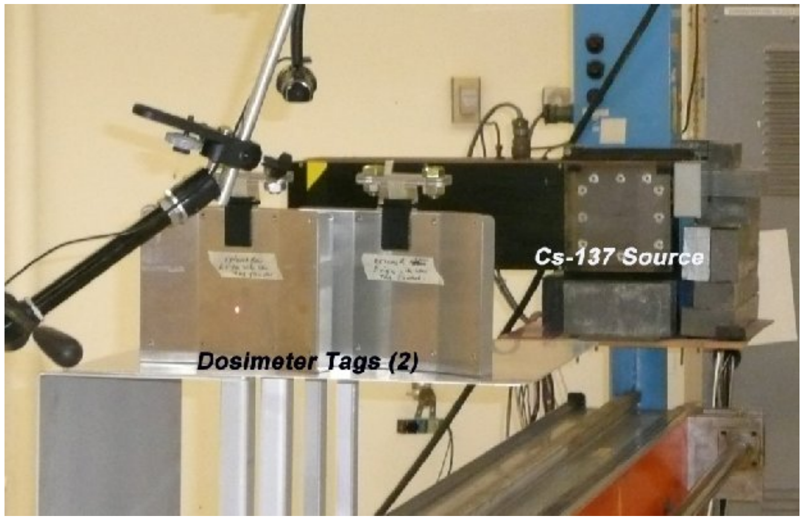

Fig. 6. Benchmark testing of dosimeter tags with a certified Cs-137 source

All benchmark testing results are in good agreement with the published data on dose rates, which indicates that the selected dosimeters are accurate. An equally important result is the ability to read off the dosimeter output via radio frequency, which indicates that the tag integration effort was successful.

Figure 7 shows the two tested tags yielding a steady reading over a period of 24 hours at a constant dose rate of 100 mR/h. The integration of the dose rate into the cumulative dose was also accurate. By changing the distance between the tags and the source and by using proper attenuators, the dose rates were varied to determine the dosimeter performance over a range of anticipated field conditions. These results are shown in Figure 8. Again, the behavior of the integrated dosimeters was highly satisfactory.

On the basis of these positive findings, the selection of the dosimeter and the design of the carrier board were finalized, and the production of the first batch of dosimeter-enabled ARG-US RFID tags is underway.

SUMMARY

A commercial gamma dosimeter was successfully integrated into the ARG-US RFID tag system via a carrier board that enables modular expansion of this system to include other types of sensors in the future. The performance of the gamma sensor was verified at a variety of dose rates, and production quantities of ARG-US RFID tags with integrated gamma dosimetry are underway. The addition of a gamma dosimeter allows the ARG-US RFID system to be used in wide array of area monitoring applications while providing the significant benefit of reduced human exposure. A modular approach allows new sensor types to be added as needed without requiring any redevelopment of the core technology.

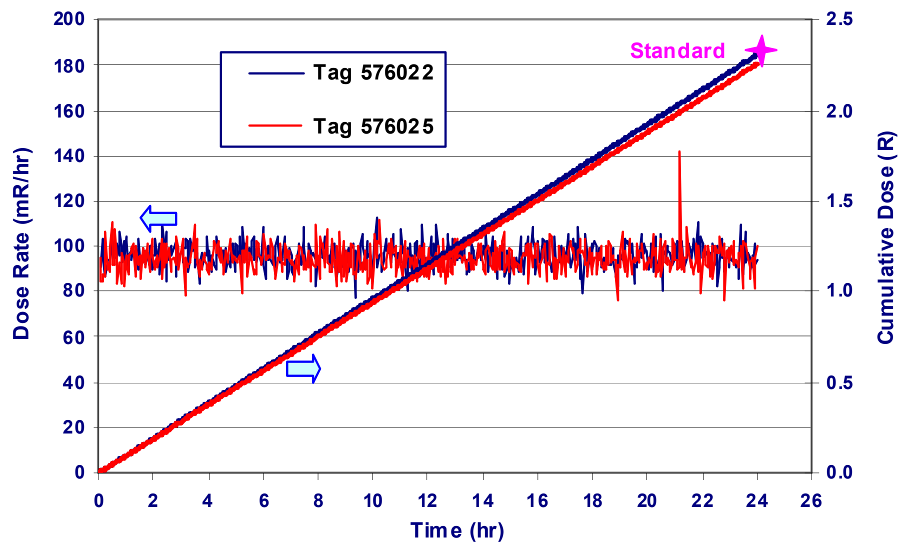

Fig. 7. Response of integrated dosimeter at a steady dose rate of 100 mR/h for 24 hours (Self-shielding of the front plastic case of the tags accounted for the ≈4% reduced readings of both the dose rates and cumulative doses.)

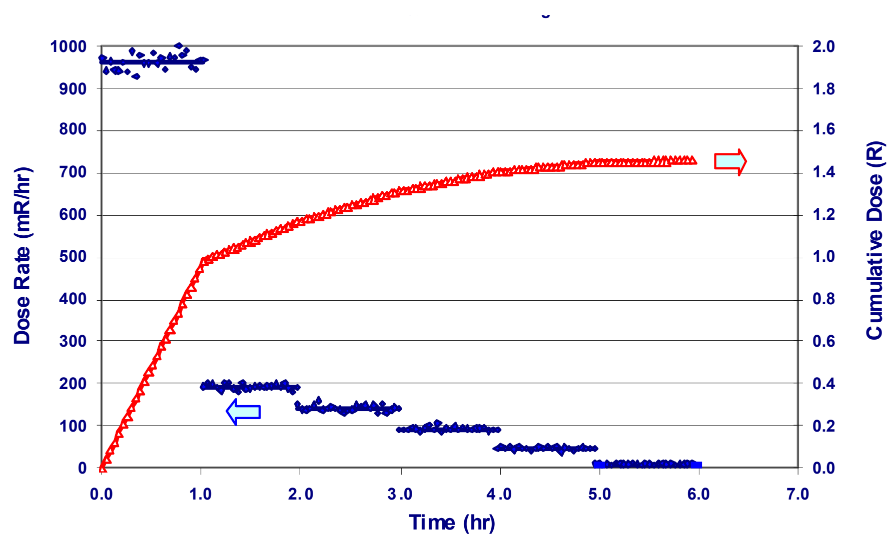

Fig. 8. Response of integrated dosimeter at dose rates ranging from 10 to 1000 mR/h (Self-shielding of the front plastic case of the tags accounted for the ≈4% reduced readings for both the dose rates and cumulative doses.)

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