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PRELIMINARY CONCEPTS FOR DETECTING DIVERSION OF LWR SPENT FUEL

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Abstract

Sandia Laboratories, under the sponsorship of the Department of Energy, Office of Safeguards and Security, has been developing conceptual designs of advanced systems to rapidly detect diversion of LWR spent fuel.

Three detection options have been identified and compared on the basis of timeliness of detection and cost.

Option 1 is based upon inspectors visiting each facility on a periodic basis to obtain and review data acquired by surveillance instruments and to verify the inventory. Option 2 is based upon continuous inspector presence, aided by surveillance instruments. Option 3 is based upon the collection of data from surveillance instruments with periodic readout either at the facility or at a remote central monitoring and display module and occasional inspection. Surveillance instruments are included in each option to assure a sufficiently high probability of detection.

An analysis technique with an example logic tree that was used to identify performance requirements is described.

A conceptual design has been developed for Option 3 and the essential hardware elements are now being developed. These elements include radiation, crane and pool acoustic sensors, a Data Collection Module, a Local Display Module and a Central Monitoring and Display Module.

A demonstration, in operating facilities, of the overall system concept is planned for the March-June 1979 time frame.

Introduction

The safeguarding of reactor spent fuel against acts of national diversion aimed at establishing a nuclear explosive capability is a principal international concern.

Sandia Laboratories, under the sponsorship of the Department of Energy, Office of Safeguards and Security, has been developing conceptual designs of advanced systems to rapidly detect diversion of LWR spent fuel.

A specific objective of international safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection. Timeliness of detection is related to the time required to convert diverted material to nuclear explosive devices.

International response to a diversion must be preceded by detection and verification and for purposes of this paper are defined as follows:

- <u>Detection</u> is the receipt of an indication by an international authority that an undeclared transfer of spent fuel may have occurred.

- <u>Verification</u> is the determination by an international authority that a diversion has occurred. It requires independent assessment of the data upon which the detection was based and may be supplemented by:

    1) additional records and reports from the state or from the facility operator,

    2) additional data from the site, e.g. physical inventory, and
    3) on-site observation.

- <u>Response</u> is the set of institutional and political actions that may be set in motion by appropriate organizations following the verification of a diversion.

<u>Timeliness of Detection</u>

A reprocessing facility is essential to recover the plutonium in reactor spent fuel for use in weapons production. Reprocessing plants located throughout the world that can produce between 0.2 and 18 kgs of fissile plutonium per day have been or are now operating. Since this basic reprocessing technology is well known and although design and construction is a complex and highly technical process, the potential for a clandestine reprocessing plant cannot be ignored.

It is possible to estimate the time from diversion to fabrication of the first weapon in the following manner. Let

T_1 = Time to transport diverted spent fuel to a reprocessing plant

T_2 = Startup time, after cold testing, for the reprocessing plant

T_3 = Time to produce enough plutonium for one weapon given an operating plant

T_4 = Time to fabricate a nuclear explosive device assuming all non-nuclear parts are available and assembled

then the time to produce the first weapon will be

$$T_{first\ weapon} = T_1 + T_2 + T_3 + T_4$$

Given the broad range of estimates which may be made for each of the various times (T_1, T_2, T_3, T_4), the time to first weapon if the diverted material is spent fuel ranges from days to months.

Detection Concepts

Three concept options have been identified for the detection of diversion of spent fuel. These concepts are defined in detail in "Preliminary Concepts for Detecting National Diversion of Spent Fuel," SAND77-1954, April 1978. They are based on the facility information contained in "Baseline Description for Reactor Spent Fuel Storage, Handling and Transportation," SAND77-1953, May 1978.

Option 1 is based upon inspectors visiting each facility on a periodic basis to obtain and review data acquired by surveillance instruments and to verify the inventory. Option 2 is based upon continuous inspector presence, aided by surveillance instruments. Option 3 is based upon the collection of data from surveillance instruments with periodic readout either at the facility or at a remote central monitoring and display module and occasional inspection. Surveillance instruments are included in each option to assure a sufficiently high probability of detection.

In Option 1, the duties of the inspector include the following:

- Reviewing accounting records for comparison with previously submitted reports
- Performing sampling tests to assure the presence and integrity of the fuel inventory
- Reviewing the recorded surveillance data and investigate anomalies detected by the safeguards instrumentation
- Observing the installation and removal of fuel assembly integrity devices

In Option 2, the duties of the on-site inspector will be similar to those of the periodic inspector, but will be performed at a much greater frequency.

In Option 3, authenticated data from on-site safeguards instrumentation would be transmitted over a tamper-indicating communication link to an off-site monitoring facility where assessment of the safeguards status of the spent fuel is made. The data could be transmitted over conventional landlines, high-frequency radio channels, or by satellite. The data transmittals could occur continuously, on a prearranged schedule, or on demand, and may include real-time observations and/or selective replays of the data recorded during periods of nontransmission. The frequency of data transmission is not necessarily limited by the technical system, but rather will be selected by interpretation of timeliness requirements and cost considerations. Occasional inspections would be conducted to confirm safeguards instrumentation integrity, and an inspector may be present at each reactor for the refueling period. Other duties of the inspector would be the same as those discussed for Concept 1.

Concept Comparison

The three concepts have been compared in terms of communication mode, reporting interval, number of personnel, and rough estimates of cost. All comparisons are based on a network of 60 power reactors and 3 supporting storage facilities.

Table I compares the three facility concepts. The manpower estimates are based on 240 work days per inspector per year, at $50,000 per year per inspector. For Concept 1, each inspection including travel time requires five days. For Facility Concept 2, Resident Inspectors, each facility is monitored 365 days of the year during normal working hours. For Concept 3, Remote Surveillance, the off-site monitoring facility is manned by two inspectors, 24 hours a day, 365 days a year; a total of 10 personnel would be required to allow for weekends, holidays, and sick leave. In addition, quarterly inspections are assumed. An additional 30 days of inspector presence is assumed to be required at each reactor during the yearly refueling operation for Concepts 1 and 3. Travel expenses are estimated for each concept based on a cost of $750 per round trip.

Cost for the basic safeguards instrumentation is estimated at $100,000 per facility; this amount is used for all concepts. It is recognized that the safeguards instrumentation for Concept 2, Resident Inspectors, may not need to be as reliable or tamper resistant and, therefore, may not be as costly as the instrumentation for the other concepts. This factor is not considered due to the "rough estimate" nature of the cost estimates. Detection, assessment, fuel assembly identification, and data processing and storage equipment are included in this amount. These costs, and other capital costs, are amortized over a 10-year period to provide annual cost estimates.

Table I

Manpower and Cost Estimates

Concept	Communication Mode	Reporting Interval	Number of Personnel	Annual Cost ($ Millions)
1-Periodic Inspections	Commercial Telephone	Every 2 Months	15	1.7
		Monthly	22	2.3
2-Resident Inspectors	Commercial Telephone	Daily	96	5.4
3-Remote Surveillance	HF Radio	Daily	22	2.7
	Leased Line	Daily	22	3.0
	Satellite	Daily	22	3.55

For Concept 3, three communication modes are compared: high-frequency (hf) radio, leased landlines, and satellite. With this concept, an off-site monitoring facility is required; these are estimated at $500,000 for the hf radio and landline modes and $700,000 for the satellite mode. The communications cost for the three modes are based on:

- High-Frequency Radio Mode - 63 transceivers at $10,000 each and 63 digital interfaces between the instrumentation and the transceivers at $100,000 each. Five relay sites at $125,000 each are also required to provide communications over a land area similar to that of the United States.

- Leased Landline Mode - 63 lines at $6,000 per year each (based on typical foreign costs of $6 per mile and an average line length of 1000 miles) and 63 digital interfaces between the instrumentation and the landlines at $100,000 each.

- Satellite Mode - 63 transceivers at $100,000 each, 63 digital interfaces between the instrumentation and the transceivers at $100,000 each, and $300,000 per year for a dedicated nonpreemptable channel. A nonpreemptable channel may not be required and this cost could be significantly lower.

In comparing these concepts, a key factor to be considered is the time for verification and response that is provided before an initial weapon can be fabricated.

Three key elements in determining this time are the reprocessing plant startup time, the daily plutonium production rate, and the device fabrication time. A range of times has been considered that encompasses available estimates for these elements and 10 kgs was used as the amount of material needed for a weapon. Table II shows the impact of these estimates on the available verification and response time.

The periodic inspection concepts, with inspection intervals of one and two months, offer the lowest costs; however, given the initiation of a diversion sequence soon after the inspector(s) departs the facility, the detection times is one to two months. Given the assumption of rapid plant startup, rapid fabrication, and a moderate production rate (5 kg/day), such a detection time may allow many weapons to be produced before detection.

Concept 2, Resident Inspectors, provides very rapid detection time at an expense of approximately $5.4 million per year--the highest of all concepts presented.

Concept 3, Remote Surveillance, also would provide very rapid detection time but with reduced inspector presence. The costs for this concept appear to be competitive with the bimonthly or monthly inspection concepts, with an improved detection time. This concept would require a comprehensive

Table II

Concept Comparison

Concept	Communication Mode	Reporting Interval	Annual Cost ($ Millions)	Time for Verification and Response (Days): 6-Day Plant Startup, 6-Day Fabrication: 5 kg/day*	Time for Verification and Response (Days): 6-Day Plant Startup, 6-Day Fabrication: 0.5 kg/day*	Time for Verification and Response (Days): 6-Month Plant Startup, 21-Day Fabrication: 5 kg/day*	Time for Verification and Response (Days): 6-Month Plant Startup, 21-Day Fabrication: 0.5 kg/day*
1-Periodic Inspections	Commercial Telephone	Every 2 Months	1.7	None (23 weapons produced before detection)	None (2 weapons produced before detection)	145	163
		Monthly	2.3	None (7 weapons produced before detection)	4	175	193
2-Resident Inspectors	Commercial Telephone	Daily	5.4	15	33	204	222
3-Remote Surveillance	HF Radio	Daily	2.7	15	33	204	222
	Land Lines	Daily	3.0	15	33	204	222
	Satellite	Daily	3.6	15	33	204	222

*Assumed Reprocessing Plant Pu Production evaluation of its feasibility, the development of subsystem elements, and a capability demonstration. The communication options are straightforward adaptations of existing communication systems. Implementation of the hf radio link on an international basis may present a significant problem in the area of frequency allocations. Similarly, implementation of the leased landline link may be severely affected by the wide range of existing landline quality.

Conceptual Design

In order to make an effective choice of the possible options available, a tradeoff analysis of hardware configurations and inspection options must be completed.

This tradeoff analysis will provide data on the effectiveness of various hardware configurations in detecting the unreported movement of spent fuel. This data will allow comparisons of relative effectiveness and cost of inspectors versus hardware in these tested configurations.

All three options require the use of surveillance hardware to assure an acceptable probability of detection. This instrumentation contributes significantly to the detection probability but does not influence timeliness of detection. Option 3 incorporates remote monitoring of surveillance equipment to increase timeliness of detection while requiring only occasional on-site inspection operations.

A conceptual design has been developed for Option 3 to meet the following performance requirements:

- o Confirm in a rapid manner reported spent fuel movements and detect unreported movements including
  - Unreported transfers of fuel between a reactor and the storage pool.
  - Unreported transfers of fuel between the storage pool and a reprocessing area.
  - Unreported transfers on or off-site.
  - Nonarrival of reported transfers
- o Provide capability for assessing alarms
- o Provide capability for rapid inventory verification

The general principles that guided the conceptual design include:

- o Assure high probability of detecting the unreported movement of spent fuel, including tamper indication

- Allow rapid reporting of detections

- Minimize need for on-site inspectors and other personnel requirements of the inspection agency

- Minimize cost and operational impact on the facility

The initial step of the conceptual system design is a detailed analysis to identify the basic activity which must be detected. The analysis that has been used is adapted from fault tree methodology where events related to specific concerns are connected using logic gates to show their interdependence. This approach has the following features:

- systematic

- provides visibility of logic

- provides traceability

Using this analysis a choice of surveillance elements required to detect specific activity can be identified. An example logic tree is shown in Figure 1.

When the trees are fully developed by following them along any desired set of branches, a set of basic activities is identified which must be accomplished before fuel diversion can take place along that particular path. Where these activities are inputs to an OR gate, the detection of all the activities is required to block that diversion path. For activities grouped as inputs to an AND gate, the detection of any one will block that path. In order to achieve reasonable reliability, however, a surveillance system should be capable of detecting more than one activity along any diversion path. For example, the detection of three activities may be a practical goal because it allows for single failures and still provides for redundancy.

A conceptual design of a system to meet the general requirement of Concept 3 and the specific requirements identified in the facility analysis is shown in Figures 2 and 3.

As a result of the analysis performed to date, the following set of sensors was initially identified as useful for fixed site, water basin storage facilities:

- Radiation Sensors, which sense radiation level changes associated with spent fuel handling operations outside the storage pool

- Crane Sensors, which detect crane activities associated with spent fuel handling operations

- Spent Fuel Pool Acoustic Sensors, which detect underwater acoustic signals associated with spent fuel handling

- Video Motion Sensors, which detect changes within a scene

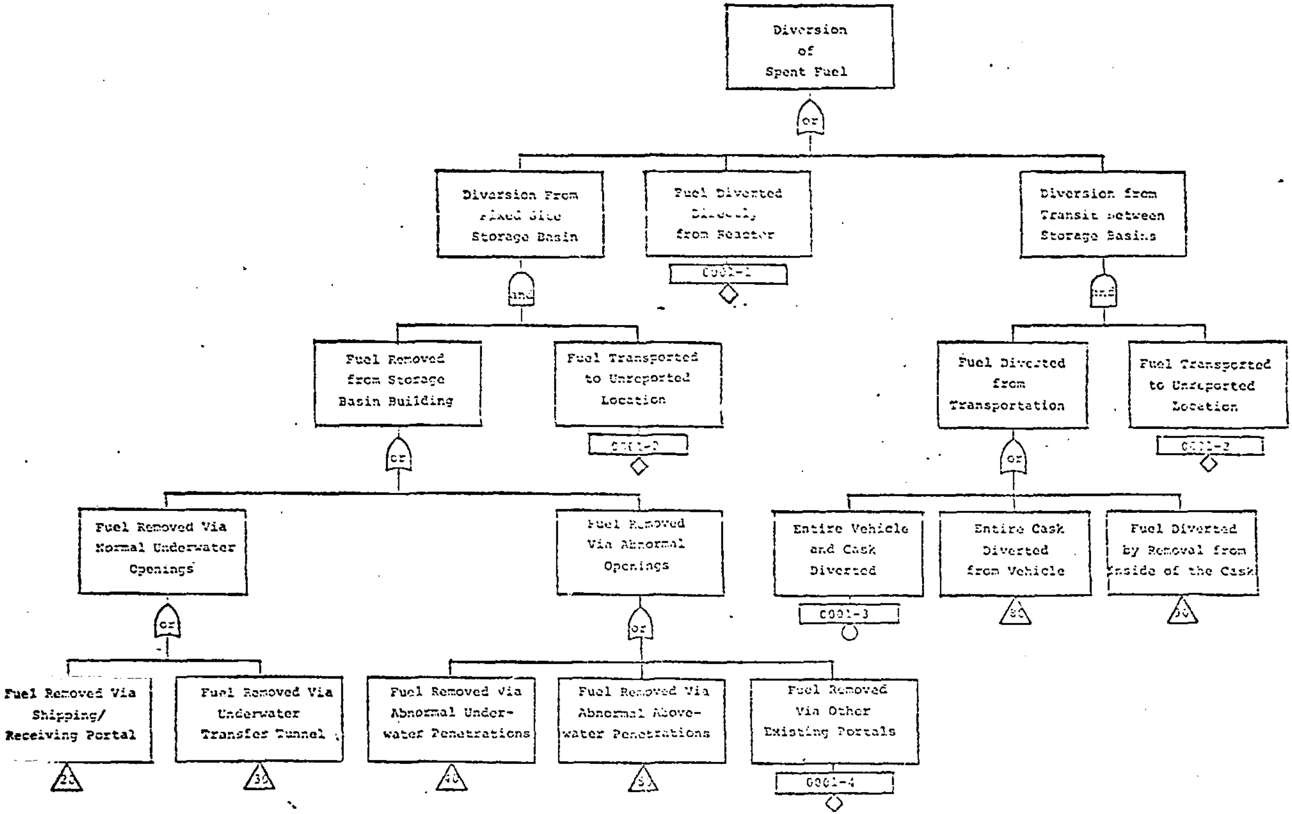

Figure 1. Example Logic Tree

- o Portal Sensors, which detect door openings
- o Electrical Power Sensors, which detect operation of motor operated equipment

In addition to the preceding detection sensors, Fuel Assembly Identification Devices (FAIDs) that could be installed on fuel assemblies to provide unique identification and integrity information, and closed circuit television (CCTV) to assist in assessment activities were included in the initial conceptual design.

Communication between the sensor modules and the Data Collection Module (DCM) takes place over fiber optics local data links. The fiber optics system and tamper indicating enclosures around the various on-site modules will allow detection of any tampering attempt on the system.

The DCM collects sensor data and tamper indicator status from the various sensor modules. It correlates the sensor data and checks for unusual or inconsistent operations.

As an example of such a correlation process, the relative radiation levels as seen by several spatially separated radiation monitors should correlate in a predictable manner with a radiation source, such as a cask containing spent fuel, being moved through the area. The monitor outputs can be used to generate source strength and position location solutions by a process called deconvolution, or simply, unfolding. An unusual condition could then be a solution which shows the radiation source (presumed to be spent fuel) moving in a direction indicating a movement that was not reported. An inconsistent condition could be one in which the unfolding process does not converge to a unique solution, possibly due to an attempt to mask or fool the system by the introduction of shielding around the sensors and/or the introduction of extraneous radiation sources within the area. Such unfolding techniques further enhance the tamper-indicating capability of the system, reduce false alarms and increase the probability of detection of an unreported spent fuel movement over what a system of uncorrelated sensors could provide.

The data base of normal operations will have to be generated on the basis of observations and data obtained from each facility during the initial installation and checkout phase.

In operation, the DCM will poll the sensors and tamper status indicators every few seconds and perform the unfolding calculations. Whenever an abnormal solution is obtained, sensor data will be stored, and when required, a closed circuit TV picture will be stored in the DCM. This sequence could also be initiated at random times or an interrogation from the local display module (LDM) or the central monitoring and display module (CMDM) as shown in Figure 1. Approximately 24 hours of data can be stored by the DCM for later interrogation by the LDM and/or the CMDM.

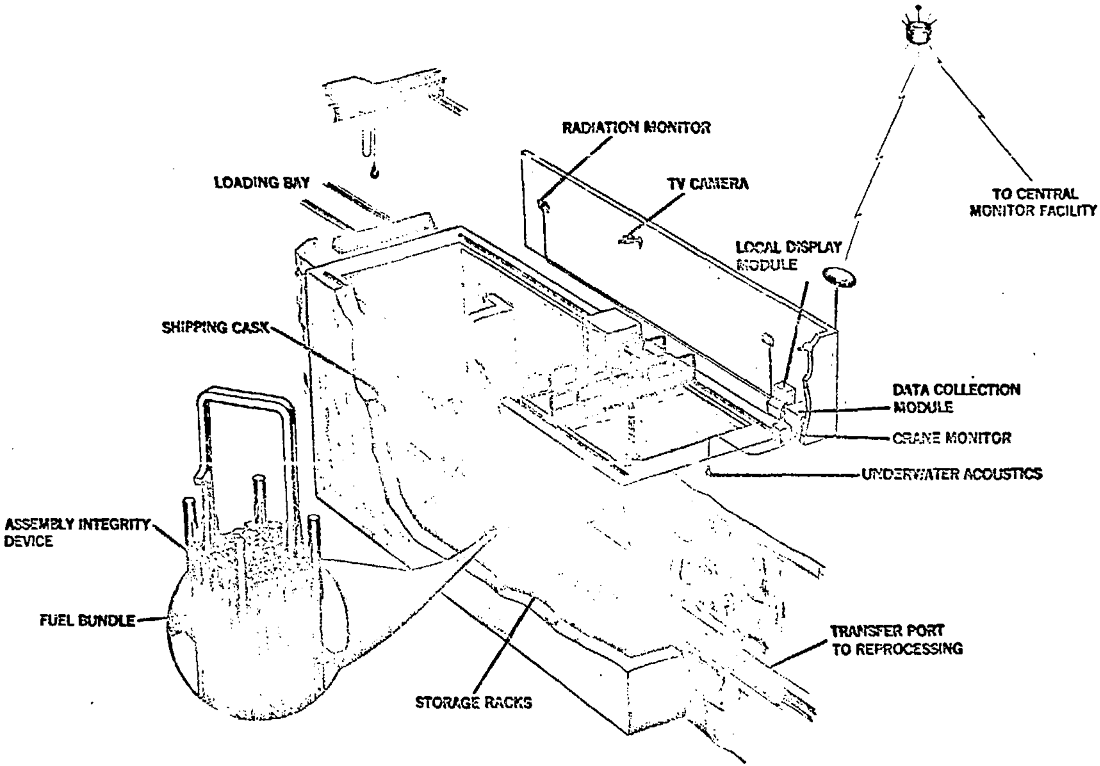

FIGURE 2. SPENT FUEL STORAGE MONITORING

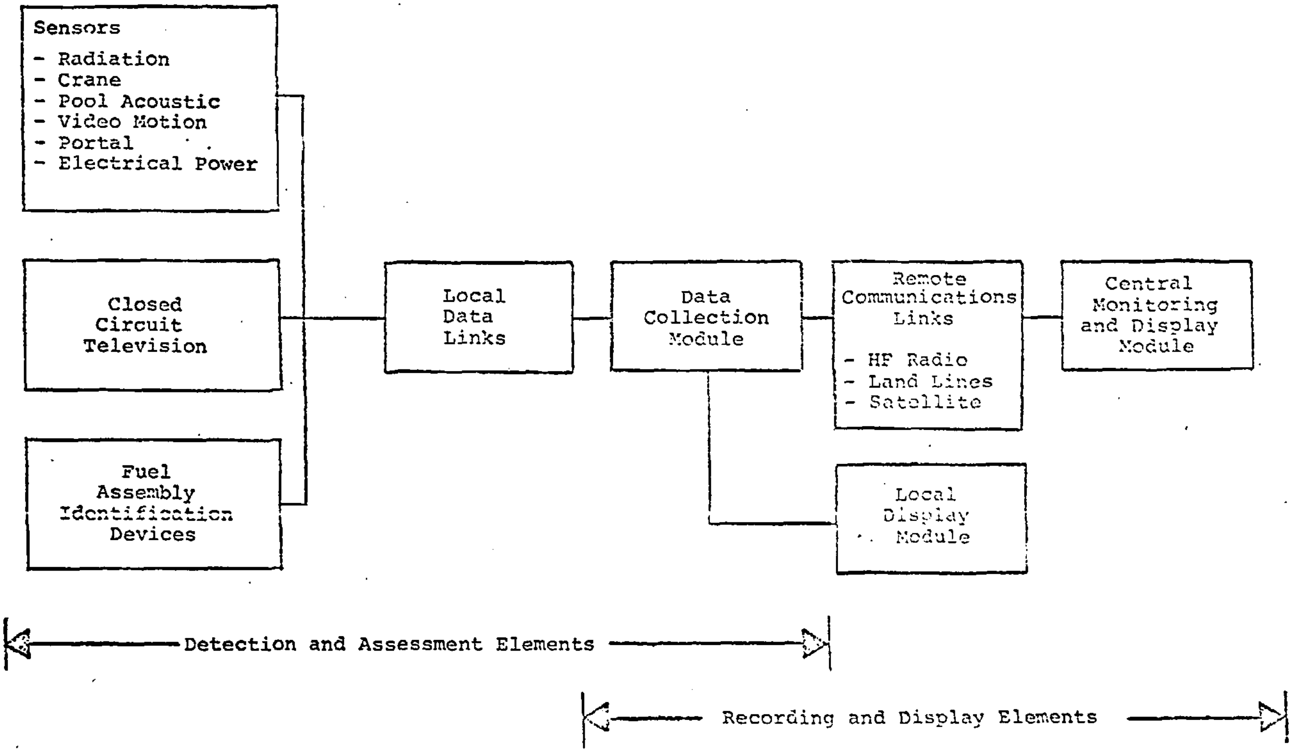

Figure 3. Conceptual Overview of Spent Fuel Containment and Surveillance System

The system elements which allow a timely reporting of a detection of a diversion are the DCM, LDM, the communication links and the CMDM. It should be noted that the DCM is included in both the detection elements and the recording and display elements. The data links to the CMDM can be satellite, ground station RF, or hardware links. Data authentication will be applied to these links to detect tamper attempts.

The CMDM may be located many miles from the spent fuel site. It contains the necessary equipment to communicate with the DCM's, to record, to process, and to display data. It also provides the capability to accomodate inputs from system operators and aid them in assessing spent fuel status via any of the system DCM's.

Hardware Development and Test

At the present time, the installation and checkout of the initial system elements are under way at the General Electric, Morris, Illinois, away-from-reactor storage facility. Preliminary design of a configuration for a pressurized water reactor is under way. The design and checkout of the initial central monitoring and display module is in the final stages and will be located in Albuquerque, New Mexico to support a demonstration of the system capability that will take place in the March to June 1979 time frame.