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Design Features for Enhancing International Safeguards of Away-from-Reactor Dry Storage for Spent LWR Fuel

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Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

The Pacific Northwest Laboratory has performed a study for the Nuclear Regulatory Commission to identify and analyze design features that can facilitate the implementation of IAEA safeguards at away-from-reactor facilities for dry storage of light water reactor spent fuels. Thirteen specific design features are identified that can enhance verification of nuclear material flow and inventory. These are assessed from the viewpoint of safeguards effectiveness and possible impacts on the IAEA and the operator of the AFR facility.

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EXECUTIVE SUMMARY

Including safeguards considerations in the early design phases of nuclear facilities can have substantial beneficial impacts on later application of IAEA safeguards. The study described in this report is the fifth of a series of studies carried out for the Nuclear Regulatory Commission's Office of Nuclear Materials Safety and Safeguards. The studies all have the specific objective of identifying and analyzing design features for nuclear facilities that can facilitate the implementation of IAEA safeguards. The previously reported studies involved light water reactors, spent fuel reprocessing plants, mixed-oxide fuel fabrication plants, and low enriched uranium conversion and fuel fabrication plants. This study involves away-from-reactor dry storage facilities for light water reactor spent fuels.

The baseline facility for the study is a 5,000 metric-ton dry storage facility. Spent fuel is received from pressurized water or boiling water reactors both as bare intact assemblies and as canistered, consolidated fuel rods. The spent fuel is received into a fuel receiving and handling building where it is inspected, packaged in sealed metal canisters, and loaded into concrete-shielded storage casks. The casks are welded closed and placed on concrete pads in a storage area. Ultimately the spent fuel is retrieved and shipped to a reprocessing plant or to a disposal site.

The assumed safeguards approach consists of item accountancy heavily supported by containment and surveillance (C/S) measures.

An analysis of the baseline facility and the safeguards approach identified areas that can be improved by facility designs. The following specific design features were identified and evaluated:

- Provide quarantine area in the fuel handling cell for storing spent fuel receipts after unloading from the transport casks. The area would be protected by C/S measures to prevent undetected passback of material into the casks.
- Design the equipment location and processes used for spent fuel rod consolidation and the canisterization operations to permit them to be viewed and recorded on video tape with IAEA CCTV systems.
- Install equipment and processes to photograph weld beads on canister covers.
- Install a station for accurately weighing spent fuel canisters after they are prepared for loading into the storage casks.
- Install NDA capability to quantitatively measure the plutonium content in spent fuel receipts and canisters prepared for loading in the storage casks.

- Install NDA equipment to qualitatively measure the gamma ray emissions from spent fuel temporarily stored in the fuel handling cell as well as canisters prepared for loading into storage casks for the presence of gamma radiation.

- Design the cask handling and spent fuel handling operations to be performed remotely from a central control room provided with IAEA controlled CCTV monitors and video recorders.

- Subdivide the storage area into sub-areas by barriers that cannot be crossed by the storage cask transporter except at gateways that can be sealed using IAEA seals after the sub-area is filled.

- Design the perimeter of the storage area so that the storage cask transporter can only enter through the storage cask loading room in the receiving and handling building or through infrequently used portals that can be sealed with IAEA seals.

- Design casks to allow use of fibre optic seals with remote electronic verification capability.

- Design storage casks to be sealed to the concrete pads on which they are placed in the storage area.

- Provide temperature sensors that can monitor the storage cask interiors.

- Incorporate a collimator in the storage cask shielding wall to permit gamma energy analysis of the contained spent fuel.

In addition to the specific design features listed above, some general characteristics should be incorporated in the facility. These include, for example, the following:

- adequate lighting in the operating areas for the IAEA surveillance cameras

- structural designs and plant layout that minimize the number of access portals from which spent fuel could be removed from the facility, thereby reducing the demand on IAEA C/S systems

- designs that minimize interferences with the surveillance cameras and reduce the frequency of anomalies resulting from restricting the view of the cameras

- design of shipping and storage casks that allow the placement of IAEA seals with minimum effort and ensure that violations of containment are detectable.

1.0 INTRODUCTION

The objective of the work described in this report was to identify and analyze design features that can influence the effectiveness and efficiency of IAEA safeguards inspections at away-from-reactor (AFR) dry storage facilities. The goals of the work were to present specific examples of design features that facilitate IAEA inspections, and to provide some perspectives on solutions to anticipated problems in verifying nuclear material flows and inventories at AFR dry storage facilities.

The level of effort required and the degree of effectiveness of IAEA safeguards in detecting diversion of nuclear material can be affected by the facility designs. These designs include material handling procedures, layout of equipment, process and storage areas, physical and radiation barriers, and degree of automation of the process. The U.S. Interagency Action Plan Working Group for Strengthening IAEA Safeguards recognized this need by recommending development of facility design features that could improve the efficiency and/or the effectiveness of the IAEA's inspection and verification efforts. Dry storage of spent LWR fuel away from reactors was recognized to have special safeguards problems and was included in the list of facility types to be investigated.

Because of the worldwide delays in reprocessing, it is becoming increasingly important to expand the capacity for storing spent LWR fuel. Options available for increasing at-reactor (AR) capacity include installing high-density storage racks, double tiering, disassembling and consolidating fuel rods, expanding the size of the storage pools, or using dry storage at the reactor site.

Separate AFR storage is a viable alternative to AR storage. Dedicated storage facilities such as the Morris Operation in the U.S. and CLAB[1] in Sweden represent wet storage facilities that are in use today. Dry storage is a technically attractive approach to interim storage of LWR spent fuel. The monitored retrievable storage (MRS) approach being developed in the U.S. is based on dry, passively cooled storage modes. One operating AFR dry storage for LWR spent fuels is the 1,500-metric-ton facility at Gorleben in Lower Saxony, FRG. This facility and a similar one being constructed at Ahaus in North Rhine-Westphalia, FRG, store LWR fuel assemblies in steel casks that are also used as transport casks.[2] Other storage modes are at various stages of development for LWR fuels as well as for gas-cooled reactor and heavy water reactor fuels. These include, for example, emplacing spent fuel in air-cooled vaults, in surface dry wells, and in silos or casks placed on the surface in open fields.

The methodology used in evaluating design features for the selected facility type was developed in earlier work.[3,4] The methodology is summarized only briefly here. The principal steps comprising the methodology are the following: 1) define the baseline facility and safeguards system, 2) evaluate the baseline system to identify safeguards problem areas, and 3) identify potential design features for alleviating the safeguards problems, and after screening out those that are impractical, determine the impact of incorporating the remaining design features in the facility design.

2.0 SUMMARY AND CONCLUSIONS

Thirteen design features were identified that have potential for enhancing IAEA capability for verifying nuclear material flow and inventory at future AFR spent fuel storage facilities. In some cases, the design features represent different approaches for resolving the same safeguards issue, and it is not expected that they all would be deployed. The design features address 1) ways to minimize demands on IAEA manpower and equipment and 2) ways to resolve those verification issues peculiar to AFR storage facilities that perform fuel handling and packing operations, e.g., frequent shipments to and from the facility, fuel bundle disassembly, and long-term storage of large inventories.

It was concluded that incorporation of design features can substantially reduce the cost of flow verification by providing ways to reduce or eliminate inspector presence without increasing the level of intrusiveness on the facility operator. Alternatives for enhancing inventory verification efficiency and methods for resolving anomalies in the event of failures of containment or surveillance measures were identified.

The issues addressed in this paper concern facilities that may be built in the future. By taking the features that effect safeguards into consideration early in the design stages, it is possible to circumvent problems in verifying nuclear material at AFR storage sites.

3.0 BASELINE ASSUMPTIONS

The baseline assumptions used in this study include a set of technical objectives for safeguarding an AFR LWR spent fuel dry storage facility, descriptions of the baseline facility including the nuclear material, buildings and equipment, and the safeguards approach needed to attain the safeguards technical objectives.

3.1 SAFEGUARDS OBJECTIVES

The safeguards technical objectives can be translated into detection goals by quantitatively defining significant quantity, detection timeliness, and probability of detecting diversion. The IAEA Safeguards Glossary[5] provides guidelines for the detection goals. Table 1 lists the values that are assumed for this study.

The values suggested in the IAEA Safeguards Glossary[5] for detection probabilities are 90% to 95%, with a false alarm probability of 5% or less. The values assumed for this study are 90% and 5%, respectively. Because no capability exists in the baseline facility for uranium-plutonium separation, the detection goal quantity is fixed by the plutonium content in a fuel assembly or package of consolidated fuel rods. On this basis, a goal quantity is 2 PWR assemblies or 5 BWR assemblies for intact fuel assemblies. For consolidated fuel rods, a canister typically contains the equivalent of 2 assemblies, thus 1 canister of PWR rods or 2 canisters of BWR rods constitute a goal quantity.

3.2 SPENT FUEL RECEIVING

The facility receives spent fuel as intact assemblies or as canistered fuel rods from rod consolidation processes carried out at the reactor site. Capability for retrieving from storage and shipping from the facility is provided. Spent fuel is received during the first 20 years of operation and shipments are carried out during the last 5 years of operation.

TABLE 1. Detection Goals

	Significant Quantity	Detection Time
Plutonium in irradiated fuel	8 kg (total element)	1 to 3 months
U-235 in uranium enriched <20%	75 kg (total isotope)	1 year

The spent fuel will be transported in massive, heavily shielded casks from the reactor sites. Transportation technology for spent fuel is well developed, and a number of rail, sea, or truck shipping casks have been fabricated and are in use today, and others are in the design stage. Characteristics of some of these casks are listed in Table 2 to illustrate typical capacities and physical sizes and masses of the casks that might be used for shipping spent fuel to and from AFR storage sites.

Only LWR UO_2 fuels (not mixed-oxide fuels) are considered in the study. Characteristics of the LWR fuels vary widely in dimensions, mass, burnup, cooling times and other factors. Table 3 describes the spent fuel characteristics that are assumed for this study.

TABLE 2. Physical Characteristics of Some Spent Fuel Shipping Casks

Cask	Transport Mode	Capacity Assemblies PWR	BWR	Weight, metric tons	Overall Dimensions, m Dia.	Length
IF-300	Rail	7	18	63	1.63	5.28
NLI-1/24	Rail	10	24	88	2.63	5.69
TN-12	Rail	12	32	106	2.49	5.41
NFS-4	Truck	1	2	23	1.27	5.44
TN-8	Truck/rail	3	--	36	1.73	5.59
TN-9	Truck/rail	--	7	36	1.73	5.84

TABLE 3. Characteristics of Typical LWR UO_2 Fuels

Characteristic	PWR	BWR
Fuel assembly dimensions:		
length, m	4.06	4.47
cross section, mm	210	139
Assembly weight:		
total, kg	665	276
uranium, kg	461	180
No. of fuel rods per assembly	264	63
Final uranium enrichment: %U-235	0.8-1.2	0.8-1.0
Plutonium content:		
kg/assembly	3.8	1.4
kg/rod	0.0144	0.0222
Decay heat, W/assembly (10 yr after discharge)	1000	400

3.3 MATERIAL FLOW FOR BASELINE FACILITY

Simplified overall material flow diagrams for the baseline facility are shown in Figures 1 and 2 for the receiving and handling operations. The receiving and handling operations take place in a single building. The spent fuel is received in a heavily shielded transport cask, either by rail or truck, in an enclosed receiving and inspection room where the vehicle and the external parts of the cask are washed down to remove road dirt. The cask and vehicle are visually inspected for damage, and surveyed and smear-tested for radioactive contamination. If no damage or contamination are found, the cask covers and protective devices are removed, and the cask is placed on a cart and moved into the cask handling and decontamination room. The IAEA seal, if one has been applied at the reactor, can be checked while in this room.

When the transport cask has been cooled and decontaminated, it is moved into the cask unloading cell. The cask unloading cell is a remotely operated concrete-shielded cell equipped with viewing windows and closed circuit television (CCTV). This cell is connected to the fuel handling hot cell by a port to which the shipping cask can be connected and sealed. This port allows the fuel transfer to be made without spreading radioactive contaminants and with minimum radiation to the workers. Fuel transfers are made by positioning the transport cask under the transfer port, removing the shielding plug in the port, removing the inner cask cover, and lifting the fuel into the cell.

After the fuel is transferred, the interior of the cask is decontaminated and the inner cask cover is replaced. The shielding plug is replaced in the port, and the cask is transferred to the cask handling and decontamination room where the exterior is decontaminated and the outer lid is reattached. The cask is then moved to the receiving and inspection room where it is placed on the transport vehicle and prepared for shipment offsite.

All operations required to prepare the spent fuel for dry storage take place in the fuel handling hot cell. This cell is a heavily shielded, remotely operated room equipped with viewing windows and CCTV. Fuel handling is accomplished with remotely operated cranes, and master-slave manipulators are used to perform process and maintenance activities. There is a port for transferring the prepared fuel to the storage cask. This cell is connected via a port to a maintenance cell overhead where the cranes and process equipment can be moved for repairs or for decontamination prior to removal from the facility.

3.4 OPERATIONS IN FUEL HANDLING HOT CELL

In the fuel handling hot cell the bare spent fuel assemblies and canisters are inspected to confirm their identity by the serial numbers placed on the assemblies by the fuel manufacturer or unique identity markings applied to canisters by the reactor operator. The bare assemblies are examined visually for damaged fuel rods, and any assemblies suspected of containing leaking rods are placed in special canisters. For fuel received in canisters, the canisters are examined for integrity and placed in overpacks if damaged. The special canisters or overpacks are welded shut, and unique identifying numbers are applied to them.

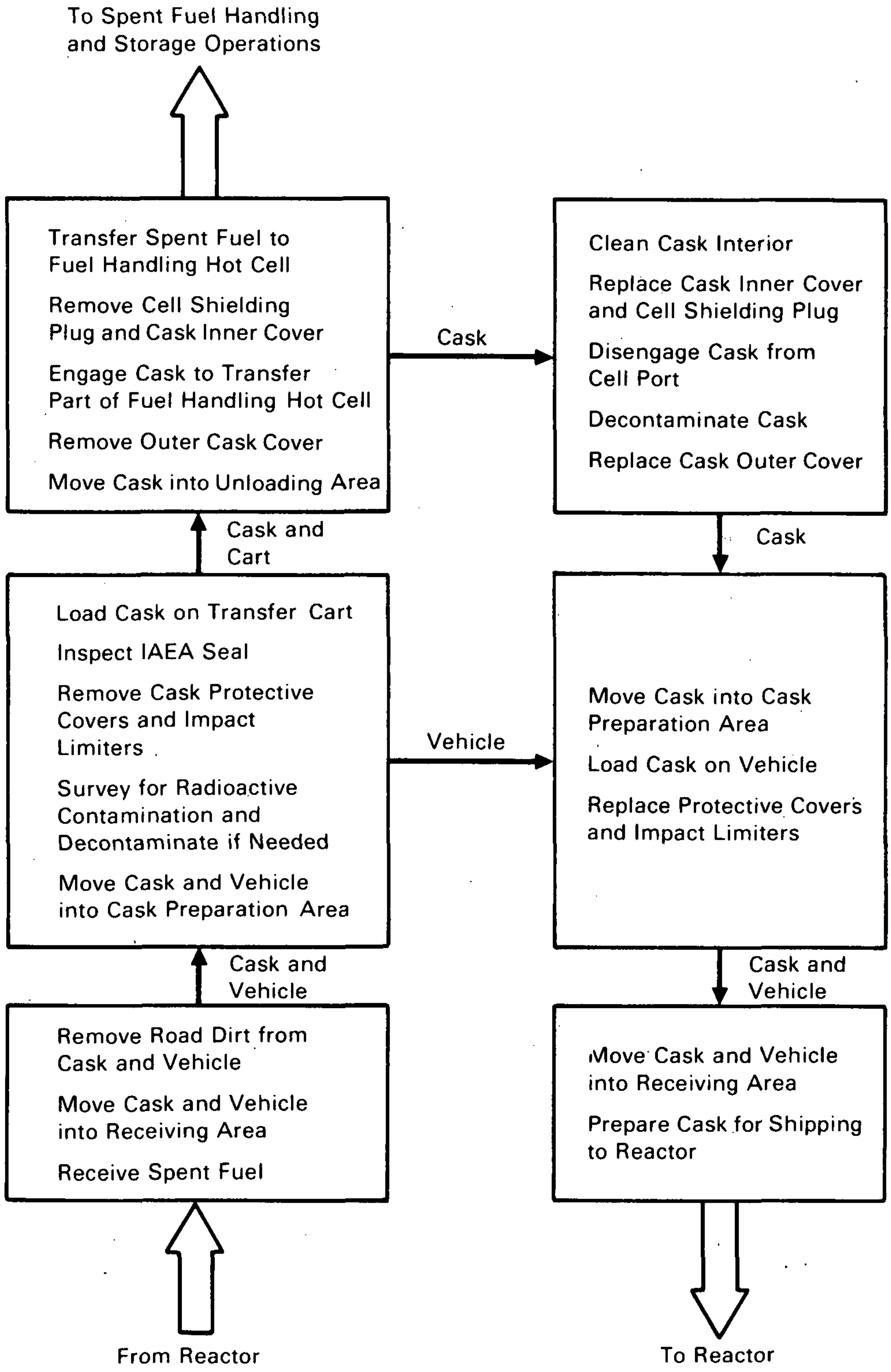

FIGURE 1. Material Flow Diagram: Transport Cask Handling Operations

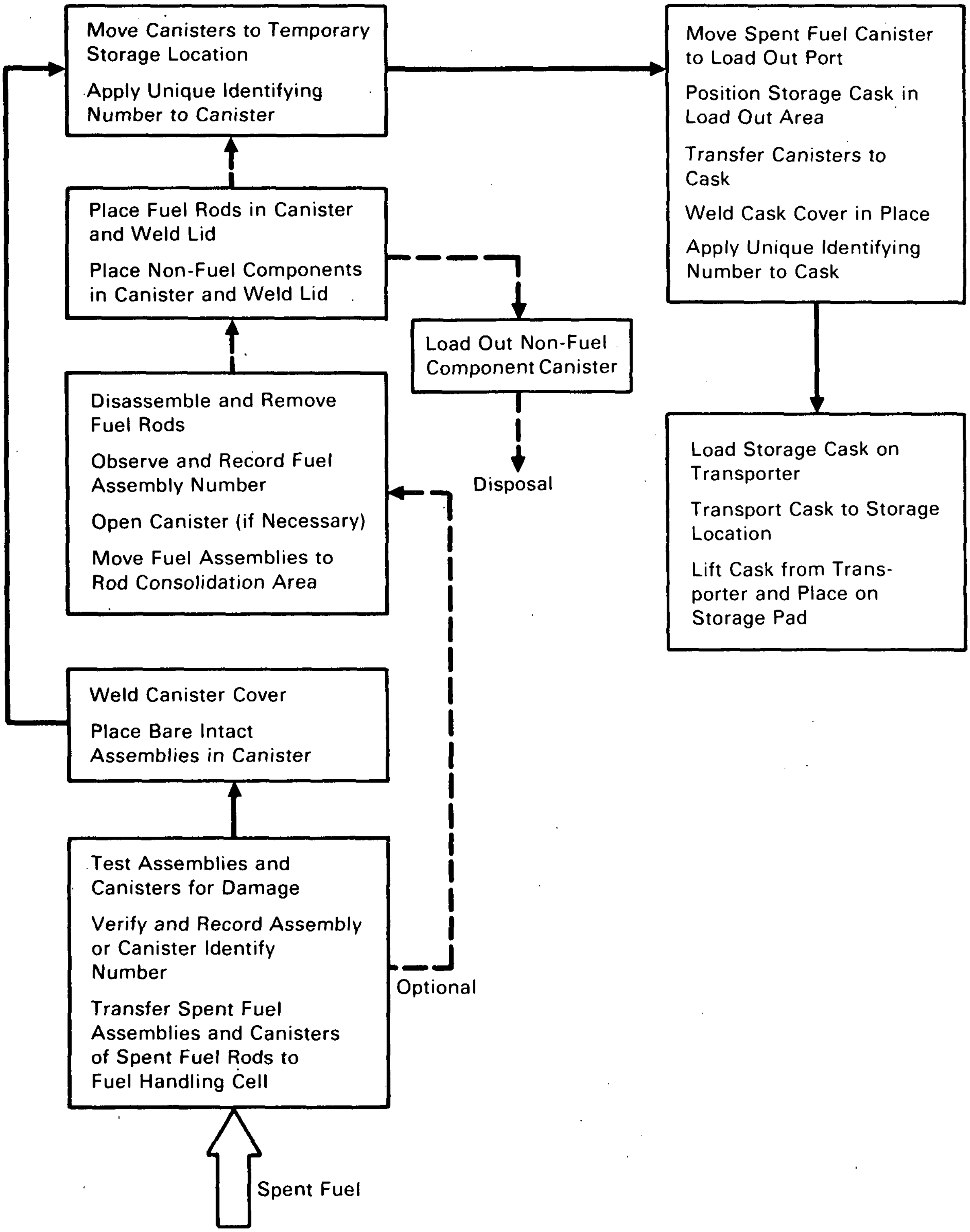

FIGURE 2. Material Flow Diagram: Spent Fuel Handling

Capability for fuel rod consolidation is provided in the cell. Equipment is installed for removal of the assemblies from the canisters, if packaged by the reactor operator, and for disassembly and removal of the fuel rods. The fuel rods are placed in canisters, welded shut, and given a unique identifying number. The consolidation process is performed so that rods from a single assembly will all be placed in one canister, but rods from more than one assembly may be packed in one canister. The stainless steel and Zircaloy hardware from the assemblies is compacted, placed in canisters, and removed from the fuel handling cell for separate storage.

3.5 LOADOUT AND STORAGE OF FUEL

The canistered spent fuel is stored in concrete casks placed on concrete pads in open fields at the site. Each storage cask holds 10 to 12 PWR assemblies or 25 to 30 BWR assemblies. After packaging operations are completed in the spent fuel handling cell, the canisters are loaded into the storage cask through the loadout port in the fuel preparation hot cell. The storage cask is moved to the storage field by the transporter and placed on a storage pad.

Retrieval of the spent fuel and shipment to the reprocessing plant or to the ultimate disposal site is assumed to involve operations essentially the reverse of the above procedure.

4.0 BASELINE SAFEGUARDS APPROACH

The safeguards approach for the baseline facility is based on a system of material accountancy heavily complemented by containment and surveillance (C/S) measures, and on descriptions given by Tkharev[6] and Ermakov.[7]

The material accountancy system is based on item control. The items are either intact fuel assemblies or canisters of fuel rods. The nuclear material content is based on the fuel manufacturer's recorded uranium element and U-235 content corrected for 1) calculated plutonium production and uranium depletion in the reactor, and 2) radioactive decay subsequent to discharge from the reactor.

Material flow verification is further complicated if fuel rod consolidation is carried out at the facility because batch identity is lost when the fuel rods are removed from the assemblies and consolidated.

4.1 RECORDS AND REPORTS

When used in conjunction with reports from the reactor facility, the AFR facility records and reports can enable the inspector to establish continuity of knowledge for each spent fuel assembly or canister of fuel rods from the fuel fabrication facility, through the reactor, to the storage facility. The operating records plan an especially important role in a dry storage facility because of the heavy reliance on C/S measures for verifying flow and inventory. Investigating anomalies resulting from CCTV failures or seal breakage may be possible only by examining the operator records and comparing them to the facility accounting records and the reports sent to the IAEA. Also, receipts or shipments of spent fuel, loading of fuel into canisters, and loading canisters into storage casks when an inspector is not present may have to be indirectly verified by comparing containment and surveillance records with operator records. Indirect measures are not entirely satisfactory, but events are likely to occur that provide no other alternative.

4.2 VERIFYING FLOW AND INVENTORY

The massive building structures and the high radiation levels associated with the spent fuel restricts the movement of the spent fuel to well-defined paths inside the facility. This offers possible approaches to help verify flow and inventory by the use of tamper-resisting seals and video surveillance equipment.

The entire facility is encompassed by one material balance area (MBA) having the following key measurement points (KMP) for flow verification:

KMP-1 - Spent fuel receipts
KMP-2 - Placement of fuel in canisters
KMP-3 - Placement of canistered fuel in storage casks
KMP-4 - Shipments of canistered fuel away from the facility.

Spent fuel inventory at the facility is located primarily in the storage casks in the storage area, but there will be additional inventory in the lag storage area in the fuel handling cell and in unopened receipts in transport casks in the receiving and inspection room. The KMPs for inventory verification are the storage area, KMP-A, the lag storage, KMP-B, and the fuel handling cell, KMP-C.

The material flow is summarized in Table 4. The rates are based on the assumption that this facility will receive fuel for 20 years followed by 5 years of shipments. The ratio of PWR to BWR fuel in tons is three to one. About 5% of the fuel is received already in canisters. The canisters filled at the facility contain one PWR or BWR assembly, but consolidated fuel rod canisters may hold rods from up to three PWR or seven BWR assemblies.

The strategic points including the KMPs and locations of IAEA C/S devices are depicted in Figure 3. Surveillance cameras are located in the transport cask handling and decontamination room, the storage cask handling and decontamination room, and the cold maintenance area. Because of the possible removal of spent fuel via the hot decontamination and maintenance cell, cameras in the cold maintenance area view the exit from that area. The other two cameras view the cask movement pathways. In this way, all access to areas in which unshielded spent fuel can be handled are under surveillance. An inspector is presumed to be present when the fuel is brought into the facility and when the canisters are filled and placed into storage casks.

TABLE 4. Material Flow at the Baseline Facility

Measurement Point	Annual Material Flow
KMP-1	30 receipts per year of 3 TN-12 rail transport casks per shipment including: -660 bare intact PWR assemblies - 35 canistered PWR assemblies or equivalent number of rods -925 bare intact BWR assemblies - 46 canistered BWR assemblies or equivalent number of rods
KMP-2	660 PWR assemblies 925 BWR assemblies
KMP-3	1666 canisters 50 storage casks
KMP-4	120 shipments of 3 TN-12 rail casks per shipment (6670 canisters)

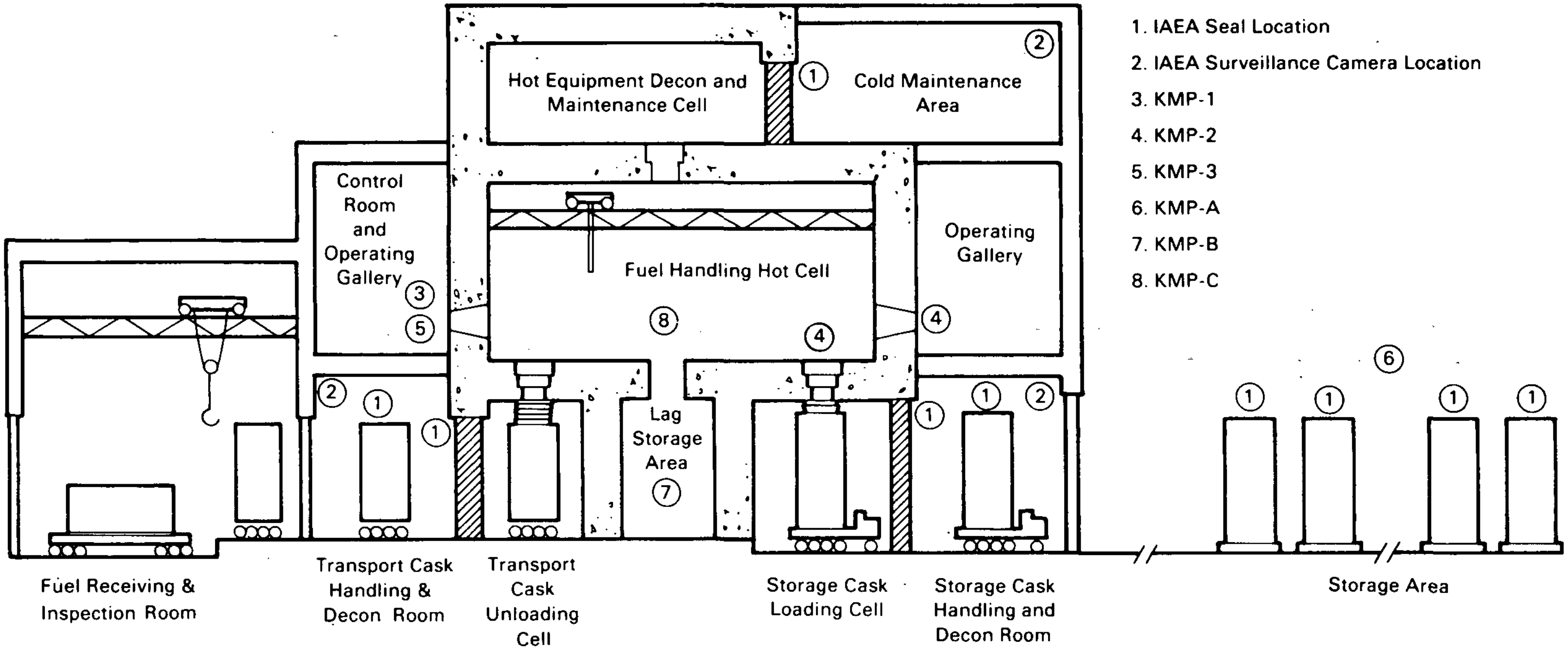

FIGURE 3. Safeguards Strategic Points at the Baseline AFR Dry Storage Facility

If an inspector is not present during these operations, the C/S system must be relied on for verification. No satisfactory methods are available for verifying receipts after the spent fuel has been canistered and placed in storage casks. This stresses the importance of defining the procedure to hold the spent fuel in lag storage until the inspector is present.

5.0 BASELINE SAFEGUARDS SYSTEM EVALUATION

In assessing the effectiveness of safeguards at an AFR dry storage facility, consideration needs to be given to the capability of the safeguards approach to achieve the technical objective with respect to the detection of diversion of a goal quantity, the timeliness, and the probabilities of detection and false alarms. In assessing the efficiency, the demand for IAEA resources, including inspection manpower both in the field and at headquarters as well as the cost of IAEA equipment, should be considered. In addition to effectiveness and efficiency, which have an impact primarily on the IAEA, the degree of intrusiveness on the facility operator must be considered. Effectiveness, efficiency, and intrusiveness are the principal criteria that can be used for judging the efficacy of a proposed design feature for enhancing the implementation of IAEA safeguards.

Other factors for consideration are the possible effects on inspectors' health and safety; e.g., the expected radiation dose that may be accumulated in performing an inspection activity, or the physical hazards encountered in verifying seals on top of the concrete storage casks in the open fields of the storage area.

5.1 CONSTRAINTS

Two quantitative constraints placed on the inspection effort are the availability of IAEA resources and the limitations specified in the relevant safeguards agreement. The basis for the latter is found in INFCIRC/153 (Corrected), Paragraph 80b.[8] It is doubtful that AFR spent fuel storage facilities were considered when the criteria for maximum routine inspection effort (MRIE) were developed, and it is not clear from INFCIRC/153 (Corrected) which criteria apply. It can be argued that the strategic importance of the spent fuel stored at the AFR is not different from that at reactor facilities, in which case MRIE could be based on Paragraph 80a. On the other hand, the large quantities of plutonium emplaced in the facility each year and the large inventory after a few years of operation, coupled with the long storage period during which verification by direct measurements cannot be made, may place a different perspective on the importance of safeguarding spent fuel. One-sixth of a man-year inspection effort as allowed under Paragraph 80a may not be sufficient for the baseline facility; therefore, it may be more reasonable to base MRIE on Paragraph 80b.

The routine inspection effort at the baseline facility was estimated using the material flows from Table 4 and the inspector manpower assumptions in the following paragraphs. For the baseline case, inspectors are present during the unloading of receipts and during the loading of the storage casks. The estimate is for the period when the facility is receiving fuel, i.e., the first 20 years of operation. No shipments from the baseline facility take place during this time.

5.2 INSPECTION MANPOWER FOR FLOW VERIFICATION

The following inspections are provided as needed:

- Up to 12 hours to observe the unloading of each receipt into the fuel handling cell.
- 4 hours to observe the loading of the spent fuel canisters into each storage cask and to apply an IAEA seal to the outer cover of the cask after it is welded in place.
- The following activities are performed at three-month intervals:
  - 8 hours to review video surveillance records
  - 8 hours to examine facility accounting records
  - 4 hours to verify seals on storage casks placed in the storage area during the three month period
  - 2 hours to count all the storage casks in the storage area
  - 4 hours to count and identify by serial number the assemblies and canisters of spent fuel in the fuel handling cell lag storage.

5.3 INSPECTION MANPOWER FOR PHYSICAL INVENTORY VERIFICATION

The following inspections are performed once a year:

- 26 hours to perform activities in item 3 in the previous paragraph
- 150 hours to inspect the seals on the storage casks in the storage area on a statistical sampling basis. (The man-hours required for this activity depend on how long the facility has been in operation; e.g., after 1 year there are 50 casks and after 20 years there are 1000 casks. We assume an average of 500 casks in the inventory and a manpower requirement of one-third hour per cask for verifying and replacing the seal, using a probability of detection of 90% for detecting 1 seal violation.)

5.4 TOTAL INSPECTION EFFORT

The total inspection time, based on the foregoing assumed activities, equals 100 inspection days per year. This value includes only routine inspection activities and does not provide time for anomaly resolution that could be needed if C/S failures occur or when accounting mistakes are detected. It is reasonable to expect that an additional 10 to 15 inspection man-days may be needed for anomaly resolution, and for the baseline case, 15 additional days are included.

6.0 DESIGN FEATURES FOR AFR STORAGE FACILITIES

Specific design features that may facilitate implementing IAEA safeguards at an AFR spent fuel dry storage facility are identified and discussed below. In general, each design feature addresses one or more of the following IAEA safeguards target areas:

- Reduce effort needed to verify spent fuel receipts, spent fuel loading into canisters, and physical inventory in the storage area.

- Enhance capabilities to verify spent fuel receipts, spent fuel transfers in the fuel handling cell, and physical inventories.

The design features considered in this study were analyzed on the basis of their impact on effectiveness and efficiency of IAEA safeguards implementation. The effect that each design feature can have on the degree of intrusiveness of IAEA safeguards on the facility operator was also assessed.

In assessing the value of a design feature, we also considered the practicality of implementation. This deals with the state of development of the particular safeguards technology that is intended to be used. It is pointless, for example, to propose adapting the facility design to permit the use of a safeguards method that is unlikely to be developed in the time frame the facility is to be operated.

6.1 SPECIFIC DESIGN FEATURES

Quarantine Area for Receipts. This design feature addresses the capability to verify receipts. In the absence of an IAEA inspector during unloading of the receipts into the fuel handling cell, it is not possible to confirm that the spent fuel was actually unloaded from the transport cask. By holding the receipts in a dedicated area that allows the inspector to count and identify the fuel assemblies or canistered spent fuel, verification can be performed any time after the cask is unloaded and before the spent fuel receipts undergo further processing. The reduction in inspection effort that can be realized depends on the capacity of the quarantine area. A quarantine area with a capacity of 15 metric-tons, i.e., one shipment, will save 30 man-days/yr. The design permits the quarantine area to be sealed off from the operating areas of the fuel handling cell. This is a moderate increase in the intrusiveness on the facility operator. No undeveloped safeguards technology is involved.

CCTV Surveillance of Fuel Loading Process. Designing the fuel loading process including equipment and equipment location so the fuel rod consolidation step and the loading of fuel assemblies into canisters can be viewed and recorded by CCTV enables verification of material flows without direct visual observation by the IAEA inspector. This feature can detect undeclared fuel transfers or attempts to substitute dummy assemblies or canisters. The effect on inspection manpower is the additional time required to service the CCTV systems and to review the recordings. This is estimated to add about one inspection man-day per inspection or 4 inspection man-days/yr. The development of the CCTV systems is well advanced, but remotizing and radiation hardening (or development of shielding designs) for the in-cell units are yet to be done. The level of intrusiveness for this design feature will be less than in the baseline case.

Capability to Photograph Weld Beads on Canister Covers. Weld beads have unique appearances that are suitable for identifying filled canisters to verify the inventory of filled canisters awaiting loading in the storage casks or to resolve anomalies. It addresses the problem of substituting dummy canisters with falsified serial numbers. Implementing the inspection activities associated with this design feature will increase the demand on inspector man-hours by several inspector man-days/yr. No additional IAEA equipment is involved. The technique for photographing weld beads is well developed, but doing it remotely in a hot cell will require additional engineering development. The level of intrusiveness will be significantly greater than the baseline case because of the need to move canisters to a viewing location.

Weighing Station for Filled Canisters. This design feature provides an attributes test for verifying the inventory of canisters in the fuel handling cell. This test can be done on a statistical sample of the items in the inventory during the annual physical inventory verification inspection. The increase in inspection manpower depends on the size of the inventory, but it is reasonable to expect it to increase by about two man-days/yr. The technology for remote in-cell weighing using load cells is well developed. The load cell can be attached to an in-cell crane, thus allowing the canisters to be weighed without moving them from the storage location.

Quantitative Measurement of Receipts. This design feature would enable verification of receipts arriving at the facility in transport casks that were not sealed at the reactor facility. It provides protection against substitution with dummy fuel assemblies or unirradiated fuel assemblies having falsified serial numbers. The impact on inspection manpower would depend on the number of transport casks that arrive without IAEA seals. Two possible systems are envisioned for the NDA measurement: a portable system similar to the one being developed by Los Alamos National Laboratory that measures the gross gamma and neutron emissions,[9] or the gamma energy analysis system described by Nilsson, et al.,[1] with a collimator built into a shielding wall of the hot cell and a mechanism for scanning the fuel assemblies one at a time. The portable system was designed for use in water storage pools at reactors and has been field tested. Additional development is required before the system can be used in a hot-cell. The gamma energy analysis system using a built-in collimator has been designed for use in the CLAB facility in Sweden.

Qualitative Measurement of Spent Fuel in the Fuel Handling Cell. This design feature permits a gross gamma emission measurement of the spent fuel assemblies and canistered fuel. It permits attributes testing for inventory verification. Because gamma ray emission is more difficult to falsely simulate than mass, it would provide greater assurance than a weighing system. The measurements are made with high-level radiation detectors such as ion chambers. The test would be performed on a statistical sample of the assemblies and canisters in the fuel handling cell during the annual physical inventory verification. The additional inspection manpower over the baseline case depends on the size of the inventory, but it is reasonable to expect it will add about 10 man-days/yr of inspection effort. The measurement technology needed for this design feature is developed, but engineering development is needed for each specific application. The level of intrusiveness will increase over the baseline case.

Remote Operation and Monitoring of the Cask and Fuel Handling Operations. Operating the process from a central control room using CCTV to view the spent fuel movements permits the IAEA inspector to observe the movements as they occur. Video recording of the process during the time the inspector is absent, i.e., during the second or third shift, will allow detection of undeclared movements around the clock. The reduction in inspection man-hours associated with this design feature is estimated to be 4 inspection man-days/yr. CCTV systems for viewing and recording operations in hot cells are widely used in the nuclear industry today. However, adaptation of designs to give the tamper-resistance needed for independent verification will be required. This design feature will reduce intrusiveness.

Compartmentalization of the Storage Area. This design feature requires the storage area to be subdivided into sub-areas that can be sealed off after all the space for storage casks has been filled. In this way, the testing of a single seal on the access gate to the sub-area can supplant the need for testing the seals on every cask in the sub-area. This will reduce the effort for the annual physical inventory inspection. The baseline facility has space for 1000 storage casks, of which 500 will be filled at the end of 10 years of operations. Assuming each sub-area contains 100 storage casks, the physical inventory verification of the storage area will require the testing of 5 seals. Under the baseline case, 450 seals on the storage cask outer covers are inspected annually to achieve 90% probability of detection. The net reduction in inspection manpower from this design feature is about 18 inspection man-days. The only IAEA equipment needed are the seals and possibly surveillance cameras, both of which are widely used by the IAEA inspectorate. The level of intrusiveness is reduced by this design feature.

Limit Access to the Storage Area by the Storage Cask Transporter to a Single Pathway. This design feature requires the perimeter of the storage area to be surrounded by a barrier that is impenetrable by the storage cask transporter except through a single access point connected to the fuel receiving and handling building. By viewing the access point with a surveillance camera, the cask movements can be monitored, permitting the detection of any undeclared storage cask movements. This provides a possibility for resolving anomalies caused by inadvertent loss of containment of a storage cask, e.g., damaged seals or indications of cask movement. The main objective is to improve safeguards effectiveness, and this design feature has little impact on safeguards efficiency. The implementation of this design feature relies only on surveillance cameras that are currently available to the IAEA. The level of intrusiveness is reduced by this design feature.

Storage Cask Designs That Allow the Use of Fibre Optic Seals with Remote Readout of the Status of the Seals. This design feature requires cask designs that permit attachment of electronic fibre optic seals with provisions for protection of the seals from the weather, and allow interrogation of the status of the seals by the IAEA from a remote location, i.e., outside the storage area and possibly from IAEA headquarters, as proposed by the RECOVER[10,11] system. Each year during the first 20 years of operation of the baseline facility, 50 storage casks are added to the storage area, requiring 50 fibre optic seals to be attached and included in the electronic readout network. A totally reliable system could reduce the inspection effort for physical inventory verification of the storage area by the time required to verify the conventional seals used in the baseline safeguards approach, less the time required to affix the 50 fibre optic seals added each year, plus the time for maintaining previously deployed seals and the readout system. There is a potential for reducing the inspection effort by 10 to 15 man-days/yr. The technology for fibre optic seals is under active development. The level of intrusiveness is reduced by this design feature.

Designs to Allow Sealing of Storage Casks to the Concrete Pads. This design feature also addresses the problem of verifying the inventory in the storage area. Considerable inspection time can be saved by eliminating the need to climb to the top of the storage casks to test and replace seals. If this design feature is implemented, the IAEA inspector will affix seals on all casks that have been emplaced in the storage area since the last annual or interim inspection. He first confirms the cask identity and verifies the containment by checking the IAEA seal placed on the outer cover of the cask while in the receiving and handling building. Reduction in inspection effort is estimated to be 4 man-days/yr. This value was reached by estimating a time for testing a seal at ground level of one-sixth hour versus one-third hour for one on top of a cask, and using 500 casks as the average number in the storage area. To this was added hours for affixing seals on the 50 casks emplaced in the storage area each year. This design feature uses no IAEA equipment other than conventional seals. The level of intrusiveness is reduced by this design feature.

Provide Temperature Sensors for the Storage Casks. This design feature involves inclusion of one or more thermocouple wells leading to the cavity of the storage casks. This will permit inspectors to observe the temperature differential between the cask interior and exterior, providing a measure of the heat of decay associated with the spent fuel. This is a straightforward test to verify the contents on an attributes basis. Failure of seals or other indications of loss of containment of the storage casks creates a difficult verification problem. It will be costly to move a storage cask back to the fuel handling and receiving building to permit direct verification of a cask's contents, but a temperature measurement is a satisfactory alternative. It is reasonable to believe that 3 to 5 casks/hr can be tested in this manner. No estimate of the impact on inspection effort can be made in the absence of data on the frequency of seal failures over long periods. Use of the test requires a calibrated thermocouple and a millivolt meter. The level of intrusiveness is not affected by this design feature.

Provisions for Gamma Energy Analysis of Storage Cask Contents. A gamma energy spectrum obtained at the time the storage cask is placed in the storage area will provide an initial measure of the gamma emitting fission products in the cask. Subsequent measurements can be made to verify the contents using the characteristic gamma spectra of long-lived fission product isotopes such as Cs-137 or Eu-152. One approach is to measure the ratio of counting rates of two different isotopes. After performing the measurement once, a subsequent measurement made at a known time in the future can be used to verify the cask's contents by comparing the two results, after correcting for radioactive decay. The main effect of this design feature on inspection effort is time required to perform the initial measurement. A single measurement can be made in about one-half hour, and 50 measurements per year are required. The increased inspection effort is about 3 man-days/yr. The technology for this design feature is developed, but specific designs for the collimator in the shielding wall of the storage casks are needed. Detectors and multichannel analyzers are available. This design feature will increase the level of intrusiveness.

6.2 GENERAL FACILITY CHARACTERISTICS

General characteristics of an AFR facility that would permit adoption of one or more design features include adequate lighting in the operating areas for the IAEA surveillance cameras, structural designs and plant layout to minimize the entry and exit portals that accommodate spent fuel, plant designs that are compatible with the placement, operation, and servicing of surveillance cameras, and storage cask design that utilizes placement of external sealing techniques.

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The Pacific Northwest Laboratory has performed a study for the Nuclear Regulatory Commission to identify and analyze design features that can facilitate the implementation of IAEA safeguards at away-from-reactor facilities for dry storage of light water reactor spent fuels. Thirteen specific design features are identified that can enhance verification of nuclear material flow and inventory. These are assessed from the viewpoint of safeguards effectiveness and possible impacts on the IAEA and the operator of the AFR facility.

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