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# Global Nuclear Material Monitoring with NDA and C/S Data through Integrated Facility Monitoring\*

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## ABSTRACT

The initiative described in this paper focuses on a flexible, integrated demonstration of a monitoring approach for nuclear material monitoring. This approach will include aspects of item signature identification, perimeter portal monitoring, advanced data analysis, and communication as a part of an unattended continuous monitoring system in an operating nuclear facility. Advanced analysis is applied to the integrated non-destructive assay (NDA) and containment and surveillance (C/S) data that are synchronized in time. The end result will be the foundation for a cost-effective monitoring system that could provide the necessary transparency even in areas that are denied to foreign nationals of both the US and Russia should these processes and materials come under full-scope safeguards or bilateral agreements. Monitoring systems of this kind have the potential to provide additional benefits including improved nuclear facility security and safeguards and lower personnel radiation exposures.

## INTRODUCTION

The amount, complexity, and throughput of nuclear materials is increasing at nuclear facilities worldwide. Continuous unattended surveillance and radiation monitoring systems can significantly reduce the inspector and guard time in the facilities. However, continuous systems produce large databases that can require large amounts of inspector and operator time for review and analysis. With complex and diverse data, it is difficult and time consuming for safeguards inspectors to examine all of the data for consistency and to find anomalies that could be caused by diversion of nuclear materials.

Technology based on pattern recognition software has been developed<sup>1</sup> to automate the review and analysis

of safeguards databases. When normal trends and patterns in the data can be characterized, such anomalies reveal themselves. Software that can recognize patterns through neural networks can be an efficient aid to inspectors. The software can analyze all the data and identify anomalies for more thorough review by the inspector or facility operator.

To efficiently analyze all of the data, it is necessary to integrate diverse sensors including C/S systems, radiation, personnel, and mechanical data into a synchronized database for the computer-aided analysis. The goal of our Integrated Facility Monitoring Initiative is to develop the architecture and technology required to make this integration possible. We have made significant monitoring advances with smart radiation sensors that filter<sup>2</sup> and buffer data prior to transmission on the network, personnel sensors that identify legitimate handlers of nuclear material, Local Operating Network (LON)<sup>3</sup> network nodes that authenticate and transmit the data, digital video images that can be transformed into the time domain [the Video Time Radiation Analysis Program (VTRAP)<sup>4</sup>] concept, and software to collect and analyze the data.

In this paper we describe our approach to integrated facility monitoring, including the architecture, enabling technologies, and demonstration facilities.

## ARCHITECTURE

An effective integrated safeguards system can be described in terms of six basic functions: sensor systems that track material, sensor systems that track people, information management systems that manage authorization information, measurement systems that perform assay, analysis tools that process the collected data, and software that ties all of the above functions together into one fast and easy-to-use system. Presently these functions exist in separate form. It is desirable that they be implemented so that information can be passed between

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them, enhancing decision-making and safeguards-assessment capability. In this section we describe in more detail each of these functions and illustrate how they can be combined into one integrated system.

### **A. Material Tracking Sensors**

Radiation sensors play an important role in monitoring nuclear materials because of the characteristic emissions from the materials. The neutron and gamma emissions are of most interest because of their high penetrability. Plutonium, mixed oxide (MOX), and irradiated reactor fuel have high rates of neutron and gamma emissions and are relatively easy to monitor using radiation sensors.

The radiation sensors can be classified as high-sensitivity fixed-area radiation monitors (FARMs) that measure both neutron and gamma rays without separating the signals. An example of this type FARM would be a large-volume plastic scintillator. For applications where it is necessary to distinguish between neutrons and gammas, one can use  $^3\text{He}$  detectors for neutrons and ion chambers, NaI, or solid state detectors that provide gamma-ray spectral information.

The radiation sensors provide counts as a function of time, and the time intervals can be selected to be shorter than the time required to significantly change the material being monitored. For typical applications, the time intervals for data collection are 2–10 s. Continuous operation results in large quantities of data, especially for systems with multiple sensors. To help alleviate this problem, we are developing smart sensors that filter data to greatly reduce data-storage requirements. Smart sensors also can buffer data to facilitate the integration of multiple sensors under the control of a central collect computer.

Information on the status and health (i.e., voltage levels, battery life, etc.) of the sensor can be provided to the central computer for preventive maintenance and data evaluation. Camera triggers and quick-response alarms can be provided by thresholds and algorithms in the smart sensors. Because the smart sensors have local data-storage capability, time synchronization with the total integrated system is needed. Local sensors provide limited data backup in case the network system or the central computer fails.

### **B. Personnel Tracking Sensors**

A major part of monitoring activities in a nuclear facility will be information on who is moving where and when. This information can be used with the material tracking systems discussed above to keep track of who

is moving nuclear material and to establish the patterns of movement of the facility personnel and material. The identification systems will be coupled with motion-tracking and activity-analysis systems to provide additional information about the activities inside protected areas such as vaults.

For the most part, personnel tracking sensors will be identification systems. These biometric systems will extend from simple hand/palm readers available now through sophisticated video face-recognition systems presently in the first stages of development. The hand readers demonstrate one aspect of personnel recognition/verification, where the individual is attempting to access some part of a facility and must prove his/her identity. Other methods also useful under these conditions are the various forms of eye scanning (retina, iris). Usually implicit in this method is that the person has identified himself and can be expected to participate in the recognition process. A far more challenging use of personnel-identification systems is to have the systems passively log the passage of facility personnel with no obstruction to their passage. Sophisticated face- and speaker-recognition systems that can do this are under development but are not presently available. Active badges that radiate information about a person's presence and identity will probably be used in the early stages of these systems, as it is far easier to verify an identity than to determine it.

Commercial video motion-detection systems can track individuals through the camera image, identifying the continuity of motion as a single person. Groups of such systems could "hand off" the person between motion detection systems, allowing us to keep a record of intermediate activities.

### **C. Information Management Systems**

The Los Alamos Integrated Facility Monitoring Initiative is designed around the concept of obtaining as much information about the functioning of the nuclear facility as possible, in an attempt to define an acceptable background pattern of activity against which we hope to detect anomalous illegal or proliferant activity. The result is that we will have immense quantities of data from a large variety of sensors, and that by its nature the data will be cross-coupled and disparate. Processing this data and searching for the anomalous movement of some portion of the nuclear material will make the proverbial search for "a needle in a haystack" appear simple. It is therefore extremely important that we arrange the databases in a manner appropriate for the various search engines that will be used.

The databases themselves will include the information from both the personnel-activity and material-movement subsystems, as well as standard material control and accounting systems [e.g., Los Alamos Nuclear Material Accounting System (LANMAS)], and some form of authorization database. This last database will be designed to contain information on what activities are expected to happen in a facility, both generally and specifically. For example, if a weapons system is to be moved from storage to a test facility, the date, time, and method of the expected movement would be inserted into the database and the actual activity could be compared against that.

## D. Measurement

The concept of integrated facility monitoring should incorporate both intelligent portal monitors and signature monitors to measure the characteristics of material being transported. Conceptually, personnel would move through a portal monitor and material would move through a signature monitor.

The personnel monitor would identify the individual as described above, followed by a database access to verify that the actions are allowed for that individual (can move sources, can move SNM, not allowed access, etc.). In addition to the standard alarms, the monitor would also allow downloading some data such as background counts to a central computing system to allow "mining" for anomalies.

The signature detector would look for signatures specific to particular sources and quantities of special nuclear material (SNM) (gamma ray energies, neutron source strength and multiplicity, weight, etc.). The source identification could be entered by key pad and the signature compared to the appropriate record in the database. Differences between the database record and measured signatures could be recorded for further study. The detector would activate an audible alarm if the signature does not match the signature of the declared item or the person does not have permission to move that item.

## E. Analysis

Perhaps the most straightforward type of analysis that can be performed on facility data is that of summarizing activity. Examples of this type of analysis include calculating

- number of fuel transfers,
- direction of transfers,
- time of transfer,
- speed of movement,
- size of fuel rod,

- consistency of sensors,
- existence of data gaps, or
- table of results and printing a hard copy.

These types of analyses may be performed in real time.

At a higher level of analysis (and usually performed off-line) is data understanding and interpretation. Analysis techniques of this type are called on to provide interpretations, predict trends, and identify anomalies. Using these techniques, we can thoroughly analyze large volumes of data to provide inspectors with information that allows them to focus on anomalies and data of interest for effective safeguards. In a real-time setting, they provide immediate feedback to potential diversion of material or other abnormal activity.

Specific techniques include

- neural networks,
- expert systems,
- clustering algorithms,
- decision trees,
- visualization tools,
- data mining (includes the above algorithms as well as rule discovery, decision trees, and other methods),
- genetic programming, and
- nearest neighbor.

A third type of analysis is reconciliation-comparison of the sensor record with stated declarations of activity, together with reconciling or explaining the differences. In an off-line application this might be a tool for the safeguards inspector to locate differences between the activities recorded by the sensors with the facility declaration. In a real-time application, it could be a comparison of a database record with access or assay information with sensor readings (palm reader and signature detector).

## F. System

The system software and hardware that ties together all of the components described above consists of the following parts:

- network,
- central database,
- alarm system, and
- user interface.

The network must provide support for authentication, time synchronization, connectivity to a wide variety of sensors and multiple databases, and support for remote access and transmission. It must also support ethernet, RS-232, and other common communication protocols.

The central database is where all status information is stored. It must support rapid retrieval, playback, and archiving. The alarm system provides notification of problems in the monitoring system. It must support acknowledgment of alarms, resolution, and integration with analysis tools.

The user interface must allow data display, hard copy, remote access, and system start-up and termination. It must also allow access to other software tools including simulation.

A simple diagram showing an example layout of the basic software system functions is shown in Fig. 1. The monitor function continuously acquires data from sensors. The data collection software stores and sorts the data. Real-Time Analysis performs simple analyses such as calculating summary information and comparing sensor output with authorization information. Review provides the visualization capability. Analysis is a higher level of off-line computation such as pattern recognition.

## ENABLING TECHNOLOGIES

Several technologies have been identified that are required for the full development of an integrated facility monitoring system of the future. Some of those that presently exist are as follows:

- interface building,
- plotting and visualization tools,
- authentication,
- pattern recognition,
- radiation sensors,
- portal monitors,
- digital video, and
- facility simulation.

The following is a partial list of technologies that need to be developed:

- anomaly detection for particular safeguards applications;
- integration of databases with analysis, alarm

- systems, and displays;
- smart sensors;
- data-mining tools;
- reconciliation tools; and
- data simulation.

The identification of these technologies is important because it directs us to areas where research and development funds should be focused.

## DEMONSTRATION FACILITIES

Integrated facility monitoring concepts have been tested for the past two years at Los Alamos. These prototype systems have provided valuable input to systems that are currently being installed. In this section we describe these systems.

### A. VTRAP-Prototype

To develop and evaluate facility monitoring and analysis concepts, we have established a testbed in a controlled radiation laboratory at Los Alamos National Laboratory. The equipment includes a nuclear material vault, a radioactive source shield, two neutron-slab totals detectors, a neutron coincidence detector (HLNC-II),<sup>2</sup> and a digital video camera.

We have developed and tested transformation algorithms<sup>4</sup> for VTRAP data that integrate temporal heterogeneous data into a consistent homogeneous data set for neural network analysis. Transformation algorithms have been applied to two-dimensional digital video images (movement) and radiation signals (nuclear material) to provide time-based data for automated analysis of movement of personnel and nuclear materials.

### B. Los Alamos Critical Assemblies Facility

A complete integrated facility monitoring program will require a testbed facility where various smart sensors, sensor networking schemes, and analysis/processing systems can be quickly and easily tested. We are

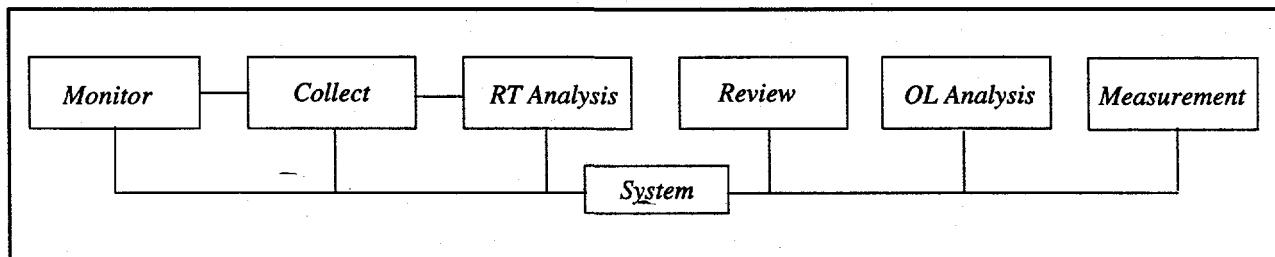


Fig. 1. Integrated Facility Monitoring System components.

implementing such a testbed at an operational Category I facility, the Los Alamos Critical Assemblies Facility, with plans of moving later to the Plutonium Facility after initial testing.

The monitoring system for the Critical Assemblies Facility will consist of (at the end of FY96)

- two portal monitors (old style),
- three badge/palm readers,
- three bar-code readers,
- single VTRAP system,
- Sentinel Video Motion Detection System,
- LANMAS system,
- simplistic authorization system, and
- facility-activity data-collection system.

An updated testbed system intended for general use by the DOE Laboratory Complex will require additional hardware and software tools, such as

- LONworks net,
- integrated database, and
- analysis tools/user interface.

In addition, the enhanced testbed facility will need additional systems to help describe the activities undertaken in the Critical Assemblies Facility. We believe that at a minimum these should include

- Authenticated Item Monitoring System (AIMS) - the Sandia National Laboratory (SNL) system for monitoring item movement, door openings, etc.;
- Authenticated Tracking and Monitoring System (ATMS) - the SNL system for reporting the position of the monitored vehicle;
- two additional VTRAP systems;
- prototype activity-analysis system; and
- additional portal monitors (old style and enhanced).

Additional personnel recognition systems will be required to detect and identify activity throughout the monitored part of the facility. These will include more badge/palm readers. We would like to install an active badge system, which would be used in conjunction with a prototype face-recognition system being developed at Los Alamos. Other personnel-identification systems, such as an iris-scan system, should also be included in the recognition system suite.

### **C. Kazakhstan BM-350 Reactor Monitor**

An unattended monitoring system is being developed for the BN-350 fast breeder reactor in Kazakhstan. The purpose of the monitoring system is to verify the

movement of spent reactor and blanket fuel assemblies without requiring the presence of international inspectors.

Radiation sensors, including high-sensitivity plastic scintillator FARM detectors, are being used together with  $^3\text{He}$ , fission counters, and ion chambers for specific neutron and gamma-ray discrimination. Prototype sensors were installed in March 1996, and a more integrated monitoring system will be tested in July 1996.

### **D. DUPIC Radiation Monitoring**

The Korean Atomic Energy Research Institute (KAERI) is developing a process to make use of the energy potential in plutonium from spent fuel without the necessity of reprocessing. This proliferation-resistant fuel cycle is called the direct use of spent pressurized water reactor (PWR) fuel in CANDU (DUPIC)<sup>5</sup> and is illustrated in Fig. 2. The plutonium in the spent PWR fuel is protected by the "spent fuel standards" that are being proposed for the disposition of weapons-origin plutonium.

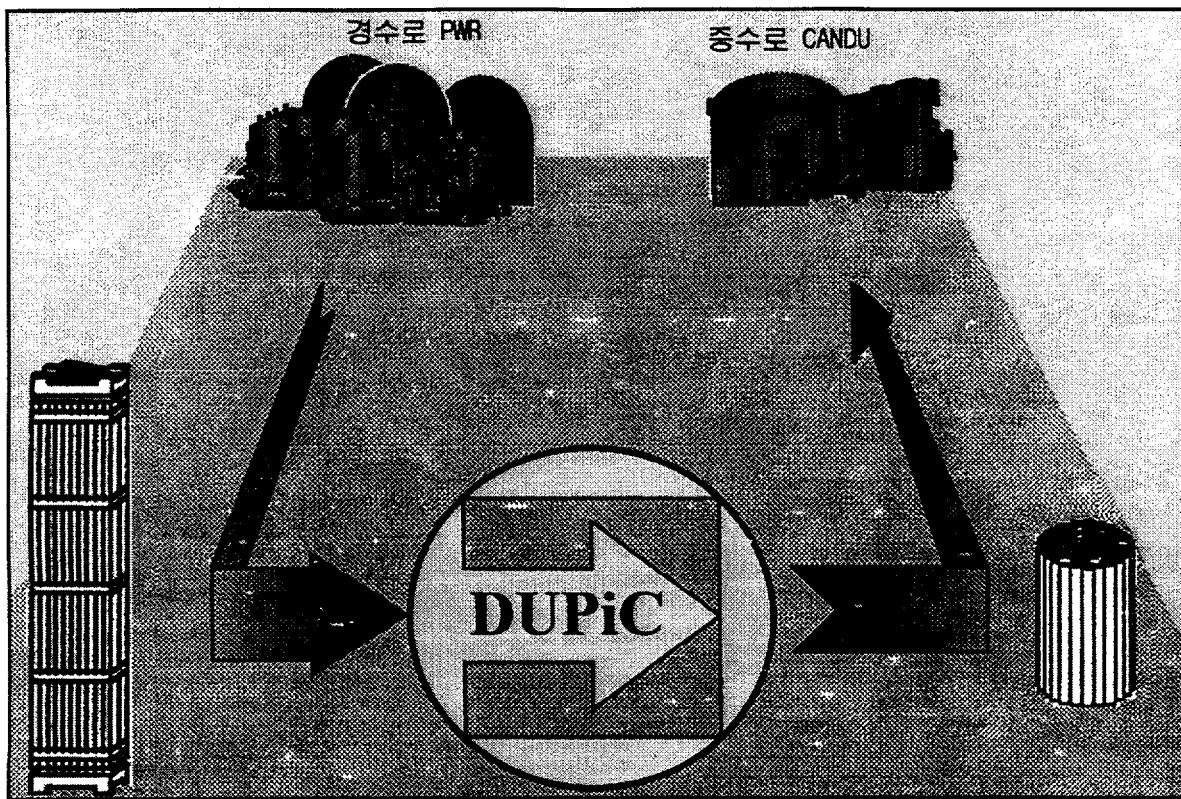
The DUPIC fuel is refabricated from PWR fuel directly into CANDU fuel bundles in heavily shielded hot cells.

We are evaluating the VTRAP method<sup>1</sup> to monitor the DUPIC process. The highly radioactive spent fuel in the DUPIC cycle provides an excellent radiation signature that can be integrated with video data after the video image has been reduced to the pixel difference metric and merged into the radiation-sensor database.

Neutron sensors and cameras are positioned near the hot cell portals to give a continuous record of all nuclear material movement into or out of the DUPIC refabrication hot cells. The activity inside the process cell is continuously monitored by the DUPIC fuel bundle counter that also provides NDA accountancy measurements. The integrated NDA and video system gives a continuous record of all activity that involves radioactive material in the process cells.

### **E. JOYO and MONJU Radiation Monitoring**

Radiation monitoring is performed at the JOYO and MONJU prototype fast breeder reactors in Japan.<sup>6</sup> The MONJU reactor is shown in Fig. 3. Radiation sensors are located at the fresh-fuel input, the reactor core, and the underwater spent fuel storage. The radiation sensors include ion chambers and NaI detectors for gamma rays and  $^3\text{He}$  tubes for neutron detection.



*Fig. 2. The diagram illustrates the fuel flow in the DUPIC process from the PWR spent fuel assemblies, through the mechanical refabrication process, to the CANDU fuel bundles containing the highly radioactive fuel.*



*Fig. 3. MONJU Prototype Fast Breeder.*

The radiation sensors are operated in the continuous mode with data collection intervals of a few seconds. Thus, large quantities of data are collected and stored between monthly inspection visits. The quantity of data is greatly reduced by data-filter algorithms that have been developed<sup>2</sup> for the radiation sensors to compact the data during background intervals when nuclear material is not moving. Also, data-review software has been written to assist in the evaluation of large quantities of data. New software is being developed to automate the data evaluation and reporting.

## CONCLUSIONS

Integration of safeguards functions into an effective system requires careful consideration. The traditional approach to safeguards systems requires too much human interaction and radiation exposure. Our approach to integration combines sensor data, authorization information, and assay together with higher level analysis, which strengthens the overall effectiveness of nuclear safeguards and increases transparency beyond current IAEA safeguards requirements while considering ALARA requirements.

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