Automated Systems for Safeguarding and Accountancy of Stored Highly Enriched Uranium (HEU)

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ABSTRACT

Oak Ridge has developed and integrated a suite of rugged, low-cost sensors into systems that are capable of remotely monitoring the physical and/or assigned attributes associated with stored nuclear materials. These systems include the Continuous Automated Vault Inventory System (CAVIS TM), SmartShelfTM, and the ReflectoActive Seal SystemTM.

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 distributive 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. The software also contains an Intelligent Facility Management (IFM) package that helps facility manager's with space planning, records management, item location, and variety of other facility specific needs.

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

INTRODUCTION

Nearly all facilities that store hazardous (radioactive or non-radioactive) 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, emphases on long-term secure storage for nuclear weapons-grade plutonium and uranium have substantially increased. Both the national and international nuclear arms control agencies must continually attempt to devise the best technological and procedural mechanisms for cost-effectively insuring that the world's supplies of these materials are thoroughly safeguarded. The current 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 TM

CAVIS TM is a system specifically designed to minimize the labor and radiation exposure associated with SNM inventories. CAVIS TM continually provides real-time weight and radiation attribute measurements, individually from each stored container of SNM. This system is built around an integrated set sensors that have been specifically designed to monitor a pertinent attribute from specific stored nuclear (radioactive) materials. These sensors include fiber optic and solid state sensors that can verify item weight, item temperature, gamma ray flux, relative uranium-235 enrichment, neutron flux, item location, and item motion.

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

The typical CAVIS™ sensor package installed in nuclear material storage vault consists of a weight, radiation, and/or 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.

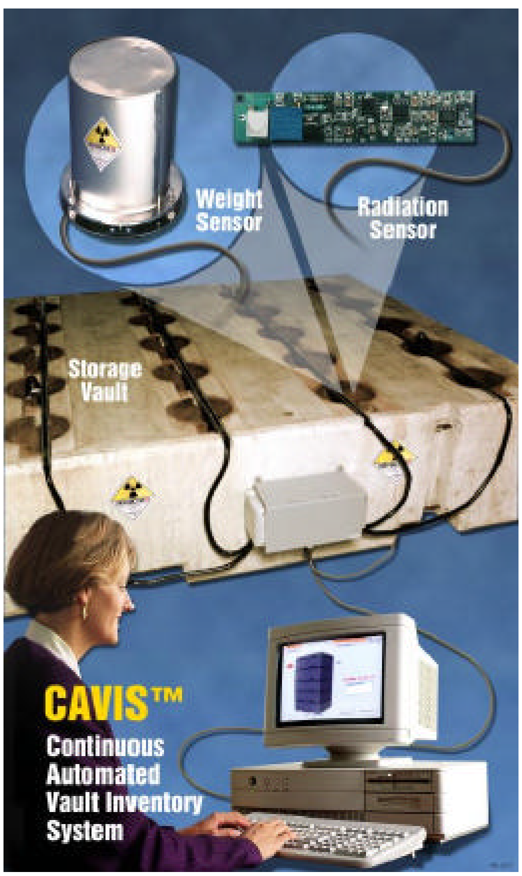

Figure 1: A Depiction of CAVIS™

The RADSiP™ gamma-radiation sensor is a small, inexpensive, virtually passive sensor designed for individual-item monitoring 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.

RADSiP™ sensors monitor the gamma-ray emission from radioactive materials. The sensors are affected by source distance, collimation of the source, and the 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 uranium-235. 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 Rad per hour. Filters in the pulse-shaping amplifier provide an impulse response having a pulse-width of 20 to 50 microseconds. After leaving the pulse-shaping amplifier, the output signals go to a pulse height discriminator where the discriminator lower level is adjusted to correspond to an energy peak of americium-241 (60 keV). The gamma-ray energy band from either the calibrated americium-241 peak to the highest energy from the Compton interaction pulses generated in silicon provide a sensitivity band with a precise region for estimating uranium enrichment.

The capacitive weight sensor can inexpensively monitor the weight and temperature of stored nuclear material for long periods of time in widely variable environments. The capacitive 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 frequency in the on-board oscillator, whose change corresponds directly to the 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 an equivalent 100K Rad radiation dose.

The unique modular design of the capacitive 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 any significant modifications.

SmartShelf™

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

Figure 2: The SmartShelf™ system

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 with 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, are connected to a node computer. 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 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.

The ReflectoActive Seal System™

The ReflectoActive Seal System™ is an active system designed to continuously monitor tamper indicating seals for any unauthorized opening or closing. The system provides immediate notification of where and when a seal breach has occurred. The system consists of a control computer, an optical time domain reflectometer (or OTDR), an optical fiber multiplexer, an immediate detection unit, and as many fiber optic connectors and cables as is needed (see Figure 3).

The seals can be attached to containers located nearby or several kilometers apart. Each seal is highly tamper resistant and reusable. 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.

Figure 3: The ReflectoActive™ Seals System

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.

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

In addition, the ReflectoActive™ Seals System interfaces with the Graphical Facility Information Center software (GraFIC™), a sophisticated monitoring and facility information system that provides an inexpensive and flexible method for remotely verifying complete "up-to-the-minute" inventory status of all secured items and important facility assets.

There are five major components in the ReflectoActive™ Seals System: an optical time-domain reflectometer, the immediate detection unit with a fast fiber optic switch, multiple seal fixtures, and a computer system running custom software developed for the seals system. The optical time-domain reflectometer is used to resolve the location of any breached seal. The immediate detection unit uses pseudo-randomly modulated light source paired with detectors to continuously monitor the seals and provide instantaneous detection of any breached seal. The fiber optic switch (or multiplexer) allows 1000's of seals to be monitored among numerous links and provides bi-directional monitoring of each link. The seal fixtures consist of the seals themselves (fiber optic couplings) and mechanical adapters used to affix the seals to the storage containers. The computer system controls the seals hardware, arbitrates alarm events, provides a graphical user interface, and communicates with plant alarm system. 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 a SNM storage vault.

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

The 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 the field test will be used to improve the hardware and software for the second-generation system.

The Graphical Facility Information Center (GraFIC™)

The Graphical Facility Information Center (GraFIC™) is an information system that provides an inexpensive and flexible method of remotely verifying complete "up-to-the-minute" inventory status of stored items and facility assets. In addition, GraFIC™ provides features needed for day to day management of storage and other facilities. GraFIC™ combines an easy to use graphical user interface with extensive online help so that users need little training. GraFIC™ can be configured to work with most sensor systems used to monitor facility assets. The initial implementation of GraFIC™ works with the CAVIS sensors to monitor SNM that is stored in Modular Storage Vaults (MSVs) at the Oak Ridge Y-12 Plant, but the system will soon be expanded to interface both with SmartShelf™ and the ReflectoActive Seal System™.

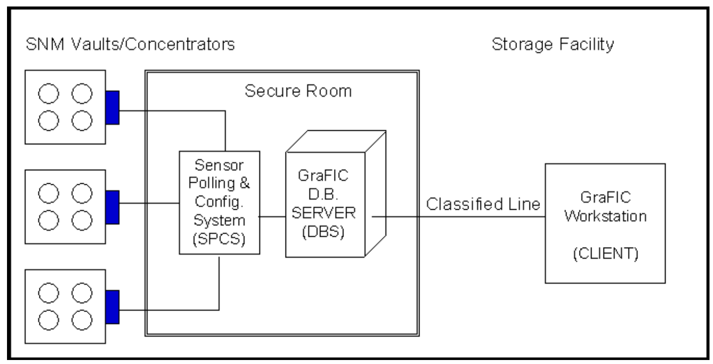

Figure 5 Example GraFIC™ System Layout

The GraFIC™ system is designed on a client-server model. The server and all client software can be run on a single system, but a more typical arrangement (see Figure 1) would have at least three processors: one or more Sensor Polling and Configuration Systems (SPCS), a database server (DBS), and one or more workstations. These are described below.

Each SPCS acquires sensor readings from up to 50 CAVIS sensor concentrators. The SPCS commands the concentrators to scan all sensors at periodic intervals. The readings from these scans are saved in medium-term storage (for a few days) and sent to the Database Server for long-term storage. In addition, the SPCS continually monitors the sensors via the concentrators and reports out-of-limits readings to the Database Server for timely alarm notification. The SPCS accepts commands from the Database Server to do such things as alter its scan rate, download information to the concentrators, etc. The SPCS software was developed using PowerBuilder® by Sybase. The main purpose of the Database Server is to maintain the relational database and to control client access to the database. The database is logically partitioned into three subsets:

1. A group of tables which holds the current facility configuration and the current facility status. These tables are normalized as is typical of a relational database.

2. A group of tables which holds facility configuration and status history. These tables are automatically updated when the current facility configuration and/or status is updated. Each of these tables is denormalized so it can serve as a stand-alone log. This data is kept online for a user-selectable amount of time (typically 30 days to 1 year) and is provided for use in problem resolution and for security auditing.

3. A single historical inventory table. This table, which is also designed as a stand-alone log, contains inventory data which is recorded once per day. This information is kept online for up to two years and then is archived to offline storage.

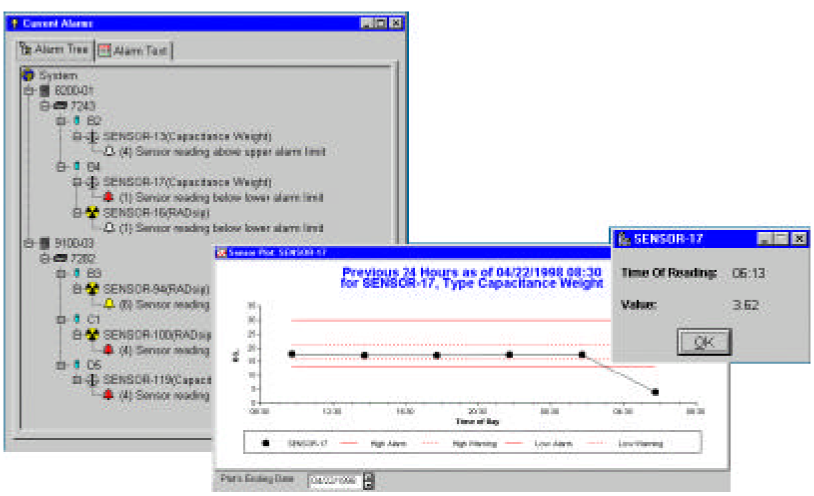

Figure 6: GraFIC™

The DBS automatically computes sensor reading limits from periodic reading and downloads these limits to the CAVIS sensor concentrators (via the SPCS) as they are calculated. The DBS also notifies all active workstation clients of data changes so the clients can update their displays appropriately. The DBS software is implemented as a combination of Oracle Triggers and Stored Procedures, written in the PL/SQL language, and tasks and libraries written with Visual C++.

A GraFIC™ installation may have one or more workstations to provide access to the user interface. These workstations may be placed in locations which are convenient to the workers who need to use them. The user interface was developed using PowerBuilder®, by Sybase, while HelpBreeze, by SolutionSoft, was used to develop the help information. The user interface provides three main services: update of facility configuration information, notification of facility status, and built-in reports.

The user interface allows the user to enter and update information about the facility configuration, items stored in the facility, and the sensor system used to monitor the items. The input windows have been designed to be as intuitive as possible and context-sensitive help is provided to answer the user's questions.

All of the GraFIC facility status displays are automatically updated in response to events, so the most current status is always visible. There are two main displays that give an overview of a facility's status. The first of these is the alarm display. This display, which can be viewed in either tree or table form, lists all sensors that currently are in alarm state. From this display, the user can call up more detailed displays which provide information which can be used to diagnose the reported problem(s). Once a problem's cause has been determined, a user who has the privilege to do so can "acknowledge" the alarm. An alarm condition will not end until the sensor reading has returned to normal and the alarm has been acknowledged.

Detailed displays include a display which shows the current status of each individual sensor, including the current reading value and the current alarm state. Information about the stored items being monitored by the sensors also appears on this display. In addition, the user can view a plot of sensor readings over time for a selected sensor and can print an “Incident Report” (containing the history of the alarm) for a selected alarm.

The second overview display is the floor plan map. Each floor of each building in the monitored facility has a map that is a to-scale layout of the floor, with positionable icons representing the monitored assets. The state of each asset's icon represents its current alarm status. All of the detailed displays that can be reached from the alarm display can also be reached directly from the floor plan map. In addition, the user can display information about rooms, such as usage, entry requirements, and any procedures applicable to storage operations in that room. Similar information can be displayed for the building as a whole.

GraFIC™ provides several Intelligent Facility Management (IFM) features to assist managers. One of these, the procedure storage and display feature, has already been mentioned. Another IFM feature which GraFIC™ provides is an asset locator function which allows the user to find the location of any stored item. The user enters all or part of the identifier of the item and all items which match are listed. The user can then select an item from this list and GraFIC™ will automatically display its location. The user can similarly locate stacks, vaults, building, rooms, etc. A third IFM features, the storage management function, is used by facility managers to plan for future storage needs. Using this feature, a user enters required storage constraints, and GraFIC™ determines the number, location, and size of available free areas which meet those constraints and will depict the recommended locations of the new storage containers on the floorplan map.
Several built-in reports are supplied with the GraFIC™ system, providing both current and historical data. Drop-down lists and radio buttons are provided for the user to enter selection conditions for most reports. When the user requests a report, it is displayed on-screen and may also be printed. Commercially available tools may be used to provide ad-hoc query and reporting support, if such support is needed. Reports can be used during problem resolution and for auditing.
Because of GraFIC's™ role with SNM inventories, security is an important consideration. All GraFIC™ processors use the Windows NT operating system to provide security features such as file access protections. The features available to a user depend on that user’s role. Since the security model is implemented using Oracle™ roles, this protection is enforced even when other products, such as browsers or ad-hoc query tools, are used to access the database. The GraFIC™ application enforces a two-person rule for facility configuration updates and alarm acknowledgements. Under this rule, two privileged users must log onto GraFIC™ before updates can be made. The rule is also implemented so that it is enforced even when products other than the GraFIC™ user interface are used to access the data. All changes to security-related configuration information and all alarm acknowledgments are logged, along with the identification of the two users involved, to provide an audit trail.

Figure 7 - GraFIC™ Floor Plan Map

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