Integrated Sensor Systems for Packaged SNM Monitoring and Surveillance

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ABSTRACT

Several new sensing devices have recently been designed as part of the Oak Ridge Systems for Enhancing Nuclear Safeguards (ORSENS^{TM}) program. These sensors were developed for use in real-time material accountability monitoring systems. The attributes that can be monitored include radiation (both gamma and neutron), weight, item identification tags, temperature, isotopic enrichment, item motion, and physical location. This paper will describe the ORSENS^{TM} technologies and evaluation/demonstration tests which are in progress in collaboration with Argonne National Laboratory-West (ANL-W) and Idaho National Engineering and Environmental Laboratory (INEEL). A Safeguard Technology Evaluation Laboratory (STEL) was installed at a Special Nuclear Materials storage area at ANL-W as part of Department of Energy (DOE) Plutonium Focus Area (PFA) activities. Within the STEL one can mock-up material storage conditions found at a given site within the DOE complex and thus test sensor systems in a realistic environment. A major emphasis of the STEL is to provide process definitive testing of technologies that have been developed for monitoring or measuring actual physical attributes from stored SNMs and to find cost effective solutions to the labor intensive physical inspections (custodial responsibilities) associated with the storage of SNM.

I. Introduction

Process definitive testing of several sensor systems under development at the Oak Ridge Y-12 Plant has been performed using the Safeguard Technology Evaluation Laboratory[1] (STEL) located at Argonne National Laboratory – West. The evaluated sensor/systems include the SmartShelf System, the RADSiP^{TM} Gamma Sensor, and the Passive Self-Powered Neutron Sensor. These systems were tested for their effectiveness in providing automated special nuclear material safeguard monitoring in the realistic, operational environments of the STEL.

II. Prototype IMSS Using ORNL Systems

A prototype monitoring and surveillance system (see Figure 1) was designed and implemented using the Oak Ridge Y-12 sensor technologies.

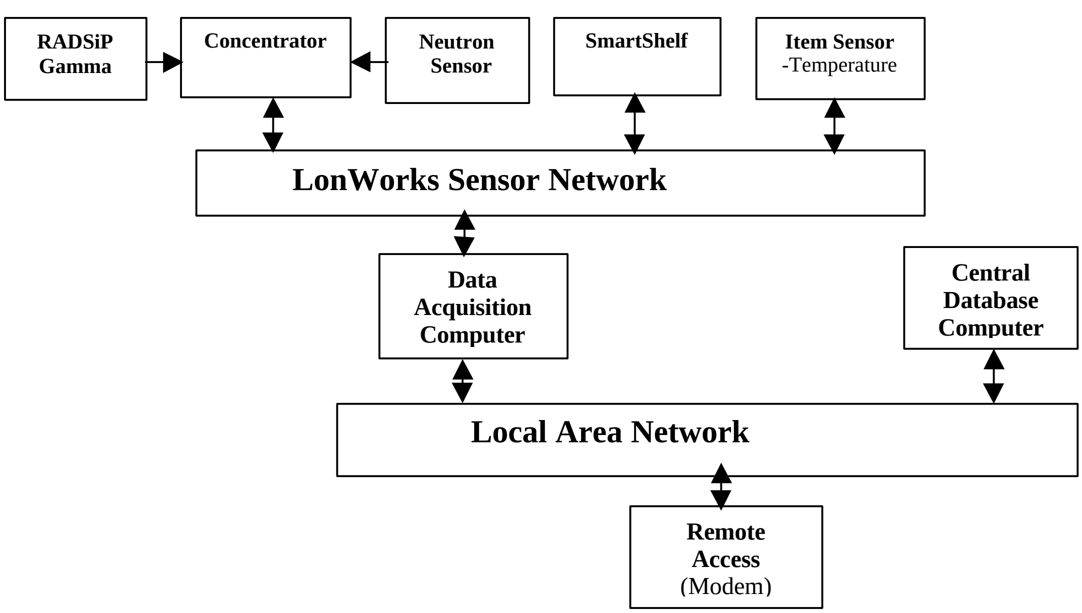

Figure 1. Prototype Integrated Monitoring System

Sensor attributes and parameters to be monitored include: 1) Real-time package radiation levels, 2) Real-time package temperature monitoring 3) Electronic tracking of 3013 container location and 4) Data integration. The components of the prototype system are detailed below.

II.A CAVIS Radiation Sensors

Several types of gamma-ray and neutron radiation detectors have been developed to support the CAVIS project at the Oak Ridge Y-12 Plant. Two of these systems, the RADSiP™ and the Passive Self-Powered Neutron Detector, have been installed in the STEL for evaluation under actual plutonium monitoring conditions.

The RADSiP™ gamma-ray detector provides a method of monitoring gamma-ray emission from Special Nuclear Material (SNM) bearing containers. The technology is based on Silicon-PIN photodiodes. Each detector has a selectable gamma-ray energy window from 20 keV to 100 ke, with pulse height discrimination of unwanted noise. The neutron detector is self-powered and does not require electrical excitation. This system provides continuous monitoring of materials in long-term storage. These detectors consist of rectangular Lucite scintillator blocks covered with a ZnS(Ag)/LiF powder in an epoxy binder. The Lucite blocks are coupled to wavelength shifting optical fibers. Neutrons create high-energy alpha particles by interacting with the LiF, which causes scintillation in the ZnS. The resulting light is detected with a photomultiplier detector. Both detectors are interfaced with the data control system using a sensor concentrator. The sensor concentrator is a configurable multichannel sensor interface and signal processing unit designed for use with a variety of Oak Ridge National Laboratory (ORNL) sensors. Developed with LonWorks® Technology, the sensor concentrator allows data to be easily and reliably accessed on a low-cost twisted pair network. A multiprocessor architecture enables redundant data acquisition to minimize the impact of single-point hardware failures. Ideally suited for monitoring applications, the sensor concentrator acquires and filters sensor data and can immediately alert network devices when user-defined thresholds are exceeded.

II.B Smartshelf™ Automated Item Identification System

SmartShelf™ is an inexpensive method for monitoring material in active storage. The system maintains continuous surveillance over all items within its domain. When an alarm or abnormal event occurs the item inventory can be quickly reconciled. SmartShelf™ substantially reduces the time required to verify inventory and eliminating the need for manual searches. As an added feature**,** SmartShelf™ can record the identity and verify the authorization of any person moving containers. A date/time stamp is provided to indicate when the container was moved.

III. Process Definitive Testing of Prototype

The STEL was developed through a joint Argonne National Laboratory and Lockheed Martin Idaho Technologies Company (LMITCO) project[2] funded by the Department of Energy's Plutonium Focus Area. The purpose of the STEL is to evaluate and test prototype integrated monitoring and surveillance systems (IMSS) using various storage configurations under both nominal and transient conditions. A product of the STEL is to provide DOE with a capability for performance testing of prototype IMSS systems and to provide a means of evaluating technology before wide scale purchase and installation.[3] The STEL is housed within the Fuel Manufacturing Facility (FMF) vault at the Argonne National Laboratory- West site in Idaho. The FMF is an active and clean vault that is ideal for testing prototype integrated monitoring systems within a realistic material storage environment. The vault is easily accessible for customer-supported sensor integration and product demonstrations. An area within FMF, yet external to the SNM vault, is used to house the data acquisition/control station and supports long-term experimentation.

Field trials were performed to test and evaluate the prototype system's ability to facilitate the unattended monitoring of weapons grade uranium/plutonium and to provide enhanced security and accountability. All tests were performed using 3013 containers packaged with various Pu/Al and Pu/Du materials in a feedstock or clad plate configuration, with surface radiation levels of 30mR gamma/5mR neutron up to 160mR gamma/50mR neutron.[3] The sensors were evaluated under both static and transient environmental conditions in the STEL. Limited testing has been completed and is discussed below.

III.A System Installation and Test Configuration

RADSiP™ and Neutron Systems were configured with 20 detectors and integrated into an IMSS. Detectors were installed on the containers at the location of maximum radiological activity. Both systems were modified for compatibility to an Echelon LonWorks Communication Network and connected to the STEL data acquisition system. The SmartShelf™ system was attached to four 3013 containers. The system was modified to work on a LonWorks distributed control sensor network and configured to detect additions and removals of containers, recognize alarm conditions, perform self-testing, and to communicate with a host data acquisition computer. During initial evaluations data were collected from the sensors at five minute intervals. During long term monitoring tests the sampling interval was reduced to one hour.

III.B Neutron Detector Evaluations

Interference, or cross-talk, between radiation detectors from different radiation sources in proximity to one another is a major consideration in monitoring packaged nuclear material. Radiation cross-talk experiments were performed using standard handheld radiation meters. A 5mR 3013 container was placed adjacent to a 20mR 3013 container. Standard criticality spacing was maintained. The radiation detectors could not resolve between the two containers. A continuous 30mR field was detected independent of placement of the detector, effectively masking the radiation reading of the 5mR container.

This preliminary test verified that neutron radiation cross-talk between adjacent storage containers may, in certain circumstances, affect the accuracy of radiation detectors and should thus be given proper consideration in vault monitoring. The tests also provided a proof of concept of the ONRL neutron detector technology. However, further development is required due to the mechanical design of system. As designed, the system is currently too fragile for field deployment. ORNL is working to improve sensor performance through re-design of detector electronics.

III.C Gamma-Ray Detector Evaluations

The RadSiP™ gamma-ray detector provides a real-time continuous gamma-ray reading and overcomes limitations of other dose rate meters. The detector is minimally impacted from radiation crosstalk and is capable of resolving a unique radiation signature of each Pu bearing container. The gamma-ray detector also has sufficient sensitivity to detect movement of containers. For optimum detector performance proper placement on the container is critical. Testing has demonstrated adequate long-term stability of the detector.

One difficulty when using the RadSip™ detector is proper and consistent detector placement. Experiments verified that the gamma-ray profile of the packaged 3013 containers used in the evaluation were not uniform, resulting in radiation "hot-spots" on the container surfaces (Figure 2). Gamma-ray readings were taken in four quadrants. The outer ring represents radiation readings at lower portion of container and inner ring represents radiation at upper portion of container. Segment length is proportional to radiation field strength. Tests verified that gamma readings could vary by as much as 273% depending on placement of the detector.

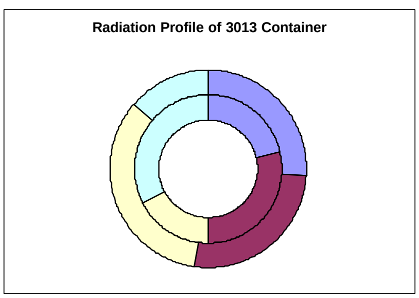

Figure 2. Radiation Profile of Pu Bearing 3013 Container.

Further tests also demonstrated that orientation of the detector had an impact on performance. Readings were taken with the detector mounted at the same location on the 3013 container, however, in four different detector positions. Experimental data is summarized in Figure 3 and illustrates that detector readings can vary by $\pm$ 13%. Testing showed that proper placement of the detector made it possible to monitor the regions that best represents the radiological activity of the material, to optimize sensor sensitivity, and to maximize detection of off-normal events. A priori testing of detector configurations using a test facility such as STEL can help optimize system configuration before deployment.

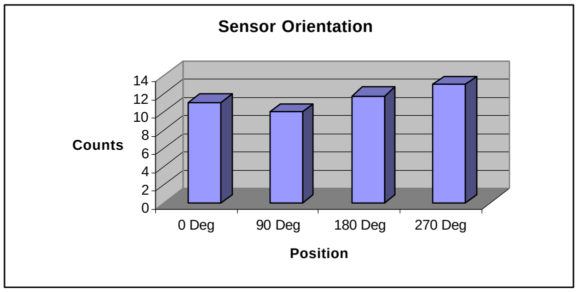

Figure 3. Impact of Sensor Orientation

Detector sensitivity must also be considered in the design and deployment of monitoring systems. Various storage configurations may physically restrict the direct attachment of the gamma-ray detector to the item under surveillance. Tests were performed to characterize the gamma-ray detector's response versus distance from a 50 mrad 3013 container. Results are presented in Figure 4. Testing showed that the detector, at distances up to 6 inches from the 3013 container, could correctly distinguish between background and the 3013 container. A signal-to-noise ratio of 1.0 was not encountered until the detector was placed 12 inches from the 3013 container. The detector had sufficient resolution to generate an alarm if the container under surveillance was moved more than 1 inch away from a stationary detector.

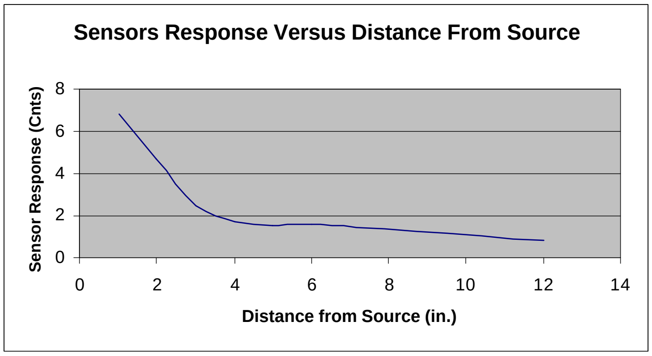

Figure 4. Detector Sensitivity Response as a Function of Distance From Source

Detector placement is an important factor in minimizing radiological cross-talk from adjacent containers. Experiments were performed using two 3013 containers in a pedestal storage configuration, which consists of two containers in a vertical stacked orientation with criticality spacing maintained between the items. Baseline gamma-ray readings at contact were 50mrad for container #1 and 160 mrad for container #2. RADSiP^{TM} gamma-ray data were collected over 15 discrete steps (approx. 2 inches per step) ranging from a detector placement at 6 inches above the 1st container to 6 inches below the 2nd container. Figure 5 shows the unique radiation signature of each container.

Testing showed that a sensor placement in the region between the two cans would result in erroneous cross-talk impaired data. A 38% increase in radiation baseline occurs between adjacent containers and would effectively mask a radiation signature of a 10 mrad container.

In a typical installation the sensors can also be exposed to significant diurnal temperature cycles. Tests verified that the sensors and electronic units have significant performance variability when exposed to temperature cycles. A correlation was made between temperature and dose rate. The effect upon the sensor is linear and is easily temperature corrected.

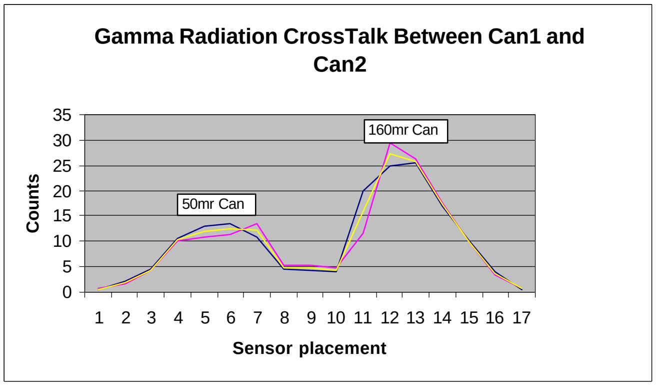

Figure 5. Gamma Radiation Cross-talk Between Adjacent Containers

Long-term detector performance was also of interest. RADSiP™ detectors were installed onto four 3013 containers and subjected to long-term performance testing (See Figure 6). Testing showed that gamma-ray monitoring can provide several important indicators including stability of the SNM material, quantity of the material, and unauthorized movement of the material. Tests are qualitative and were performed with un-calibrated sensors. However, data verified a strong statistical correlation between detector response and the actual radiation attributes of the 3013 containers. Sensitivity and long term stability was sufficient to resolve between a 40 mrad and 50 mrad source.

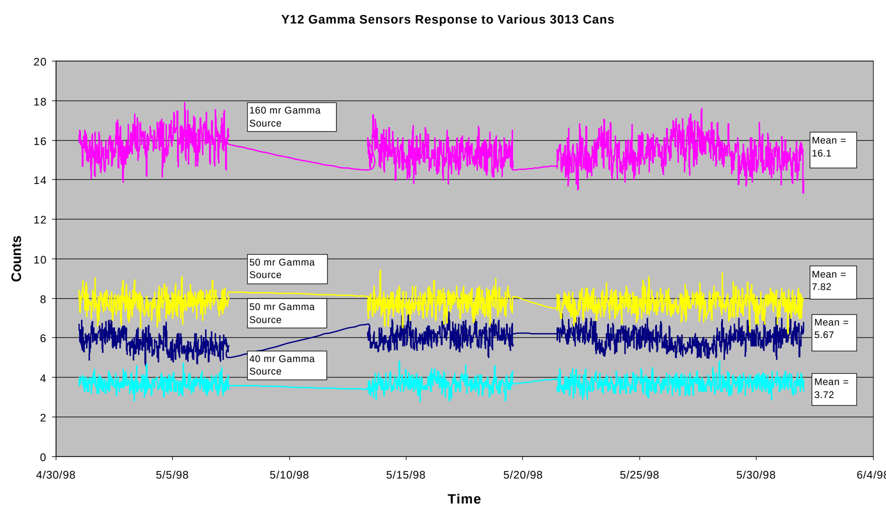

Figure 6. Y12 Gamma Sensor Response to Various Pu Bearing 3013 Containers

III.D SmartShelf System Evaluations

SmartShelf™ monitors the presence of controlled items via electronic buttons attached to the items. The electronic buttons contain integrated circuits that are laser-engraved at the time of fabrication with unique serial numbers. Electronic buttons were attached to several 3013 containers and placed under SmartShelf™ system surveillance. Tests were performed to verify that SmartShelf™ properly detects and responds to all conceivable threats. Testing involved access control, tamper indication, alarm response time, robustness and system vulnerability. Results are summarized below.

SmartShelf™ is based on the fact that only authorized personnel are issued identification buttons and thus are allowed to make an authorized material movement. During the access protocol, an authorized operator is required to present his or her identification button to the system. Tests verified that if the protected item (i.e. 3013 container) is not disconnected according to protocol, an alarm is generated in 100% of the cases. The system was also designed to be robust in the face of loss of parts of the system. The data acquisition central computer generates an alarm when it detects the absence of a

SmartShelf™ node. Likewise, if the central computer fails, the node has distributed control capabilities and will continue surveillance. Alarm status is stored in local memory until the central computer is restored.

Vulnerability analysis was performed to determine if SmartShelf™ could be defeated. The following off-normal tamper events were attempted: 1) Operator left the ID key connected, 2) Operator presented ID key without following protocol, 3) Wiring to network tampered and 4) Smartshelf node disconnected. The system detected all tamper tests.

When a tamper condition is detected an alarm is actuated and the event is logged onto the Data Acquisition Computer. Tests were performed to characterize the alarm response time. Fifteen seconds of the total alarm response time is a function of the protocol software and can be user modified. Results are summarized in Figure 7 and show a fairly uniform response time.

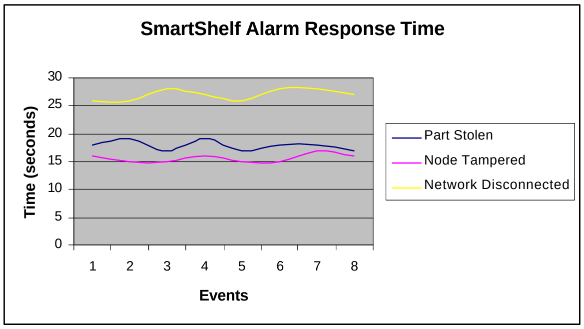

Figure 7. SmartShelf™ Alarm Response Time.

Several methods of attachment of the electronic button to the 3013 container were evaluated, including adhesives, straps and retainer plates. In all cases it was shown that SmartShelf™ could be defeated by removing the button from the container, while maintaining electrical connections to the system. It is recommended that SmartShelf™ be integrated with supplemental monitoring sensors such as container and/or button motion and tamper indicating devices.

IV. Conclusions

The prototype IMSS based on ORNL systems has been continuously collecting data for four months. More than 2000 data sets have been collected and analyzed from each 3013 container. Preliminary conclusions are:

1) All ORNL technology was successfully integrated into a standardized integrated and monitoring system with minimal effort. However, some specialized firmware/software was required.
2) The system as currently configured does not meet all DOE STD-3013 requirements, such as weight and temperature monitoring. Efforts are underway to integrate the Oak Ridge Capacitive Weight Pad into this prototype IMSS to fulfill additional requirements.
3) Gamma-ray detectors have performed to site-specific requirements. However, additional field tests need to be performed to fully characterize long-term behavior under additional storage configurations and off-normal thermal conditions.
4) Performance data will be used for future design enhancements to the prototype Neutron Detector system.
5) The SmartShelf™ system performed to vendor specifications. More than 3000 transitions were processed without a missed or failed event.
6) The SmartShelf™ system was designed for Inventory Control, not as a Security System. It still, however, exhibits many security access control capabilities and has lower vulnerability risks than that of competitive barcode techniques.

References

[1] "System Specification for the Integrated Monitoring Surveillance System", DOE/ID-10595, U.S. Department of Energy , Plutonium Focus Area, , September, 1997.

[2] "Plutonium Focus Area (PFA) Integrated Surveillance System (ISS) Final Draft"

[3] Aumeier, S.E. et al., "Integrated Monitoring and Surveillance System Demonstration Project Phase II Accomplishments," Argonne National Laboratory ANL/ED/9