Automated Systems for Safeguarding and Accountancy of Stored Nuclear Materials

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ABSTRACT

Oak Ridge has developed several sensor systems that are capable of providing unattended monitoring of the physical and/or assigned attributes associated with stored nuclear materials. These systems include the Continuous Automated Vault Inventory System (CAVIS™), SmartShelf™, and the ReflectoActive Seal System™.

Each of these systems can be implemented independently or may be integrated with existing systems through the Graphical Facility Information Center or GraFIC™ software package. GraFIC™ is a versatile software package designed to operate in a distributed computing environment. GraFIC™ can monitor and report all item and facility activity from the various sensors and systems to an unlimited number of authorized remote clients through a common interface. The software also contains an Intelligent Facility Management (IFM) package that helps storage facility managers with space planning, records management, item location, and variety of other facility specific needs.

Results and details from several system deployments will be described, along with the specific features and possible uses of each system.

INTRODUCTION

Nearly all facilities that store hazardous materials must comply with prevailing federal, state, and local laws. These laws usually have components that require periodic physical inspections or inventories that are designed to insure that all materials remain safely and securely stored.

With the end of the Cold War, the emphasis on long-term secure storage for nuclear weapons-grade plutonium and uranium has increased substantially. Both the national and international nuclear arms control agencies continually must attempt to devise the best technological and procedural mechanisms to cost-effectively assure that the world's supplies of these materials are thoroughly safeguarded. Safeguard systems operating at many facilities today include automated security systems and site-specific material accountability systems. The accountability systems generally rely on physical measurements with specialized equipment and intermittent audits performed by highly trained personnel. These systems for special nuclear material (SNM) accountability, although effective, are very labor intensive and highly procedural. Unfortunately, the inspections are slow, put personnel at risk, and only find anomalies after they have occurred.

The Continuous Automated Vault Inventory System - CAVIS™

CAVIS™ is a system specifically designed to minimize the labor and radiation exposure associated with SNM inventories. CAVIS™ provides weight temperature, and radiation attribute measurements in real-time, individually from each stored container of SNM. This allows for near real-time inventory reconciliation (through automated database comparison with book values). In other words, up-to-the-minute inventories are possible on demand. The system can support information from four to five sensors per item. The sensors that have been built for CAVIS include monitors of an item's weight and temperature, gamma ray flux, relative ^{235}U enrichment, neutron flux, item location, and item motion.

CAVIS™ also is capable of handling information from other remote sensing systems or information systems (e.g., SmartShelf™ and the ReflectoActive™ Seals) through the Graphical Facility Information Center (GraFIC™) software package.

The typical CAVIS^{TM} sensor package installed in nuclear material storage vault consists of a weight sensor, and one or both of a radiation and temperature sensor. The sensors being installed to monitor stored uranium at the Oak Ridge Y-12 Plant are described below and illustrated in Figure 1.

Figure 1. A Depiction of CAVIS™

The RADSiP™ gamma-radiation sensor is a small, inexpensive, virtually passive sensor designed for monitoring individual containers of stored nuclear materials (shown if Figure 1). The sensor provides a method for maintaining 24-hour surveillance of stored radioactive materials by monitoring each item for change in its gamma radiation level. Applications for this sensor include nonproliferation monitoring, spent fuel safeguards, and long-term monitoring of stored radioactive wastes. Deployments to date have demonstrated that the sensors are affected by source-to-detector distance, collimation of the source, container thickness and material matrix. The count-rate is maximized by placing the sensors as close as possible to the source.

The main elements within the sensor unit are a silicon PIN (p-material, intrinsic, n-material) photodiode, a low-noise preamplifier, and a pulse-shaping amplifier. Signal levels are selected with a pulse height discriminator, which includes a lower-level adjustment for precise gamma-ray energy band monitoring of ^{235}U. The Surface Mount Technology (SMT) circuit board is designed for use with either a silicon-PIN photodiode or a CdZnTe (Cadmium-Zinc-Telluride) gamma-ray radiation detector (called RADTELL™). The RADTELL™ radiation detector extends the gamma region into the energies associated with stored plutonium.

Pulses resulting from the photon interactions in the silicon detector are produced at an approximate rate of 500 counts per second per R/hour. Each charge pulse from the diode is amplified and shaped to provide a 20 - 50 microsecond wide pulse to a discriminator. The discriminator's lower level is adjusted to correspond to the full energy peak of 60 keV line from ^{241}Am. The gamma-ray energy band from 60 keV to the highest energy Compton interaction pulses generated in the diode (~300 micrometers of silicon) provide a sensitivity band with a precise region for estimating uranium enrichment.

The capacitance weight sensor can monitor inexpensively, for long periods of time and in widely variable environments, the weight and temperature of stored nuclear material. The capacitance weight pad consists of two stainless steel plates separated by load bearing springs and a differential capacitance proximity detector (shown in Figure 1). As weight is applied to the unit, the springs compress and the top plate moves closer to the proximity detector. This plate movement changes the duty-cycle of the on-board oscillator, which change corresponds directly to the change in item weight. Weight information is combined with temperature information and sent back to the system in a low-noise time-domain format. A single coaxial cable is used for power and signal, simplifying facility wiring.

The novel proximity probe uses a differential capacitance configuration that compensates for atmospheric humidity and temperature without the need for a sealed housing. All the electronics in the weight pad are radiation-resistant solid state devices that are expected to withstand a radiation dose of 10^5 R.

The unique modular design of the capacitance weight pad allows it to be customized for different size containers and different weight loads. The open frame design accommodates a variety of radiation detectors that can be installed in the weight pad without significant modifications to the pad.

SmartShelf™

SmartShelf™ is a hardware and software system for asset management applications in which it is

Figure 2. The SmartShelf™ system

necessary to know the physical location of controlled items at all times. It has been designed for rapid record keeping in dynamic storage environments (environments where items are frequently moved or removed from storage locations). The system provides an inexpensive method for maintaining 100%, 24-hour surveillance on all stored items and/or facility assets. Reports of current inventory, employee activity, access to particular assets, or any other system feature are available in minutes and on demand. SmartShelf™ provides the who, what, when, and where of asset management.

SmartShelf™ keeps track of controlled items via electronic buttons attached by the user to the items. Attachment may be effected by adhesives, straps, spot welding, or by the use of specially designed retainer plates. Buttons are 16 mm in diameter, 5 mm high, made from stainless steel and house an electronic integrated circuit that is laser-engraved at the time of fabrication with a permanent unique serial number. Authorized personnel are issued identification buttons by which they make themselves known to the system when accessing controlled items.

Each controlled item is electronically connected to a SmartShelf™ node for surveillance. Nodes are chained together, and up to 8 chains, connecting hundreds of nodes, may be connected to a node computer (the gray rectangular box in the center of Figure 2). Many node computers can be chained together and connected to a desktop personal computer running Microsoft® Access. In this way thousands of nodes and controlled items may be monitored from a single central site.

SmartShelf™ continuously monitors itself to verify the presence of its nodes. Alarms are raised if nodes are lost or disabled. Each node is also queried to determine if a controlled item has been attached or removed. During the access protocol, an authorized operator is required to present his or her identification button to the system, and if this is not done according to the protocol, an alarm is raised.

SmartShelf™ has been designed to be robust in the face of loss of parts of the system. The central computer can raise an alarm when it detects that a node computer has failed, but will continue to monitor other working node computers. Similarly, should the central computer fail, the node computers will continue their surveillance and simply store records of activity in local memory until the central computer is restored. Discrepancies between the expected inventory and actual inventory are resolved when the restored hardware becomes operational.

Microsoft® Access® is used to store the information about activity at nodes. The database can be queried to determine the frequency of access by personnel, the current inventory, the status of any item, or any other attribute. New queries and reports can be designed with ease by the end user familiar with Access.

SmartShelf™ systems have been deployed at Oak Ridge, and are under evaluation at the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) in Sarov, Russia, and the Kurchatov Institute in Moscow, Russia.

The ReflectoActive Seal System™

The ReflectoActive Seal System™ (Figure 3) is an active system designed to monitor tamper-indicating seals continuously for unauthorized opening or closing. The system provides immediate notification of where and when a breach has occurred.

An active seal is a device that continuously monitors whether a storage container or other repository is opened or closed. The custodian of the container uses the active seal to guard against unauthorized access to the contents of the container. To access the contents of the container, a person must breach the seal affixed to the container closure. Once breached, the active seal immediately alerts a centralized monitoring system, which records the event and initiates the appropriate response. An active seals system provides real-time inventory control and an extra level of protection against tampering or theft.

ReflectoActive Seal System™ technology was developed at Oak Ridge for the purpose of reducing the frequency of physical inventories on containers of SNM stored at Department of Energy (DOE) facilities in the United States. It has a larger capacity than other active seals systems and, because, it uses an entirely optical method of monitoring, it does not suffer from the disadvantages associated with conventional electrical or radio frequency based methods. The ReflectoActive™ Seals System provides a simpler, more cost-effective, method for inventory verification than manual inspection.

Figure 3. The ReflectoActive™ Seals System.

The major components in the ReflectoActive™ Seals System are an optical time-domain reflectometer (OTDR), the immediate detection unit (IDU) with a fast optical multiplexer, multiple seal fixtures, and a computer system running custom software developed for the seals system. The IDU performs preliminary analyses of fiber optic cables and, if a breach is detected, the OTDR is used to pinpoint the location.

The IDU (dark box in upper center of Figure 3) uses a pseudo-randomly modulated light source paired with detectors to continuously monitor the seals and provide instantaneous detection of any breached seal. A breach is indicated by the loss of light at the receiver end of the cable and the associated strong reflection from the breach.

The fiber optic multiplexer (internal to IDU) allows thousands of seals to be monitored among numerous links and provides bi-directional monitoring of each link. This last feature permits the system to remain operational even in the event of a single permanent break in a fiber optic cable.

The OTDR (instrument with screen at center of Figure 3) is used to resolve the location of any breached seal by timing the round-trip reflection of light pulses and relating the time-of-flight to the length of physical cable between the OTDR and the breach.

The seal fixtures consist of the seals themselves (fiber optic couplings) and mechanical adapters used to affix the seals to the storage containers. Seals are reusable and highly tamper-resistant, and can be attached to containers located up to several kilometers apart. The system can be utilized to monitor containers in nearly any type of indoor or outdoor storage location (with containers being monitored individually or in groups). Optical fiber multiplexing allows the system to detect multiple breaches and provides event redundancy.

The computer system controls the hardware, arbitrates alarm events, provides a graphical user interface, and communicates with facility alarm systems. All of the hardware components are industry-standard equipment that can be purchased “off-the-shelf.”

Figure 4 shows a photograph of an active seal being attached to a storage container at the Oak Ridge Y-12 Plant. In this facility, the ReflectoActive™ Seals System is actively monitoring the seals individually attached to a large array of containers located in an SNM storage vault. The seal adapter (A) is affixed to the bolt on the container’s lid-ring-closure mechanism. The seal consists of the coupling and cables (B) attached to the adapter. Also visible on the bolt is a passive cable seal (C).

This system is operationally being evaluated in a field test that randomly requires the seals to be routinely opened and closed. The operational data acquired from this field test is being used to improve the hardware and software for the next-generation system.

Figure 4. ReflectoActive™ Seals System attached to a storage container at the Oak Ridge Y–12 Plant.

Work in Progress

The results of operational testing have, for the most part, been encouraging. All systems have performed as expected in the field. However, operating experience has provided insights regarding desirable improvements.

Although the weight sensor includes compensation for temperature and humidity, that compensation is not complete. Improvements to the differential capacitance circuit are being investigated to extend the range of the device.

RADSiP™ technology works well in environments in which there is sufficient radiation emanating from the container. In low-level environments (<0.5 mR/hr) the resulting low pulse rate makes it necessary to increase the active area of the photodiode. In response to this, a version of the RADSiP™ using diodes with 1 cm^2 of surface area has been developed.

SmartShelf™ was originally developed with only about a dozen nodes. Tests were performed in Oak Ridge with a 50-unit system and response time was observed to be under 10 seconds. Deployment of a 200-unit system has revealed that the response time increases approximately proportionally to the number of nodes, and steps are being taken to reduce this. The present system uses a single microprocessor in the node computer to monitor all nodes; the next generation will use a separate microprocessor for each chain of nodes, thereby reducing the response time by a factor of 8. A 400-unit system so constructed is expected to have a response time less than 6 seconds.

Work is in progress to increase the number of ReflectoActive™ seals that can be placed on a single optical fiber. Each seal on a fiber introduces a small, but measurable, loss of light, and eventually insufficient light is transmitted through the fiber from the transmitter to the receiver of the IDU and OTDR. Although the present limit is over 100 seals, further increases effectively decrease the per-unit cost of the system by amortizing the cost of the IDU and OTDR over more containers.

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* Managed by Lockheed Martin Energy Systems, Inc. for the U.S. Department of Energy under contract DE-AC05-84OR21400