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BASELINE DESCRIPTIONS FOR LWR SPENT FUEL STORAGE, HANDLING, AND TRANSPORTATION

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Sandia Laboratories

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ABSTRACT

Baseline descriptions for the storage, handling, and transportation of reactor spent fuel are provided. The storage modes described include light water reactor (LWR) pools, away-from-reactor basins, dry surface storage, reprocessing-facility interim storage pools, and deep geologic storage. Land and water transportation are also discussed. This work was sponsored by the Department of Energy/Office of Safeguards and Security as part of the Sandia Laboratories Fixed Facility Physical Protection Program.

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SECTION I

INTRODUCTION

In April 1977, the United States announced its decision to defer indefinitely the commercial reprocessing of spent fuel and the recycling of plutonium produced in U.S. nuclear power programs. In addition, the intention was expressed to continue discussions on a wide range of international approaches and frameworks that would permit all nations to achieve their energy objectives while reducing the spread of nuclear explosives capabilities. In October, the Department of Energy announced a federal government offer to accept and take title to nuclear reactor fuel from U.S. utilities and selected foreign utilities for a one-time storage fee. Implementation of these policies will increase the quantities of reactor spent fuel that must be kept in long-term storage.

Spent fuel from a light water reactor (LWR) contains fissile plutonium. For example, pressurized water reactor (PWR) spent fuel contains approximately 3 kg of plutonium per assembly, while boiling water reactor (BWR) assemblies each contain approximately 1 kg. At the present time there are approximately 12,000 spent fuel assemblies weighing a total of 3000 metric tonnes uranium (MTU) stored in U.S. reactor pools and at Away-From-Reactor (AFR) storage facilities. These represent 15,000 to 20,000 kg of fissile plutonium.* If no reprocessing occurs, this quantity is expected to double by 1980. Comparable quantities are or will be stored in foreign facilities.

Following the April policy announcement, a spent fuel safeguards project sponsored by the Department of Energy/Office of Safeguards and Security (DOE/OSS) was initiated to establish safeguards system

*LWR Spent Fuel Disposition Capabilities, ERDA 77-25, May 1977.

performance criteria for the detection of national diversion and the prevention of acts of sabotage and theft perpetrated by subnational groups. These criteria will be developed through the application of a recently developed systematic approach to the design of engineered safeguards systems. The initial step in this approach is the preparation of baseline descriptions.

This document contains baseline descriptions for spent fuel handling, storage, and transportation. The facilities which are described include LWR, AFR storage basins, reprocessing facility interim storage pools, Dry Surface Storage (DSSF), and deep geologic storage. This range of facilities covers short-term, mid-term, and long-term storage of spent fuel. The descriptions are considered generic and are based on a review of available documentation presented in the bibliography.* These facility descriptions include:

1. Material characteristics -- the form of the material at the facility,
2. Facility description -- site layouts, buildings, and operating and service areas,
3. Facility operations -- receiving/shipping, handling, and storage, and
4. Essential support systems -- ventilation, waste management, water, electricity, etc.

The transportation of spent fuel by road, rail, barge, ship, and combinations thereof is described, including the shipping casks.

The descriptions form the basis for the subsequent preparation of Preliminary Safeguards Concepts in which safeguards concerns related

*Engineering design details have not been emphasized in this document. No attempt has been made to identify preferred design concepts, nor should it be inferred that concepts and designs presented are recommended to the nuclear industry for adoption where these differ from current practice.

to national diversion and subnational threats of sabotage and theft will be identified, as well as safeguards measures to mitigate these threats.

SECTION II

LIGHT WATER REACTORS

This section describes spent fuel handling facilities and operations in LWR plants. A generic description is derived from the latest designs which represent 1000 MWe class reactors. Similarities exist between PWRs and BWRs in the arrangement of refueling and storage pools and in the methods of handling spent fuel assemblies. For example, modern PWRs and BWRs utilize similar locations of refueling pools in their respective containments, and spent fuel storage pools and shipment facilities in the adjacent fuel handling building. At both types of facilities a transfer tube system connects the refueling pool and the spent fuel storage pool.

Differences between PWRs and BWRs are more significant in the older reactors. In some BWR units, the storage pool may be located within a primary, spherical containment. In BWRs with the wet well pressure-suppression type containment, the storage pool is located within a secondary containment provided by the reactor building. It may also be located above grade and connected to the refueling pool by a water channel as opposed to the below grade pools with connecting transfer tube found in the most recent designs.

The geometry, weight, number of fuel rods, and design of fuel assemblies differ considerably between PWRs and BWRs.

In both PWR and BWR facilities, spent fuel storage and handling is concerned with refueling the reactor core, storage of irradiated fuel, and preparatory operations for the shipping of spent fuel. Core refueling is performed every 12 to 18 months and necessitates removal of part of the core and replacement with fresh fuel. Core reshuffling also is performed at that time. Spent fuel is removed from the reactor and placed in the spent fuel storage pool, while fresh fuel is taken from storage and loaded into the reactor. After a minimum cooling time of 90 days, the irradiated fuel is placed in a cask and removed from the reactor site. However, in most cases, the spent fuel remains at the reactor for much longer periods of time. Recent DOE announcements indicate that this time may be 5 years or longer.

Due to the deferral of spent fuel reprocessing and the resultant increased requirement for spent fuel storage, some PWR and BWR facilities are currently reracking their storage pools with High-Density Fuel Storage Systems (HDFSS) to provide additional storage capacity. This will enable many facilities to retain spent fuel for periods of 8 to 10 years. Consequently, AFR facilities will receive some spent fuel which has been aged longer and is thermally and radioactively cooler.

Also, deferral of spent fuel reprocessing may potentially cause power reactor facilities to consider plans for:

1. The recycling of fuel rods into assemblies reconstituted from spent fuel which material tests have indicated contain significant additional burnup time, or
2. The disassembly of assemblies to allow for increased storage packing of spent fuel rods in higher density containers.

In past years, BWR assemblies have been disassembled and rebuilt underwater and the handling techniques are well established. Disassembly and reconstitution of PWR fuel bundles, which has perhaps been done on a lesser scale in the past, may also receive consideration in similar future planning. Consequently, these practices should also be applicable for PWR assemblies.

The major spent fuel storage and handling operations occur at the Refueling Pool and Transfer System, Spent Fuel Storage Pool, and

Cask Loading Area. Material characteristics, system descriptions, operations within the area, and support systems will be discussed for each location.

Pressurized Water Reactor

This subsection describes the details of the fuel handling facilities and operations in a generic PWR plant. A typical site plan is shown in Figure 1; the arrangement of the fuel handling and storage systems is shown in Figure 2.

Material Characteristics

The material flow during spent fuel handling is summarized in Figure 3. The fuel assembly is an entity that retains its identity through various handling operations. Thermal and nuclear properties of the fuel contained within the fuel rods change with the fuel age. In the interfacility transportation phase, the assemblies are contained within shipping casks which are handled as entities. These casks are described in Section V.

PWR Fuel Assemblies Structure -- The fuel assembly shown in Figure 4 is comprised of 264 fuel rods bound together by guide tubes which are fastened to upper and lower end fittings of the assembly. Spring clip grid assemblies are fastened to the guide tubes along the height of the fuel assembly to provide support for the fuel rods in two perpendicular directions. Because the fuel rods are not bound physically to the support points, they are free to expand longitudinally, thereby preventing bowing because of thermal expansion. The fuel rods are contained and supported, and the rod-to-rod centerline spacing is maintained within this skeletal framework.

The lower end fitting of the fuel assembly controls the coolant flow distribution and also serves as the bottom structural element. The top end fitting functions as the upper structural element of the

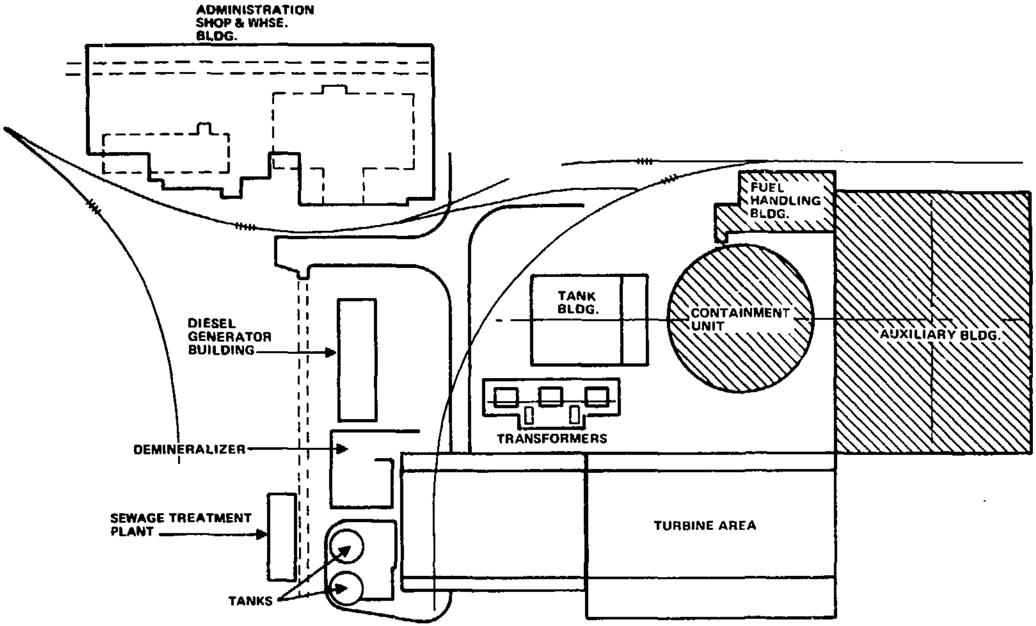

Figure 1. Typical PWR Reactor Site Plan

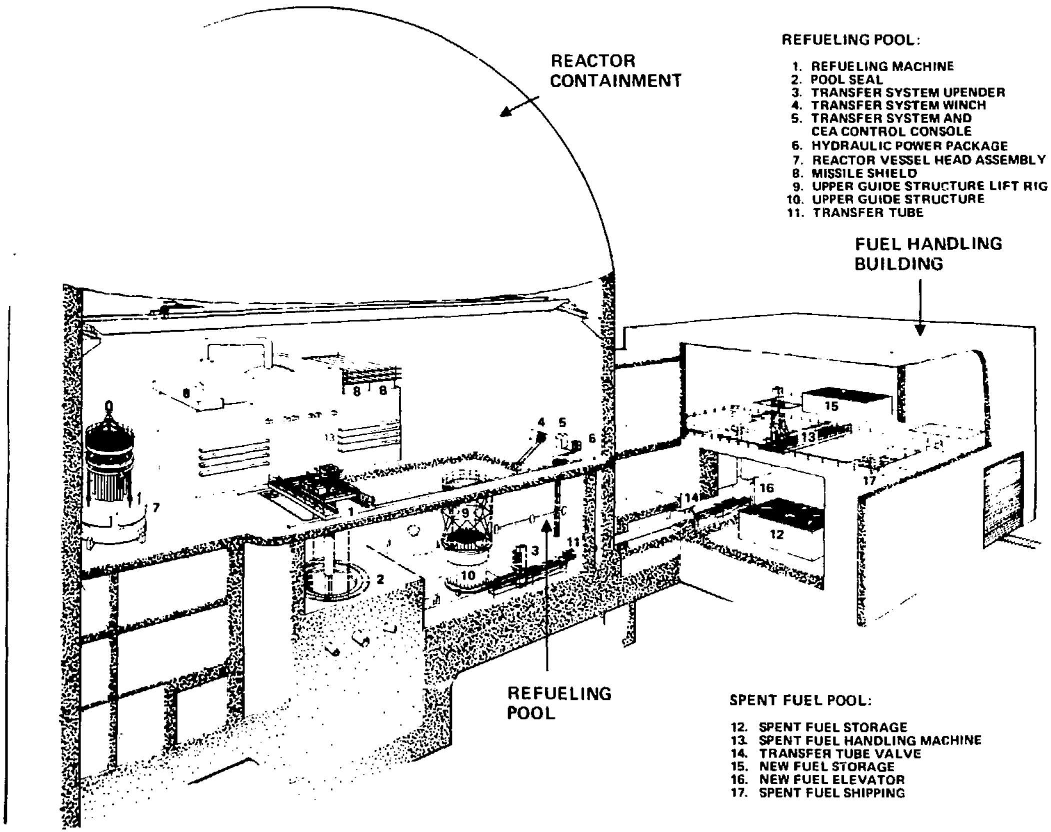

Figure 2. Fuel Handling and Storage at a PWR Facility

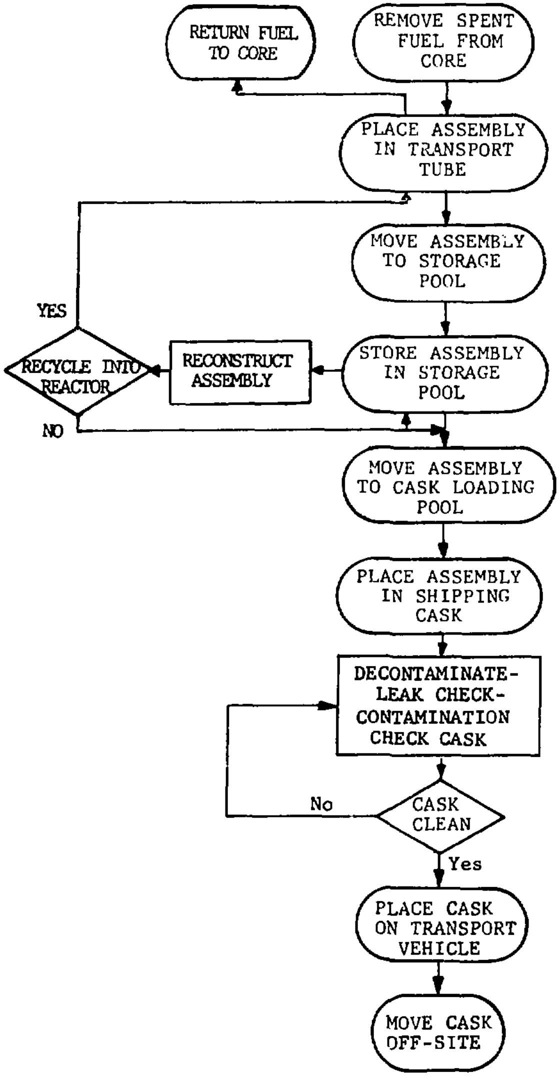

Figure 3. Spent Fuel Handling and Storage Operations at LWR Reactor

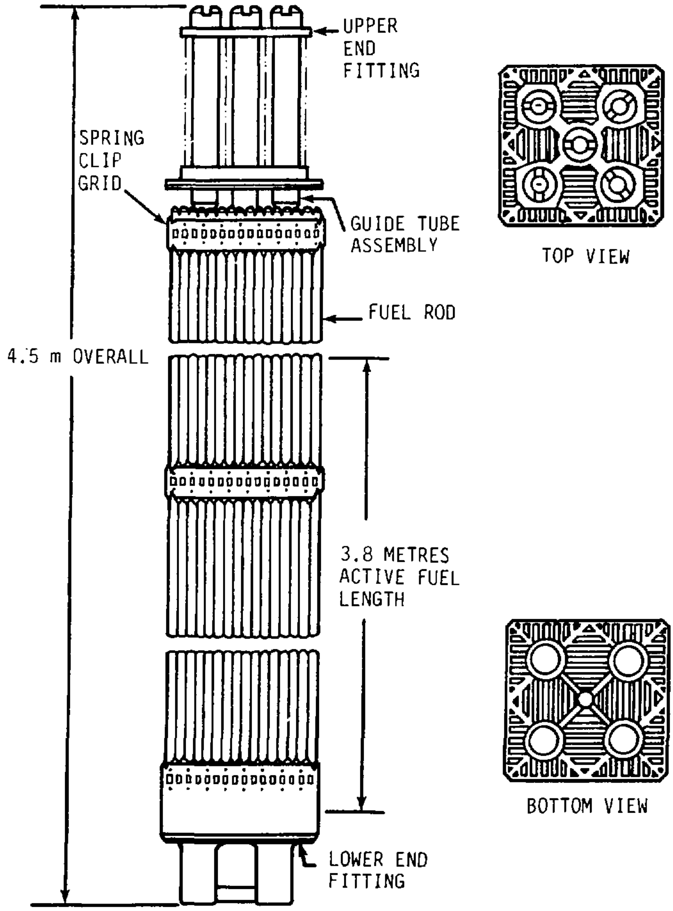

Figure 4. Typical PWR Fuel Assembly

fuel assembly and forms a plenum space where the heated reactor coolant is mixed and directed toward the flow holes in the upper core plate. Also, it provides a means for lifting the assembly.

<u>Properties of PWR Spent Fuel</u> -- When removed from the reactor, spent fuel assemblies contain uranium, plutonium, and fission products. Properties of a typical PWR assembly after its removal from the reactor are summarized in Table I for the period of up to 10 years. The high level of radioactivity and heat generation imposes the necessity of handling the assemblies under water, which provides both a shielding and a heat removal medium.

TABLE I

Summary of Properties of a Typical PWR Spent Fuel Assembly

		TIME AFTER REMOVAL FROM REACTOR		
		120 days	1 year	10 years
Assembly Total Weight (kg)	668			
Uranium Weight (kg)	447			
Plutonium Weight (kg)	3.8			
Total Radioactivity (Ci)		2.7×10^6	1.1×10^6	2.0×10^5
Fission Product Activity (Ci)		2.5×10^6	9.8×10^5	1.1×10^5
Transuranic Activity (Ci)		1.7×10^5	1.4×10^5	8.9×10^4
Neutron Source Strength (neutrons/s)		2.0×10^9	1.8×10^9	1.2×10^9
Total Thermal Power (kW)		12.6	5.4	0.81

Departure from normal underwater handling of spent fuel will necessitate protective devices because of the radioactivity and the thermal effects of the assemblies. These effects are functions of fuel isotopic composition, exposure in the reactor, power decay after removal from the core, etc. The approximate order of magnitude estimates for typical assemblies are shown in Figures 5 and 6. Figure 5 shows the dose rate that would be received by a person standing 1 metre from an assembly that had been taken out of the pool. A person attempting to handle an unshielded assembly after 300 days of cooling would receive a whole body dose of about 500 rem within a fraction of a minute. Radiological data indicates that 50 percent of exposures to such a dose would result in fatalities. Heavy shielding would be required for such abnormal operations.

Another problem associated with handling uncooled spent fuel in air is that the heat generated by fission products will cause a significant increase in the temperature of cladding material, especially in the fuel freshly removed from the core. Figure 6 shows the heat generated within the spent fuel as a function of time after discharge.

Approximate calculations indicate that the fuel rod clad temperature may approach and even exceed 1000° C if the assembly is withdrawn into air immediately after discharge from the reactor. The maximum temperature reached in air drops to about 350° C for spent fuel aged 1 year, and to approximately 100° C after 10 years.

Facility Description

The location of various elements of fuel handling and storage systems at the reactor is shown in Figure 2. The spent fuel storage pool and the cask loading and shipping area are located within the fuel handling building with railroad and roadway access for transport. The refueling pool is located within the containment and is connected to the storage pool through a transfer tube. During refueling, fuel is transferred between the two pools via the transfer tube. Water

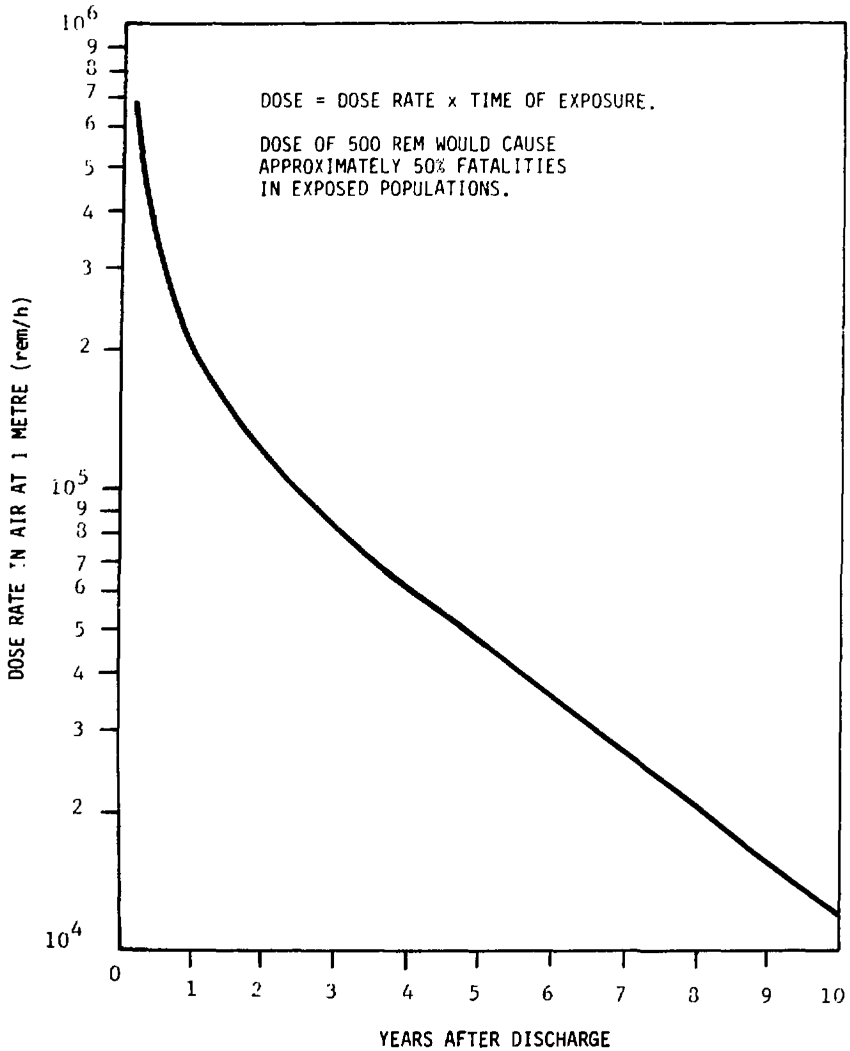

Figure 5. Dose Rate from PWR Spent Fuel Assembly

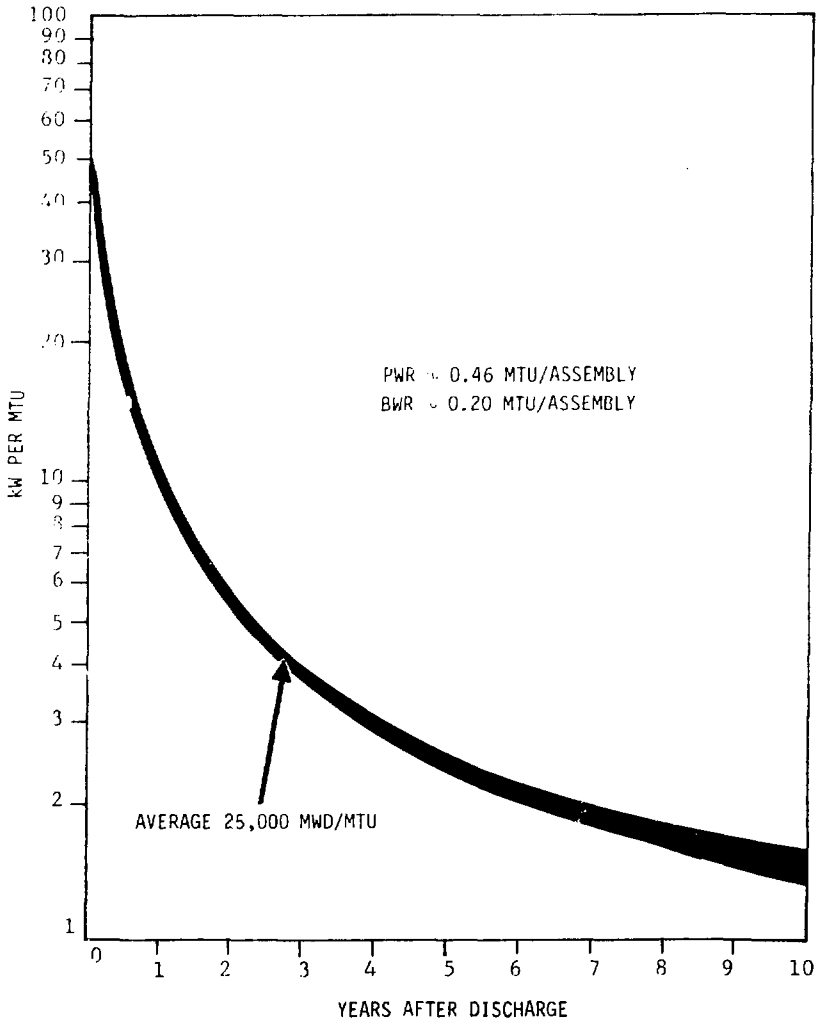

Figure 6. Heat Generation Rate of Spent Fuel

pumping and treatment, and the heating, ventilation, and air conditioning systems are also located in the fuel handling building. The emergency water supply is located in the auxiliary building adjacent to the fuel handling building and containment.

Refueling Pool and Transfer System -- The refueling pool is an area above the reactor vessel that is flooded only during refueling operations or when it is necessary to remove the reactor vessel head for other reasons. Figure 2 shows the location of the refueling pool within the containment and also shows the transfer tube connecting the refueling and storage pools. The refueling machine handles operations involving spent fuel within the refueling pool. The pool is borated to ensure reactor subcriticality. A minimum water shield distance of approximately 3 metres is maintained between the top of the spent fuel and the pool surface.

The transfer system delivers spent fuel assemblies from the refueling pool to the fuel storage pool in the fuel handling building through a connecting transfer tube. The tube consists of coaxial cylinders approximately 9 metres long, with a 1.2 metres outside tube diameter, and 1 metre inside tube diameter. When in use, the inside cylinder contains borated water. The transfer carriage rides on tracks that are welded to the bottom of the transfer tube. The transfer carriage, which holds the assembly, is pulled through the tube between the buildings by an electrical winch. Upending machines located at each end of the tube rotate the assembly to a vertical position, enabling the cranes to pick them up. Figure 2 shows the locations of the upending machine and the transfer tube.

All fuel handling equipment has devices that detect any unexpected overloading, and, when this occurs, the operation is stopped. The equipment also has stops and interlocks that provide protection if safe travel limits are exceeded and minimize fuel handling accidents. A tiltable TV camera on the refueling machine hoist can be aligned to provide direct viewing prior to and during removal of an assembly from the core.

Spent Fuel Storage Pool -- The spent fuel storage pool is also shown in Figure 2. Normally, it is located in a pit approximately 12 metres by 6 metres and 13 metres deep. The walls and floor are reinforced concrete that is at least 1.2 metres thick. The pool has a stainless steel liner that prevents water leakage. All plumbing and connections are designed to preclude the possibility of siphon draining. The spent fuel storage pool is connected to the cask pit by underwater channels with a gate to permit isolation of the pools.

A shielding depth of 7 metres of borated water is provided during storage, and a minimum coverage of about 3.1 metres of water is maintained during handling operations. This protection limits the radiation dose at the surface to 2.4 mrem/h. The pool is borated to match the water in the refueling pool. The cooling system is designed to maintain the normal water temperature at 25° C (and below a maximum of 55° C).

A fully loaded spent fuel storage pool can hold approximately 300 PWR assemblies (one and one-third cores). Spent fuel racks anchored to the liner floor are located to ensure subcritical geometry. A fully loaded PWR storage pool contains approximately 1.3 x 10^5 kg uranium (0.8 percent enriched U^{235}) and 1200 kg plutonium (all isotopes).

Cask Loading Area -- The loading area is composed of the following sections: the cask receiving bay, the cask washdown area, and the cask loading pool. The cask loading pool is connected to the spent fuel pool by an opening penetrating a 1.2-metre thick reinforced concrete wall and is isolated by a gate. The opening is large enough to allow spent fuel assemblies to pass through it.

The loading pool is approximately 16 metres deep and has thick reinforced concrete walls. This is to ensure that if the cask is tipped and hits a wall, no penetration of the wall will occur. The intermediate hoisting ledge provides a location for installing a yoke extension to keep the crane hook out of the water. A redundant crane and yoke are provided for protection against cask drop accidents. The loading area can receive either trucks or rail cars which enter through an overhead gate at grade level.

For a design basis earthquake (DBE), restraining lugs in the design of both the cask handling crane and the spent fuel handling machine prevent any part of them from falling on the structures below. Both the cask handling crane and the spent fuel handling machine have interlocks and stops to prevent motion that could result in a fuel handling accident. In the event of a power loss both the equipment and the load will remain in a safe condition.

Facility Operations

This section describes typical activities associated with spent fuel handling and storage. The activities consist of core refueling once every 12 to 18 months which involve the use of both the refueling pool and the storage pool; periodic checks and maintenance in the storage pool; and cask loading and shipping, involving the storage pool and the loading area, at a frequency that depends on the mode of transport and scheduling of shipments.

Refueling Pool Operations -- Periodic reactor refueling is the major operation performed within the refueling pool. Core refueling is performed every 12 to 18 months. On the average, the refueling operations begin 4 days after reactor shutdown and require 15 to 30 days for completion. A description of the typical sequence of key events follows.

Prior to refueling, the preparations for core access which are performed are

1. The control drive mechanisms, cooling air ducts, reactor vessel head insulation, and in-core instrumentation are detached from the reactor vessel head and moved to storage.
2. The reactor-vessel-to-pool seal is bolted down, and the blind flange of the fuel transfer tube is removed.
3. The reactor vessel head is unseated and raised by the plant crane while the water level in the spent fuel pool is raised simultaneously, keeping it just below the head flange.
4. The vessel head is stored in the dry storage area.
5. The reactor vessel upper internals are lifted out of the vessel and stored in the refueling pool, thus providing access to the assemblies.

The removal of spent fuel assemblies proceeds as follows:

1. The refueling machine hoist mechanism is positioned to the desired location over the core.
2. Alignment of the hoist to the top of the fuel assembly is accomplished by using a digital readout system, and the process is monitored by closed-circuit television.
3. The operator energizes the actuator assembly which locks the fuel assembly to the hoist.
4. The assembly then is withdrawn into the hoist box to protect it during further transfer.
5. Interlocking between the grapple and the fuel assembly prevents uncoupling caused by inadvertent initiation of an uncoupling signal.
6. After removal from the core, the spent fuel assembly is moved underwater to the transfer area of the pool.
7. The assembly is lowered into the transfer carriage in the refueling pool.
8. If the assembly contains a control element assembly (CEA), the CEA change mechanism transfers the element to a new fuel assembly.

9. The transfer carriage containing the spent fuel assembly is placed in the upender in a vertical position; the upender then rotates the carriage to a horizontal position on the transfer carrier.
10. A cable drive then transports the carriage on tracks through the transfer tube into the spent fuel pool.

If leakage from the cladding is suspected, an optional sipping* operation to detect radioactivity release is conducted after the assembly is removed from the reactor vessel.

Storage Pool Operations -- Storage pool operations include:

1. During refueling, fuel assemblies are transferred from the refueling pool into the storage pool. A substantial amount of equipment is utilized in the area. The equipment consists of the spent fuel handling crane, the new fuel elevator, and the upending machine. After the spent fuel is delivered to the storage pool, an upending machine returns the transfer carriage to the vertical position. The spent fuel handling machine removes the spent fuel assembly from the transfer carrier and transports it to the spent fuel racks.
2. Other normal operations in the spent fuel storage pool are routine maintenance and periodic checks of the water level and quality. Occasionally, rearrangement of assemblies

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*PWR Sipping - Dry

An assembly is placed in a sipping container and the container is pumped dry. Then dry nitrogen which is circulated through the assembly is sampled for gaseous fission products. Suspect fuel assemblies are later prepared for proper disposition.

PWR Sipping - Wet

Reactor coolant flows through each spent fuel assembly. After the fuel is removed from the reactor, individual assemblies are placed in a special container in the refueling pool. The contained and relatively stagnant coolant is then sampled for buildup of iodine 131. Suspect fuel assemblies are later prepared for proper disposition.

in the pool is necessary to accomodate load-in/load-out requirements.

3. Assemblies suspected to be leakers are tested by sipping with a fuel sampler. Assemblies determined to be leakers are canned.
4. Preparation of spent fuel for shipment from the facility requires that it be moved from the storage pool racks by the spent fuel handling crane to the cask loading pool. The operation is performed underwater.

Cask Loading Area Operations -- Cask loading operations proceed as follows:

1. The empty cask arrives in a transporter at the unloading area.
2. The overhead crane raises the cask to a vertical position.
3. The main hoist of the crane lifts the cask to the operating floor and transfers the cask to the washdown/laydown area where it is washed to remove road grime.
4. The cask is then transferred over the operating floor to the loading pit using the cask handling crane.

Positioning the cask is a two-step hoisting operation governed by administrative controls and crane interlocks. The hoisting operation proceeds as follows:

1. The first hoisting operation sets the cask on an intermediate ledge to interrupt the single lift over the full depth of the pool.
2. A redundant yoke is installed.
3. The cask head is loosened and the slave cable is attached.
4. The spent fuel is canned if it is a leaker.
5. The second hoisting step lowers the cask to the bottom of the loading pit where the head is removed and the spent fuel is loaded into the cask.

6. The head is replaced and the loaded cask is removed to the decontamination area via the two-step hoisting operation described above. At the decontamination area, the cask is prepared for either dry or wet shipment.
7. After the decontamination is completed, the cask is loaded on the transporter for shipment.

A typical cask for road transport without an overload permit holds one PWR assembly. Under these conditions, approximately 54 shipments and corresponding cask loadings may be required per year. Approximately 10 hours are required to load a single assembly in a truck cask and to load the cask on the transporter (including all washdown operations). If different means of transportation, such as rail, are used, larger casks, which typically accomodate 10 assemblies, may be employed. The time for loading operations is estimated to be 2 days and the number of shipments will vary accordingly.

Essential Support Systems

This subsection describes the support systems that are required to operate the storage pool, the cask loading area, and the refueling pool. These systems include ventilation, water cooling, water purification, pumps and heat exchangers, and safety systems.

Water Systems -- The refueling pool and the storage pool handle spent fuel assemblies capable of generating a significant amount of heat (e.g., 12 kW/assembly after 120 days and 0.8 kW/assembly after 10 years).

The necessary cooling for the storage pool water is provided by one pump and one heat exchanger. A second pump and heat exchanger provide redundancy in the case of a primary component failure. The storage pool temperature is maintained at a nominal 25° C temperature (and below 55° C maximum) by the cooling loop. The cooling loop is capable of removing the heat from one-third of a core stored 7 days after shudtown, plus one full core cooled for 90 days. If all cooling were lost to the spent fuel storage pool under the above conditions, it would take at least 18 hours for the pool temperature to rise from 25° C to 100° C. This allows reasonable time to effect repairs and restore cooling. The shutdown cooling system may be utilized as backup cooling for the spent fuel pool when the full core is removed from the reactor vessel.

The cask loading pool has a submersible pump for draining the pool. This pump is used to transfer water from the loading pool to the spent fuel storage pool. If the pool level becomes excessively high, the pool purification pump can reduce the water inventory by discharging it to the refueling water tank. The cask loading area uses demineralized water to wash and fill the casks.

Water for the refueling pool and for the reactor vessel during refueling is provided by the circulation water system. The water is borated to ensure subcriticality. Two heat exchangers and two pumps are used during refueling operations to provide the necessary flow and heat transfer to keep the core and the assemblies cool.

The cooling water system is a closed loop recirculation system that is constantly purified. Heat is removed by the exchangers. A redundant pump and heat exchanger operate when the primary system fails.

Purification System -- Both the spent fuel storage pool and the refueling pool have water purification loops to remove particulate matter from the surface of the pool and to remove soluble and insoluble matter in the pool. This system maintains water clarity and purity and permits visual observation of underwater operations. The water purity also reduces personnel exposure and deterioration of fuel cladding and basin surfaces. The loops consist of a pump, filters, strainers, ion exchangers, surface skimmers, and associated valves and piping.

HVAC System -- The Heating, Ventilation, and Air-Conditioning (HVAC) system provides purification of the air and cooling in the fuel handling building so that equipment can operate continuously and personnel can work comfortably. The system has filter units to purify the incoming air and the exhaust air before venting it to the plant stack. The HVAC system is capable of providing emergency filtering in the event of a fuel handling accident. The fans, filters, and air-conditioning units are located in the fuel handling building. The ventilation system is designed so that air flows from areas of potentially low contamination to areas of potentially high contamination.

Safety Systems -- The safety systems warn operators in the control room of hazardous conditions present in the fuel handling building. The safety system for the pools warns the operator if:

1. The pool pump if off,
2. The pump discharge pressure is too low,
3. The pump suction temperature is too high,
4. A criticality hazard is developing, or
5. Radiation levels are exceeding normal limits.

The HVAC system has various safety systems to indicate loss of flow, blockage of filters, or an increase in gaseous radioactivity. In the event of any abnormal condition, an alarm warns the operator in the control room of the failure of the component.

Electrical System -- Under normal operating conditions the reactor supplies power to a highly interconnected power grid, as well as the required facility operating and control power.

During reactor shutdown periods, power is provided from the off-site grid. Should the power grid fail, two redundant diesel or turbine generators supply the necessary power for essential loads--principally safety related. Shedding nonessential loads and transferring to standby power is accomplished automatically with provision for manual override. An uninterruptible battery power supply is provided for critical instrumentation and alarms as a further backup.

Boiling Water Reactor

This subsection describes the details of the fuel handling facilities and of operations in a typical BWR plant. Similarities to and differences from PWRs are appropriately noted. An example of the reactor and the spent fuel pool arrangement is shown in Figure 7.

Material Characteristics

The material flow in BWR spent fuel operations is similar to that shown for PWR operations in Figure 3 with the exception that the fuel channels (square shaped Zircalloy tubes which jacket each BRW assembly during reactor operation) are removed from stored spent assemblies and transferred to the fresh fuel prior to refueling. The fuel assembly structure is described below. Thermal and nuclear properties and isotopic composition of the fuel contained within BWR fuel assemblies are about the same per unit weight of heavy metal as for the PWR spent fuel assemblies. Shipping casks used for transportation of BWR fuel are similar to those used for PWRs and are described in Section V.

BWR Fuel Assembly Structure -- A typical BWR fuel assembly (see Figure 8) is composed of 64 rods enclosed by a fuel channel. These rods are spaced and supported in a square (8 x 8) array by both a lower and an upper tie plate. The lower tie plate has a nosepiece that fits into the fuel support piece and distributes coolant flow to the fuel rods. The upper tie plate has a bail for transferring the fuel assembly. Tie rods in each assembly have threaded plugs which screw into the lower tie plate casting and extend through the upper tie plate casting. A stainless steel hex nut and locking tab are installed on the upper end plug to hold the assembly together.

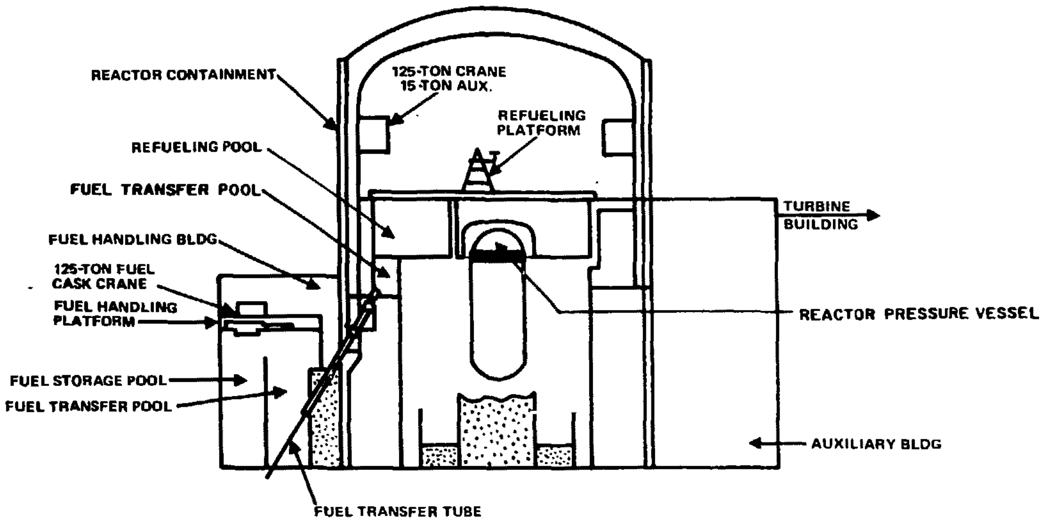

Figure 7. Fuel Handling and Storage at a BWR Reactor

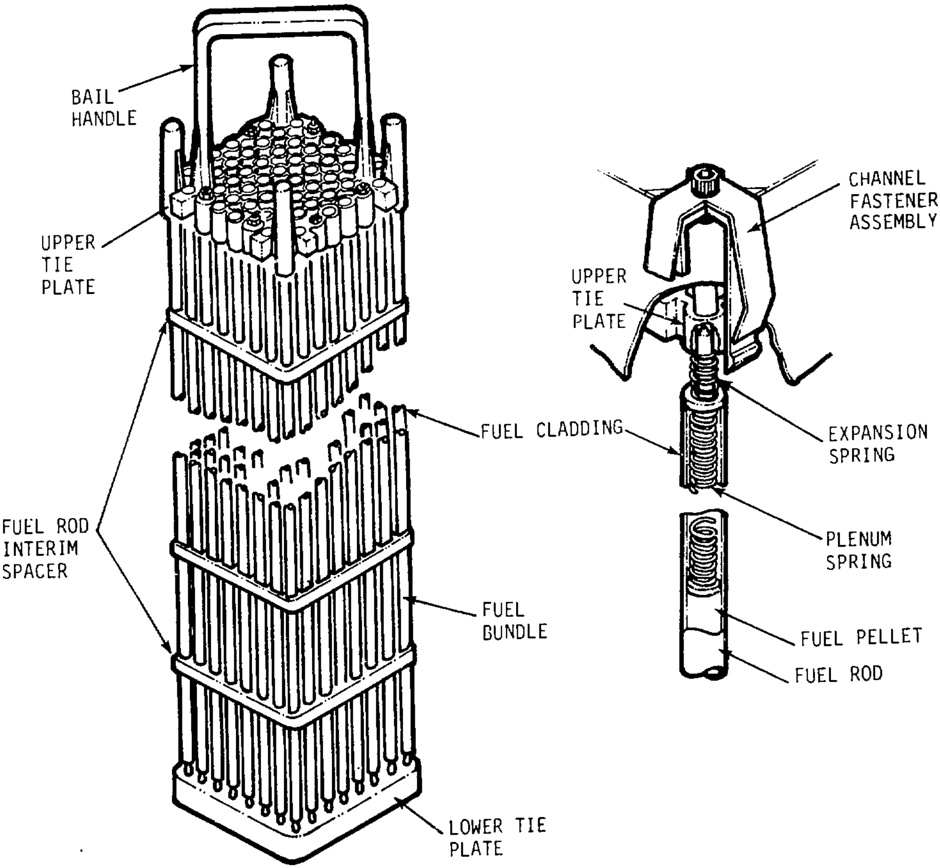

Figure 8. BWR Fuel Assembly

These tie rods support the weight of the fuel assembly during handling when the assembly hangs by the bail. The fuel rods are composed of sintered UO_2 pellets stacked in a Zircalloy tube cladding. There are 64 fuel rods with pins on the end plugs that fit into the anchor holes on the tie plates. Longitudinal expansion is accommodated by an Inconel spring which fits over the top end plug pin.

The Zircalloy fuel channel, not shown in Figure 8, makes a sliding seal fit on the upper tie plate surface and is attached to the upper tie plate by a channel fastener assembly and a capscrew secured by a lockwasher. A completed BWR fuel assembly is approximately 0.14-metre square, 4.2 metres long, and weighs 272 kg. A comparison between the BWR and PWR fuel assembly is shown in Figure 9.

<u>Properties of BWR Spent Fuel</u> -- Typical BWR spent fuel assemblies contain approximately the same isotopic mix of uranium, plutonium, and fission products per unit weight of heavy metal as PWR assemblies. Because a BWR fuel assembly contains less weight in fewer fuel rods, there are correspondingly less plutonium and fission products per assembly. Nuclear and thermal characteristics differ accordingly and are summarized in Table II. The BWR assembly radioactive dose rate and heat generation assembly are lower by a factor of 2 to 3 (refer to Table I and Figure 5).

Facility Description

The location of the various areas of the fuel handling and storage operations at a BWR facility are shown in Figure 7. The fuel storage pool and the cask loading and shipping area are located in the fuel handling building. The refueling pool is located within the containment and is connected to the storage pool by the transfer tube through which fuel is transferred during refueling. Water pumping and conditioning systems also are located in the fuel handling building. Heating, ventilating, and emergency water systems are located in an auxiliary building.

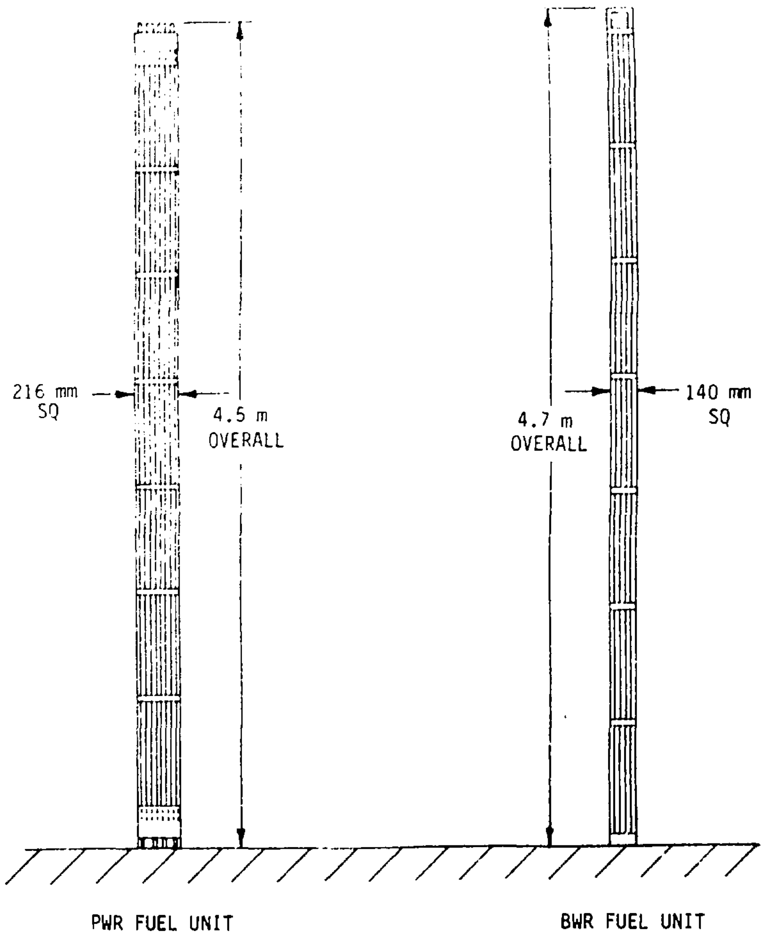

Figure 9. Comparison between Typical PWR and BWR Assemblies

TABLE II

Summary of Properties of a
Typical BWR Spent Fuel Assembly

		Time After Removal From Reactor		
		120 days	1 year	10 years
Assembly Total Weight (kg)	272			
Uranium Weight (kg)	179			
Plutonium Weight (kg)	1.3			
Total Radioactivity (Ci)		1.1×10^6	4.5×10^5	7.8×10^4
Fission Product Activity (Ci)		1.0×10^6	3.9×10^5	4.4×10^4
Transuranic Activity (Ci)		6.6×10^4	5.7×10^4	3.4×10^4
Neutron Source Strength (neutrons/s)		7.8×10^8	7.2×10^8	4.8×10^8
Total Thermal Power (kW)		5	2.2	0.32

<u>Refueling Pool and Transfer System</u> -- The upper containment pool (refueling pool) is a rectangular stainless steel-lined basin located above the drywell area (Figure 7). The drywell area roof slab serves as the base slab for the pool. The water in this basin provides shielding during normal reactor operations. In a PWR containment pool, the water is borated; in a BWR containment pool, it is not. The containment pool is compartmented and has a temporary storage capacity equal to 25 percent of initial core load to facilitate the refueling operations. Fuel is not stored in the upper containment pool during normal operations. The design incorporates an inclined fuel transfer tube to transfer the fuel between the upper containment pool and the fuel storage pool in the fuel handling building.

The purpose of the transfer tube is to transport spent fuel from the refueling pool to the storage pool. The inside diameter of the stainless steel pipe lining is about 0.55 metre. The tube is jacketed by a carbon steel pipe which lines the penetration in the concrete. Valves at each end of the tube keep water from draining from the refueling pool to the spent fuel pool.

A carriage powered by a winch attached to two cables shuttles the fuel between the containment and the storage pool. Upenders are used to rotate the carriage enabling the cranes to grapple the assemblies. Interlocks prevent rotation of the carriage unless the carrier and the auxiliary or refueling platforms are in the correct position.

The transfer system is controlled from two stations, one on the operating floor of the reactor and the other on the operating floor of the refueling building adjacent to the transfer pool. Controls, instrumentation, and communications needed to operate and monitor the transfer system are grouped at these locations.

Spent Fuel Storage Pool -- The BWR spent fuel storage pool is similar to a PWR storage pool except that it holds a larger number of smaller BWR assemblies and is not borated. The spent fuel pool is designed to hold one and one-fourth cores (850 assemblies). One BWR assembly contains 179 kg uranium (0.8 percent enriched U^{235}) and 1.3 kg plutonium (all isotopes), with a heat generation rate of 5 kW (after 120 days cooling). A fully loaded pool would contain 1.5 x 10^5 kg uranium and 1100 kg plutonium. The cooling system is designed to remove heat from a core cooled 90 days plus one-fourth of a core cooled 7 days. Movement of the spent fuel within the storage pool is performed by the spent fuel handling crane.

Cask Loading Area -- This area, like its PWR counterpart, contains the unloading bay, the decontamination pit, and the cask loading area. The designs are similar, with thick, reinforced concrete walls.

The casks may be brought in or discharged by either truck or rail. Handling of the cask is performed by the cask handling crane.

Facility Operations

Operations at a BWR site associated with spent fuel handling consist of refueling the reactor, storing spent fuel, channel removal, and loading spent fuel for shipment. These operations are described in the following sections.

Refueling Pool Operations -- The frequency and duration of refueling operations in BWRs are similar to those described for PWRs. The refueling platform is used to remove fuel assemblies from the reactor and to transport them to the refueling pool. The platform is equipped with two auxiliary hoists which handle and transport other core components. The operations after removal of the reactor head are as follows:

1. The steam separator and dryer are removed from the vessel and stored at the opposite ends of the upper pool.
2. The grapple is aligned over the fuel assembly, lowered, and attached to the fuel assembly handle.
3. The assembly is raised out of the core through the refueling slot in the dryer assembly shield and then placed in the upender.
4. The upender tilts the assembly onto the transfer carriage of the inclined transfer tube which connects the pool to the fuel transfer pool in the fuel building.

Sipping* of the fuel assemblies may be performed to verify suspected leakage of fission products.

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*BWR Sipping - The fuel sampler or sipper isolates a 16-assembly array in the core, stops water circulation through the assemblies, and allows fission products to concentrate if an assembler is defective. A water sample is taken for fission product analysis for identification of the defective assembly. Suspect fuel assemblies are later prepared for proper disposition.

Storage Pool Operations -- These operations are performed in a manner similar to PWR operations. When spent fuel is received through the transfer tube, the fuel grapple of the fuel handling platform locks onto the fuel assembly and hoists it (underwater) to the racks in the spent fuel pool. The platform also loads the spent fuel assemblies into the spent fuel shipping cask.

Additional operations specific to BWRs are (1) the transfer of channels from the spent fuel assemblies to the fresh fuel, and (2) the reconstruction of BWR spent fuel assemblies. The preferred method for the transfer of channels is to perform channeling of a reload batch of new fuel while the reactor is operating to ensure that the fresh fuel is ready for use during subsequent refueling operations.

The BWR spent fuel assemblies have the potential for underwater disassembly and reconstruction into new configurations. This has been done in the past to over 1000 assemblies both in the United States and Europe. Fuel assemblies have been reconstructed to replace leaker rods for warranty consideration, replace damaged hardware, destructive inspection and testing of fuel rods, and replacement of failed rods in spent fuel assemblies to allow off-site shipment of intact assemblies to a reprocessing plant or AFR facility.

In the future, assemblies may be reconstructed for reinsertion in reactors to obtain more complete fuel burnup if the fuel is not reprocessed for recycling. Assemblies may also be disassembled and stored in more compact configurations in the spent fuel storage pools. As space becomes more limited, economics could dictate this option for increasing storage capacity or possible disposal.

Cask Loading Area Operations -- The method of operation is similar to that for a PWR spent fuel loading. A typical truck cask load is 2 BWR assemblies; rail casks typically carry 24 BWR assemblies.

Essential Support Systems

The spent fuel storage pool, the refueling pool, the transfer system, and the cask loading area all have cooling and purification systems similar to a PWR facility. These systems are located within the fuel handling building below the normal fuel pool water level. The heating, ventilation, and air purification supply systems for the storage pool are located in an auxiliary building. A portable underwater vacuum system is used to clean pool walls and floors.

Variations in BWR Spent Fuel Storage

The containment system for BWRs has evolved from the dry spherical type used in older and smaller reactors (up to approximately 200 MWe) through several generations of the pressure-suppression type to a system which combines both the pressure-suppression and the dry containment concepts. The use of earlier containments can result in variations in the storage pool location and transfer methods discussed previously. In the reactors with dry spherical containment, spent fuel storage pools may be located either outside or inside the containment. In reactors with wet well pressure-suppression containments, spent fuel storage pools are located outside primary containments but inside the secondary containment structure. These variants are described in the following subsections.

Storage Pools Located Within Primary Containment -- In some BWRs which use steel spheres as a primary containment, the storage pool is located within the containment. It is adjacent to the refueling pool. Thick, reinforced concrete walls separate it from the reactor (see Figure 10).

To perform refueling, a permanent extension tank (welded to the reactor below the flange) is filled with demineralized water and the refueling platform is placed on the extension tank. The reactor head has three access ports through which assemblies can be removed and replaced with fresh fuel. The assemblies are withdrawn into the water-filled extension tank by using the grappling tool and are placed into

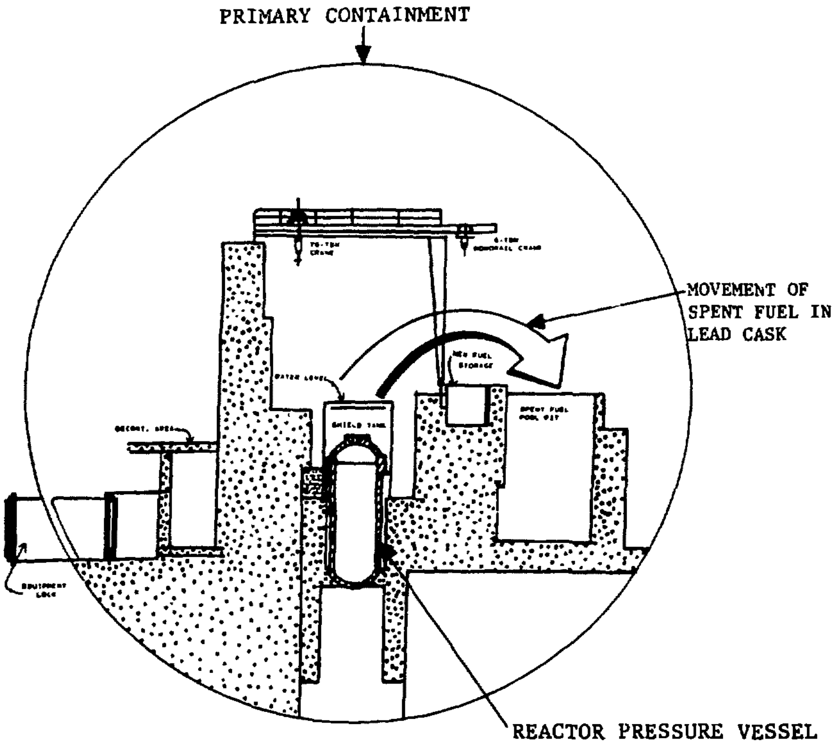


Figure 10. Example of Spent Fuel Storage Pool Within Primary Containment

a lead shielded transfer cask. The loaded cask weighs 24 tonnes and is approximately 0.9 metre in diameter and 4.6 metres long. It is handled by the polar containment crane. During the transfer of fuel, the cask is lifted out of the refueling pool and is transferred to the storage pool where a lower door opens to discharge spent fuel into the pool storage racks.

To load the spent fuel for shipment off-site, a shipping cask is first brought to the unloading dock outside the containment. The outside door of the equipment lock is opened and the cask is brought into the equipment hatch. The outside door is closed after the cask passes through, and the second door is opened to transfer the cask into the containment. The cask is then transferred across the containment building and lowered into the storage pool where it is loaded with spent fuel. After loading, the cask is moved to the washdown area in the containment to remove any surface radioactivity. When washdown is completed, the cask is removed through the equipment lock for placement onto the transport truck or railcar at the cask loading dock.

Storage Pool Located Within Secondary Containment -- BWRs with wet well-pressure suppression containments have the spent fuel storage pool located within the secondary containment and adjacent to the upper refueling pool above the top of the reactor vessel. Both pools are above grade. This type of system is shown in Figure 11. The storage pool has a stainless steel liner to prevent leakage. Unintentional draining of the pool is prevented by locating penetrations to the pool above a safe water level. The passage between the refueling cavity and the fuel storage pool is facilitated by a canal with movable gates. The pools have sufficient water depth to shield and cool irradiated assemblies.

During refueling, the water level in the refueling pool is raised to a level common with that in the storage pool. The refueling crane removes the spent fuel from the reactor, transports it through the canal, and loads it into the storage racks.

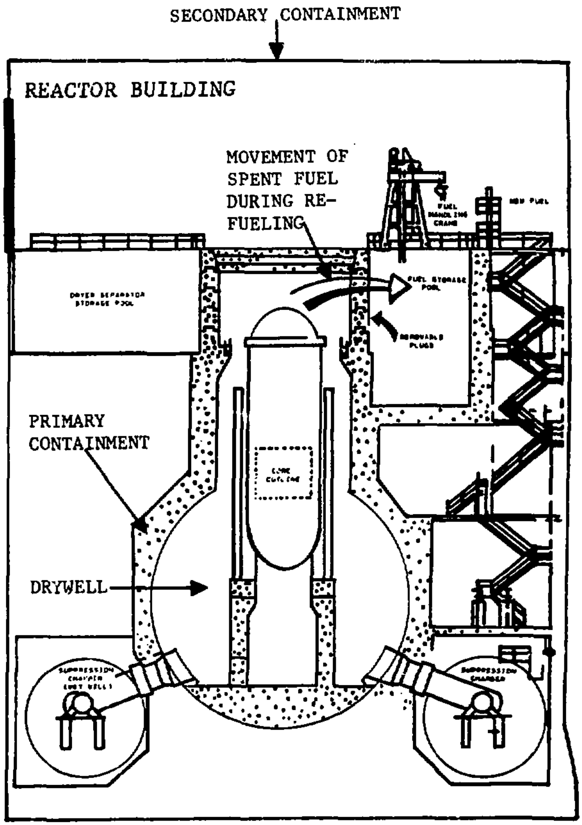


Figure 11. Example of Fuel Storage Pool Within Secondary Containment

To load spent fuel, the shipping cask is brought into the reactor building through the equipment lock and lowered into the cask loading area of the storage pool. After decontamination, the cask is moved by the reactor building crane through the equipment lock to a truck or railcar in the equipment access area.

SECTION III

INTERIM SURFACE STORAGE FACILITIES

Water basin and dry surface storage facilities for LWR spent fuel shipped from power reactor storage pools for longer-term temporary storage are discussed in this section.

It is anticipated that approximately 5-year-old fuel will normally be received at these facilities from LWR storage pools. Under unusual circumstances, spent fuel aged as little as 90 days may arrive for storage. After 10 or more years, spent fuel stored at these facilities could be transferred to more permanent deep geologic storage facilities mined in rock such as granite, shale, or salt, or to a fuel reprocessing facility should reprocessing be authorized.

Water-basin storage of spent fuel (AFR and DSSF) are discussed in this section. Each of these facilities receives, handles, and stores bare or canistered fuel assemblies.

While it is not known at present how long beyond 10 years spent fuel assemblies might be stored in AFR facilities, it is postulated that DSSFs could safely contain the projected accumulation of these assemblies for periods in excess of 100 years.

Away-From-Reactor (AFR) Water-Basin Storage Facility

A water-basin AFR storage facility must include receiving and unloading facilities for various rail and truck transporters; cask inspection, washdown, cooldown, flushing, and radiation monitoring equipment; cask-unloading and fuel assembly-transferring equipment for all types of fuel; storage basins with their own handling capability; and cask decontamination and maintenance facilities. Facility operations are depicted in the operational flow diagram shown in Figure 12. The facility described has an initial capacity for 2000 MTU of spent fuel assemblies. Support systems for electrical power, basin water treatment, basin leak detection, radioactive waste treatment and packaging, heating, ventilating, air-conditioning and utility steam, and air and demineralized water are also necessary. Spent fuel is handled in water in existing storage pools. Projected designs include concepts for dry hot cell handling as well as water pool handling operations. The design described in this baseline uses hot cells for handling the spent fuel from its removal from the shipping cask to its transfer into the storage pool. However, water pool handling is also discussed as another option.

Material Characteristics

The characteristics of spent fuel assemblies, and transport casks at, and between, the AFR and other facilities considered in this report are discussed in Sections II and V.

Facility Description

A schematic of the spent fuel AFR storage facility is shown in Figure 13. The design concept allows building the facility in stages. In the first stage of construction, four storage pool modules having a total capacity of 2000 MTU would be built along with the complete receiving, handling, and cask preparation and unloading facilities (see Figure 14). As shown in Figure 14, the expansion options are all accommodated within a monolithic building concept; the storage farm can be expanded as required.

Two identical truck/railcar receiving, handling, and preparation areas for spent fuel assemblies, which are received in sealed shipping casks, are provided. The receiving, handling, and preparation area

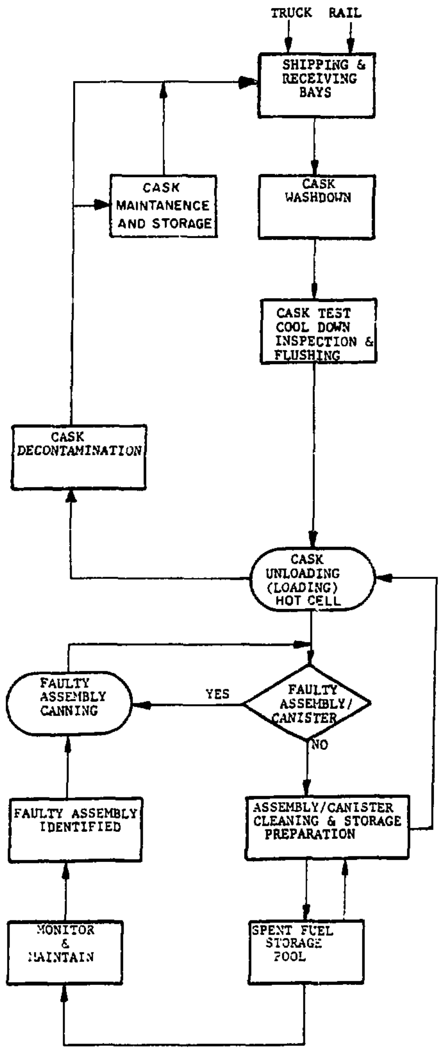


Figure 12. Receiving, Handling, and Storage Operations Flow at Spent Fuel AFR Storage Facility

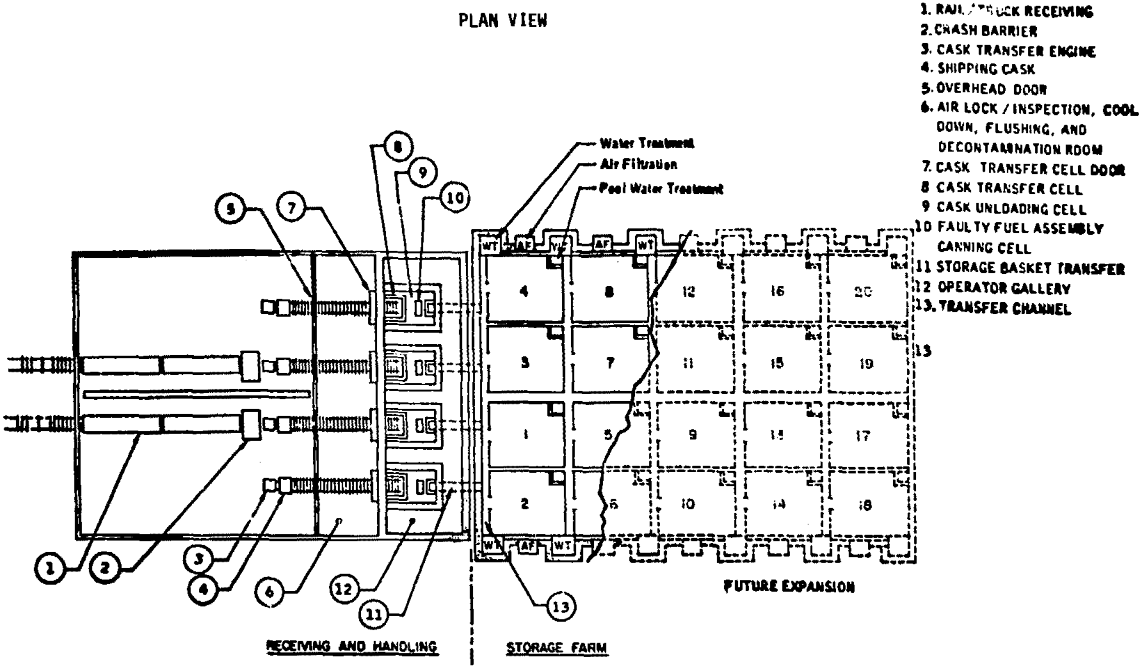


Figure 13. Spent Fuel AFR Storage Facility

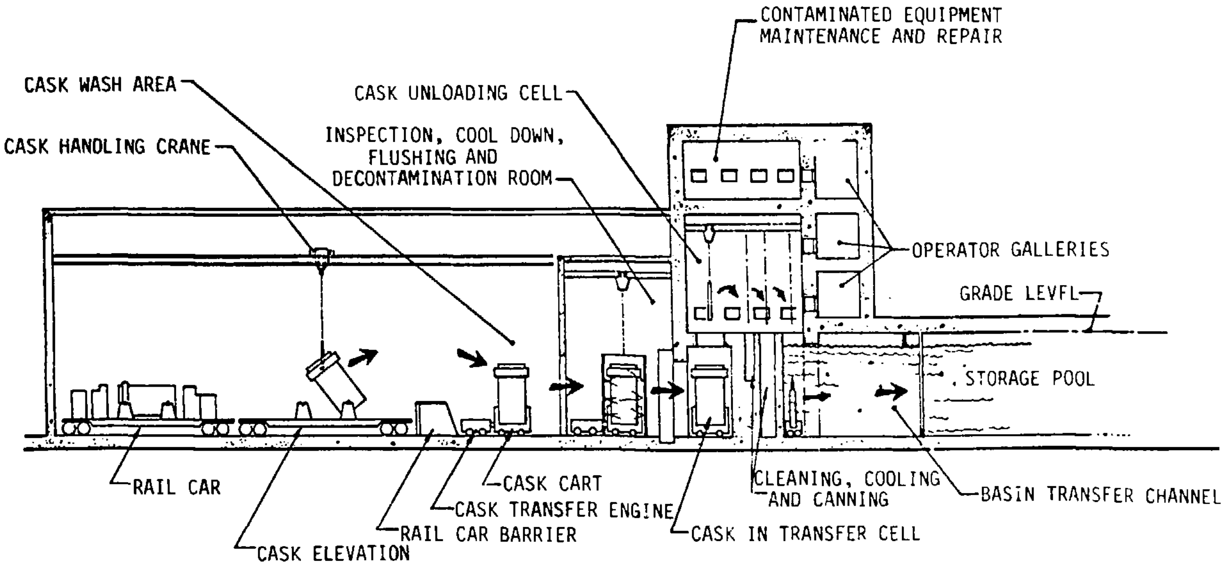


Figure 14. Spent Fuel AFR Storage Facility
Receiving and Handling

with its four stations is sufficient to support a fully expanded 10,000 MTU or more storage capacity.

Two alternative concepts for unloading of fuel assemblies from shipping casks are shown in Figure 15. For an AFR facility which is not collocated with a reprocessing plant, the long storage times involved make it potentially desirable that a hot cell be provided that is fully equipped with canning facilities and material sampling and analysis capabilities. The dry unloading alternative will therefore be described for this case. The wet unloading alternative is discussed in later paragraphs, which also discusses AFR variations for storage at reprocessing plants.

Site Layout -- The AFR site at maximum storage capacity covers over 0.1 km^2. Perimeter fencing, security requirements, and environmental considerations further increase the dedicated real estate required for the AFR. The site selected for the AFR has suitable topographic features to enable construction of the rail and truck access routes to a receiving/shipping area that is approximately 8 metres below grade. Figure 13 shows the site layout. Primary facilities include the rail/truck receiving and shipping building and the associated train spur and switching yard (not shown), the cask handling and preparation-for-unloading building, the fuel transfer channel, and the storage farm (basin) complex. Essential support systems not shown include the support water cooling and treatment, waste handling and solidification, air ventilation and filtering, monitoring and control, utilities, and water reservoir facilities. Support systems and service required for normal plant operations include personnel services and emergency equipment, safe operations, communications, etc.

Receiving, Handling, and Preparation -- The receiving areas run from the main entrance along a straight corridor approximately 60 metres long and 30 metres wide. The floor of each is located approximately 8 metres below grade level and consists of heavy

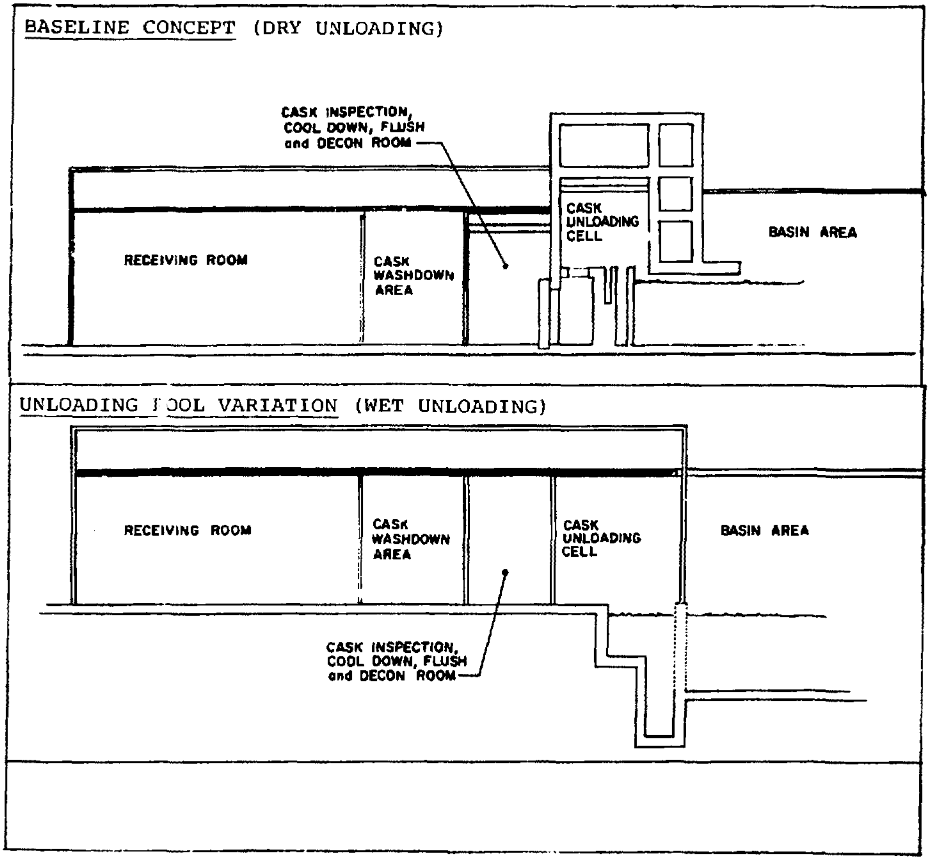


Figure 15. Cask Unloading Variations
Spent Fuel AFR Storage Facility

reinforced concrete in which rails are embedded. The areas are separated by a partition at the building midline and crane support wall. The rails in each area end in massive concrete crash barriers.

Each receiving area has an unloading zone, a cask inspection and washdown zone, and a cask cooldown, decontamination, flushing, and transfer-to-unloading zone. Two 120-tonne-capacity overhead cranes service the unloading zones. The unloading zones have storage areas for repair and maintenance equipment and for grappling fixtures which handle different cask designs. Also, a holding area equipped with water cooling equipment is provided for casks which cannot be transferred directly to a decontamination room.

Cask inspection, cool down, flushing, and decontamination take place inside steel framed rooms which have insulated siding and approximately 20-metre-high ceilings. These rooms are entered through low air-leak doors. The rooms are sufficiently airtight to provide ventilation and airborne contaminant control. They are serviced by high pressure water and cleaning solution lines. The rooms are drained to a sump which in turn drains to a low activity waste vault. A separate cask flush line in each room connects to this vault through a radiologically shielded and monitored pipeline. A 13-tonne crane services the area.

Each room connects to the cask transfer cell through a thick concrete door which rolls on rails embedded in a concrete trench. The doorway can accommodate the largest cask. A segment of the cask cart transfer rails is integral to an extension foot of this door to provide a continuous rail path when the door is in the open position. Inflatable seals make the door a gas-tight barrier in the closed position. The cask cart rails end inside the transfer-to-unloading staging area beneath a hatch to the cask unloading cell.

The cask unloading cell is a reinforced concrete shielded hot room lined with painted stainless steel. Room interior dimensions are about 9 metres long by 13 metres wide, with 1.5-metre-thick walls, ceiling, and floor. The ceiling is approximately 13 metres above the cell floor. Above the unloading cell is a 6.5-metre-high contaminated equipment maintenance cell fitted with its own crane.

The entrance hatch to the cask unloading cell is equipped with a cask connection bellows shroud. A 4.5-tonne remotely-controlled crane operates across side rails in the walls of the unloading cell. An operating gallery on the long walls of the cell is provided with view ports. Spent fuel assembly cleaning and cooling facilities are provided, as is a spent fuel assembly canning station. Manipulators mounted in the hot cell walls and from the overhead crane service the cell also.

A current method for cask unloading in U.S. facilities which differs from the preceding concept is shown in Figure 15. In this method, after the cask passes through the cask preparation room, it is lowered into a water pool, the cover is opened, and the bare assembly is removed. If a leaker assembly must be canned, an underwater sealing method which provides a long term storage seal is used.

Preparation-for-Reshipping and Reshipping -- The facility design is such that stored spent fuel assemblies can be handled in reverse order from the storage pool to the transportation vehicle. If necessary, the shipped fuel assemblies may be canned or overpacked before shipment.

Storage Farm (Basin) -- The AFR spent fuel storage farm in the first phase construction program provides four modules services by water, air, and waste handling facilities. Once the first phase is completed, all support facilities for expansion of the farm to the maximum capacity are established.

The pools, as shown in Figures 13 and 14, are 15 meters wide by 18 metres long by about 8 metres deep. The pool system is structurally connected to the receiving, handling, and preparation building structure. Pool structure is designed for protection against loading conditions and combinations that result in high stress.

The base slab and pool structure is designed as a rigid system on an elastic foundation. Soil pressures are based on a transient saturated condition of surrounding soils to approximately natural grade. The influence of the foundations of the surrounding structures is also included in the design.

Each storage pool receives spent fuel assemblies in storage baskets from the preparation facility through channels which are 8 metres deep. The individual pools are also connected by an integral system of transfer channels 8 metres deep through which spent fuel assembly baskets are moved by 14-tonne capacity cranes. Pools are accessed from these channels through water tight gates. A water treatment and leak detection system is provided for each pool, with larger treatment systems servicing discharge water from the complex. A central waste handling area receives liquid waste collected from the water treatment and leak detection systems. This waste is solidified and shipped from the site. Facilities are also provided for compacting, incinerating, and preparing for shipment solid wastes and failed equipment. Exhaust stacks for low level gaseous effluents service these areas. Pool water is cooled by circulation through heat exchangers and the secondary loop water circulates through cooling towers. Make-up pool and channel water is provided from two storage reservoirs. Air ventilation fans, ducting, and filtration are provided. Pool water and overhead air are maintained at a nominal temperature of 25° C (and never more than 55° C).

The entire storage complex, including the processing-to-storage transfer channels, is enclosed in a monolithic building.

A series of 14-tonne overhead cranes with telescoping extension grapples service the transfer canals. Each storage pool is equipped with a 22-tonne overhead crane. These cranes can be operated both remotely and manually. Remote crane operations are conducted from shielded bays above the pools or from the control room console.

Holding fixtures are provided to secure fuel-loaded baskets in the storage pools. Fixtures for clamping the baskets to each other or to pool fixtures are used. The clamps are located near the tops of the baskets. Minimal protruding fixtures are mounted in pool floors so that cleaning operations are simplified and so that several basket geometries can be accomodated. The holding fixtures secure the loaded baskets safely during design basis earthquakes and tornadoes.

Since the pools are open and unobstructed, the specific storage array of the baskets is changeable. In one example, a pool containing a maximum capacity of 500 MTU in high-density packed baskets could be arrayed to allow for a centered 18-metre long aisle from the pool gate to the opposite wall and five side aisles 8 metres long and 1.5 metres wide on each side of the center, assuming the use of baskets 660 mm square.

Facility Operations

Operations Central Control -- Critical plant operations are under surveillance at the plant central control station. The operation of all doors and portals through which spent fuel passes can be controlled from this point. In addition, the operation of all machines used for transfer or manipulation of fuel in any form can be disabled from this control station. Capability for TV surveillance of all plant operations is provided, together with a voice intercom to all plant areas.

Receiving, Unloading, and Preparation for Storage -- Receiving, unloading, and preparation operations are described below (refer to Figures 13 and 14):

1. Spent fuel casks are received at the AFR site by rail or road transport. Casks are delivered to a siding or staging area at which point shipment verification and inspection are performed and road grime is washed from the vehicle.
2. A dedicated site engine with limited maximum speed couples to a rail car and moves it from siding to the receiving areas. Road shipments are transported on site with a dedicated tractor.
3. The cask unloading crane is fitted with a lifting yoke appropriate to the cask design while the cask is being de-coupled from the transportation vehicle cooling system.
4. Cask holddown mechanisms are unlocked in preparation for lifting the cask from the vehicle. The vehicle is stabilized by wheel locks to prevent motion when the cask is raised. The lifting yoke is fitted to the cask lifting trunnions. The cask is pivoted about its support trunnion until it is in the vertical position. The crane lifts and moves the cask over the transfer cart.
5. The cask is lowered and locked into position.
6. The lifting yoke is removed.
7. A yoke attached to the side support rail is fixed to the cask to provide side stability.
8. The cask is washed.
9. The cask transfer engine moves the cask cart along rails in the floor into the airlock room.
10. The cask is inspected, cooled, and then flushed prior to bolt removal, as necessary.
11. The retaining bolts of the outer cask closure are removed.
12. The crane raises the outer closure and stores it near the door of the decontamination area.
13. A cask collar designed to mate with the transfer cell bellows is fitted to the cask head.

14. The internal heat transfer medium is flushed out to the low activity vault.
15. The flush line is monitored to provide an indication of the presence of damaged fuel elements.
16. The air pressure in the cask transfer cell and the unloading cell is checked to ensure ventilation control during the next operations.
17. The transfer cell door is opened until the rail section integral to the door mates with the transfer cart.
18. The transfer engine moves the cask rail cart into position inside the transfer cell.
19. The engine decouples and backs into the decontamination room and the transfer cell door is closed.
20. As part of the cell door closure operations, an inflatable seal seals the door.
21. A transfer cell bellows is lowered to mate to the previously attached cask collar.
22. The cask unloading cell portal is opened and the inner cask cover is removed and stored in that cell, using the unloading cell crane.
23. The crane grapples individual fuel assemblies and lifts them into the cask unloading cell.
24. Each spent fuel assembly is visually inspected and then inserted into a well where it is cooled and cleaned.
25. If radiation monitors in the well indicate the assembly has a leaking fuel element, the assembly is transferred into a can which is then filled with a heat transfer medium and welded to provide a hermetic seal.
26. The bare assemblies and those which have been canned are loaded into a storage basket on the canal transfer cart.
27. When the cask is empty, the inner cask cover is refitted to the cask and the bellows is disengaged.
28. The cask unloading cell portal is closed and the transfer cell door is opened to admit the transfer engine, which then pulls the cask transfer cart into the decontamination room.

29. The cask and cart are decontaminated and the outer cask cover is refitted.
30. The cask is returned to the transportation vehicle for return shipment or to a cask maintenance and storage area.
31. The storage basket loaded with bare and canned fuel assemblies is lowered into a cart in the water transfer pool and rolled by a hydraulically operated ram under the building wall into the transfer canal.

Storage Farm Operations -- In the transfer-to-storage pool, cranes attached to monorails suspended above the transfer channels move the loaded baskets from the cask handling and assembly and preparation area transfer canals to the preselected storage pool. At the entrance gate to the pool, the loaded basket is transferred from the transfer channel crane to the pool overhead bridge crane after the pool access gate is opened. The basket is transferred into the storage pool.

The overhead bridge crane places the loaded basket at the designated destination in the pool. The basket latches are secured to the pool and/or neighboring baskets and the crane grapple is released and retracted. Aisleways allow for removal, replacement, and rearranging of baskets in the pool area with very little vertical displacement.

Essential Support Systems

Basin Leakage Detection and Handling -- Water which may leak through cracks and seams of the stainless steel storage farm pool liners and, thence, through the concrete basins, is collected in channels and discharged into a collection and monitoring sump. Monitors are placed in the control room to identify the locations of unusual leakage conditions so that inspection and repair can be undertaken. The leak collection system discharges to a liquid radiation waste collection tank.

Storage Basin Water Circulation and Treatment Systems -- Systems are provided to circulate water through and within the basin modules and interconnecting channels. The water circulation system provides controlled flow rates for water circulated through all transfer channels and storage pools to maintain a satisfactory temperature. External water circulates between the heat exchange and cooling tower outside the main building.

Water from the basin is processed by pumping it from the modules through a filter and ion exchange system and returned to the basin at the main transfer canal. The cleanup stations maintain activity levels in the water at safe operating levels and provide clarity for direct viewing.

Air Ventilation and Filtration -- The air pressure in the several plant areas is controlled so that air flow is from areas of low potential radioactivity through areas of intermediate potential contamination to areas of high potential radioactivity. Three ventilation systems serve the site. One provides personnel comfort to office and personnel areas in parallel with the receiving, decontamination, and cask unloading cells. Another serves the dry waste building and incinerator. The third services the spent fuel storage farm.

Waste Management -- There are no high level radioactive wastes generated in the plant operation. Loose surface contamination of the fuel assemblies is either removed in the cask unloading cell and flushed into a low level waste vault or it is removed during the storage operation by water circulation and trapped in cleanup filters. Any fission gas leakage from faulty assemblies is controlled by the air ventilation and water circulation systems. Solid waste at this facility contains low level radioactivity and is disposed of accordingly. Liquid radioactive waste processing systems are remotely controlled.

Monitoring and Control -- The primary function of monitoring and control systems is to ensure that operating personnel and the public are protected against accidental radiation exposure. The secondary function is to verify proper functioning of the AFR.

Utilities -- The water and electrical systems provide services to maintain continuity. The water system is supplied by raw water pumps feeding a reservoir and a fire water storage tank. Connections which can supply once-through emergency cooling water are made to the utility water main. Systems fed by the utility water are

1. A demineralizer system for basin fill, make-up, cask flush, water, etc.,
2. The domestic water system where a filter and chlorinator produce potable water,
3. The utility cooling water system consisting of a closed-loop evaporative cooler designed to retain any radioactivity entering from process cooling, and
4. The chilled water system for the air conditioners.

Normal three-phase power is received from off-site utility sources and supplied to a distribution station on site. Standby power consists of two redundant diesel or turbine generators plus auxiliary equipment which can restore power to essential loads. Snedding non-essential loads and transferring to standby power is accomplished automatically with provision made for manual override. An uninterruptible battery power supply is provided for critical instrumentation and alarms as a further backup.

Variations for Reprocessing Plant Storage

Except for area size, the physical design of transfer channels and the storage and preparation-for-reprocessing pools would be similar to those described for the AFR facility. The shipping cask is unloaded underwater. Also, faulty assemblies are canned or placed in overpacks during the unloading operation. The flow diagram for spent fuel receiving, handling, storage, and preparation-for-reprocessing operations at this facility is shown in Figure 16.

In any reprocessing facilities which might be activated in the future, the differences between the AFR facility and the system of receiving and preparation facilities and storage pools are as follows:

1. The amount of spent fuel stored in the reprocessing facility would most likely be considerably less than in AFR facilities. Most likely it would not exceed 1000 MTU.
2. The fuel would remain in the storage pool for a shorter duration of time than it does in the AFR facility storage pool.
3. The fuel would be transferred into the plant shearing cell. It would not likely be transferred back to receiving for transportation out of the facility as is planned in the AFR facility.

Facility Description -- The reprocessing facility would include:

1. Shipping Cask Unloading Bay--A 120-tonne remotely controlled overhead crane spans the cask unloading bay and cask unloading pool. A 7-metre extension fixture which can be attached to the crane is provided for lowering and raising the cask in the pool and removing and replacing the cover.
2. Spent Fuel Unloading Pool--The spent fuel unloading pool is approximately 16 metres deep and 100 metres square in area. It contains space for a rail cask and several storage baskets.
3. Spent Fuel Interim Storage Pools--Two 500-MTU capacity storage pools are required. Pool construction and support systems, material handling equipment, loaded-basket pool storage holding fixtures, and storage arrays were described in Section II. Each pool can be isolated from access transfer channels.

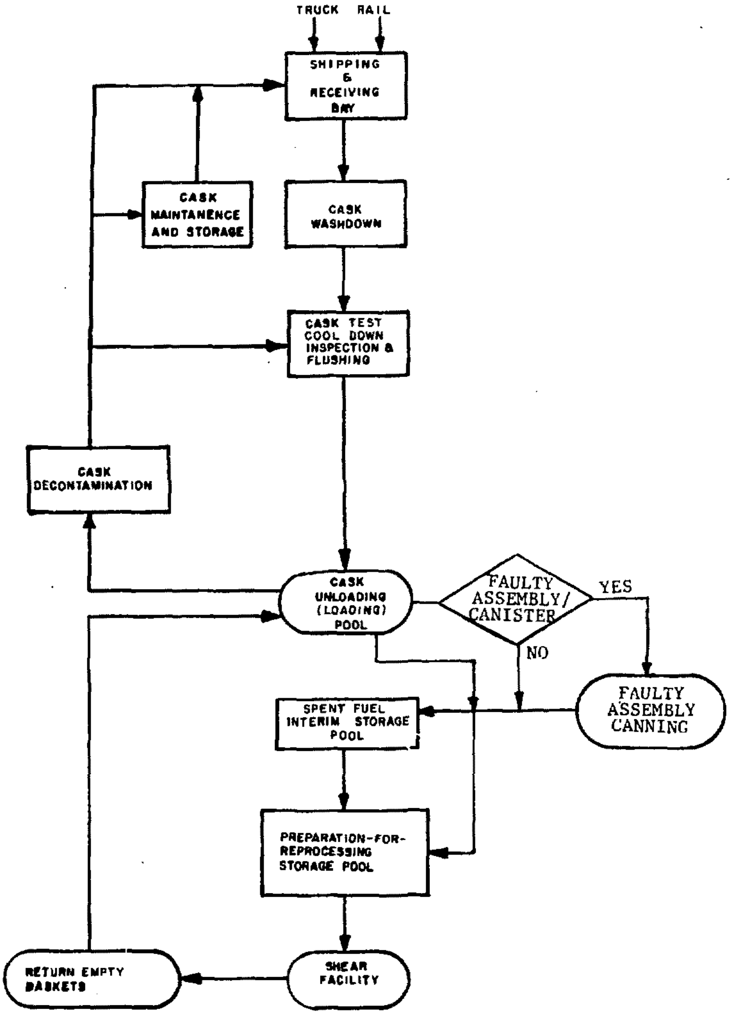


Figure 16. Receiving, Handling, Interin Storage, and Preparation-for-Reprocessing Operations Flow Spent Fuel Reprocessing Plant

4. Preparation-for-Reprocessing and Faulty Fuel Storage Pool-- A preparation-for-reprocessing storage pool connected by transfer channels to the spent fuel interim storage pool, the cask unloading pool, and the shear facility provides for containment of 100 MTU, including spent fuel assemblies in storage baskets. The pool is 10 metres deep and approximately 30 metres square. A 13-tonne crane services the pool. It can be isolated from access to transfer channels.

<u>Facility Operations</u> -- The reprocessing facility operation includes the following steps:

1. Following shipping cask receipt and preparation, the cask is moved by the overhead crane to the holding area next to the cask unloading pool.
2. The crane extension arm is attached to the crane.
3. The shipping cask is lowered into the cask unloading pool.
4. The cask cover is removed and the assembly(s) is transferred to storage baskets.
5. Faulty fuel assemblies are canned or placed in overpacks prior to transfer to storage baskets.
6. Loaded storage baskets are transferred to the interim storage pool.
7. Empty shipping casks are covered, removed from the unloading pool, returned to the decontamination area, decontaminated, and then placed in the empty cask storage area or transferred to the load-out area for shipment.
8. Loaded storage baskets are transferred to the shear facility.
9. Empty baskets are returned to the cask unloading pool or to decontamination and basket storage areas.
10. Loaded faulty fuel assembly containers are sent into the reprocessing plant. If contaminated, the containers are scrapped; if clean, they are returned to the cask unloading pool.

Other Considerations -- Should interim spent fuel storage be accomplished at an inactive reprocessing facility, all receiving, unloading, and placement-in-storage operations would be as described in this section. The preparation-for-reprocessing pool could be used for additional storage space. Operations for shipment of fuel from such a facility would be the reverse of the receiving operations.

Dry Surface Storage Facility (DSSF)

In addition to storage in water basins, numerous concepts for interim dry storage of spent fuel have been proposed. These storage concepts vary in active or passive cooling, above or below ground placement, and other design details. Descriptions of leading candidate systems are summarized as follows:

1. The sealed storage cask (see Figure 17). In this system the canistered fuel is placed in an approximately 51-mm-thick low carbon steel storage cask and mounted in a concrete radiation shield. The annulus between the overpack and the shield acts as a draft tube for heat removal by natural air convection. The entire assembly is placed on a concrete pad in an above ground array. Several designs for the total assembly have been proposed, including sealing the total assembly where heat rates allow (old or low burnup fuel).
2. The natural convection air-cooled vault (see Figure 18). This concept stores fuel in 13-mm-thick overpacks suspended vertically in a shielded cell. Radioactive decay heat is dissipated by natural air convection. A variation of this concept involves mounting the storage assemblies horizontally.
3. The forced circulation air-cooled vault (see Figure 19). This concept consists of placing spent fuel in a remotely operated and maintained canyon facility where heat is removed by forced circulation.

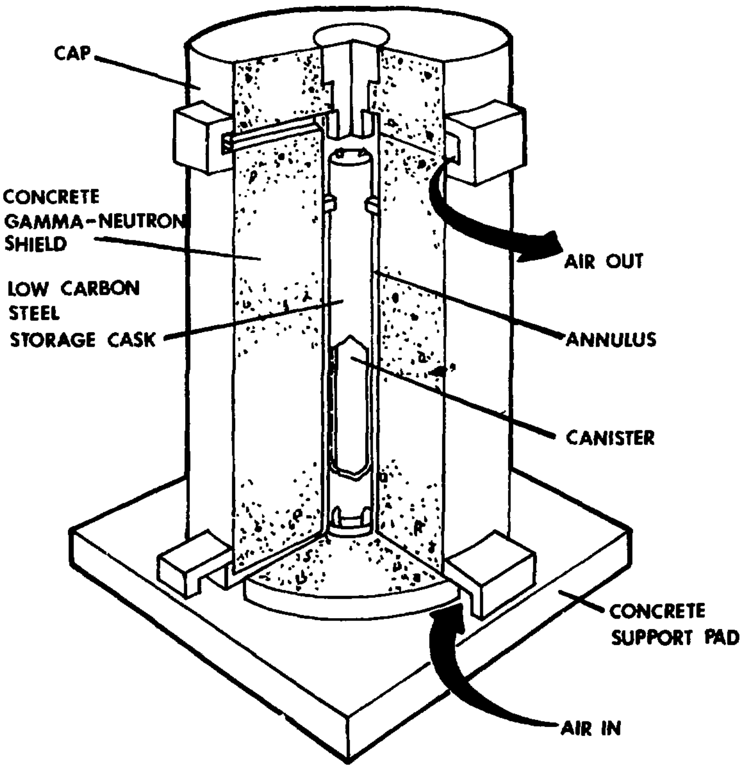


Figure 17. Sealed Storage Cask Concept

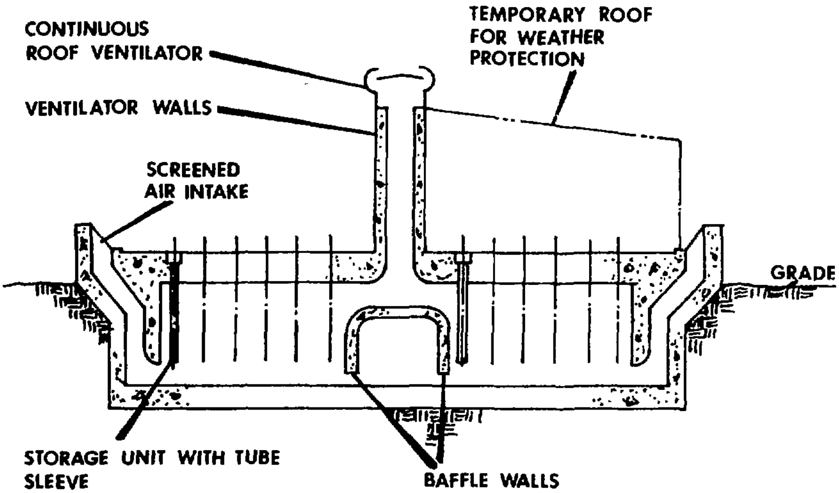


Figure 18. Natural Draft Air-Cooled Vault Concept

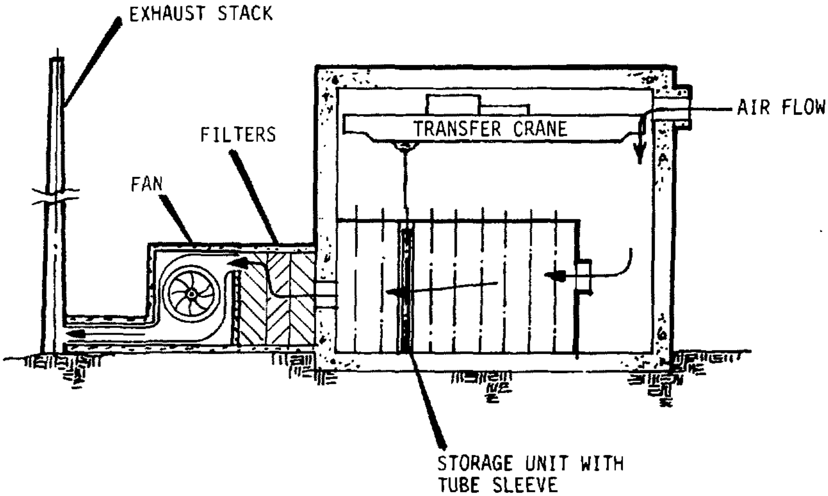


Figure 19. Forced Air-Cooled Vault Concept

4. The horizontally mounted storage cask (see Figure 20). In this system the canistered spent fuel is surface mounted in a massive (up to 200-mm-thick) welded, low carbon steel cask. Heat is conducted away from the cask surface by natural air convection.
5. The closed caisson (see Figure 21). A caisson is placed in a drilled hole. The canistered fuel is placed in the caisson, a high density shield is added, and a weather proof cover on the caisson is locked in place. Heat is removed by conduction through the soil.
6. The natural draft caisson (see Figure 22). This modification of the closed caisson allows the handling of higher heat loads. Heat removal is by convection to air.

Other storage modes which have been considered include surface and subsurface warehousing, closed canyon facilities, and covered concrete trenches.

Each DSSF storage mode has specific advantages related to heat removal, containment integrity, handling ease, and cost. Any of these options may be selected to maximize heat dissipation and radiation shielding, depending on the fuel properties.

The DSSF concept based on the use of a sealed storage cask was chosen for this baseline description because of its applicability and generic relation to other DSSF alternatives. Operations involved with the sealed storage cask are readily applicable to other DSSF concepts. The remainder of the section discusses the details of a typical facility.

Material Characteristics

The DSSF is designed to handle BWR and PWR fuel assemblies as previously defined. Additionally, shipping cask volumes and weights can be minimized by shipping uncanistered assemblies. Within the

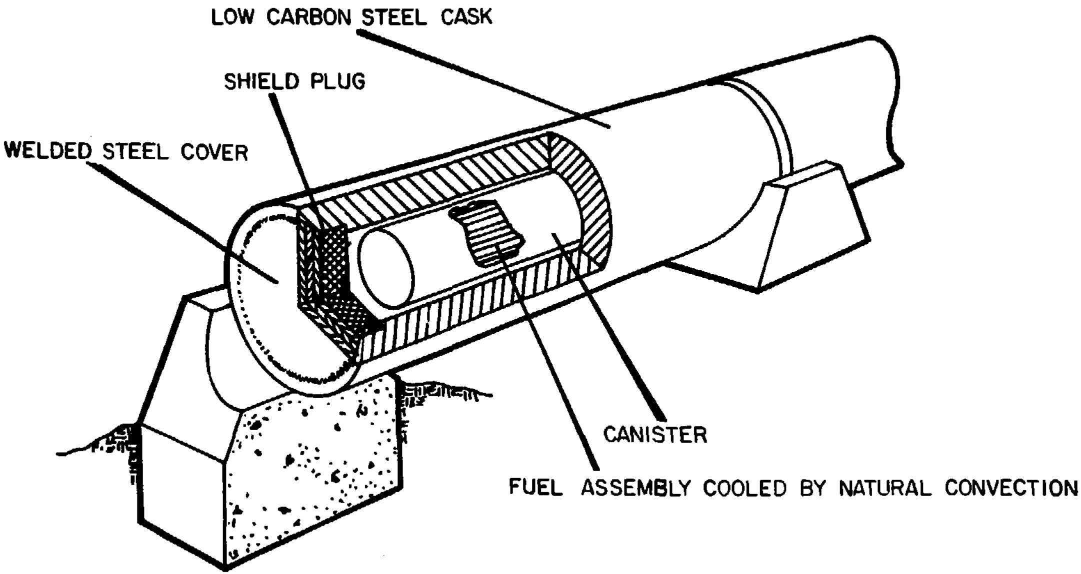


Figure 20. Horizontally Mounted Cask Concept

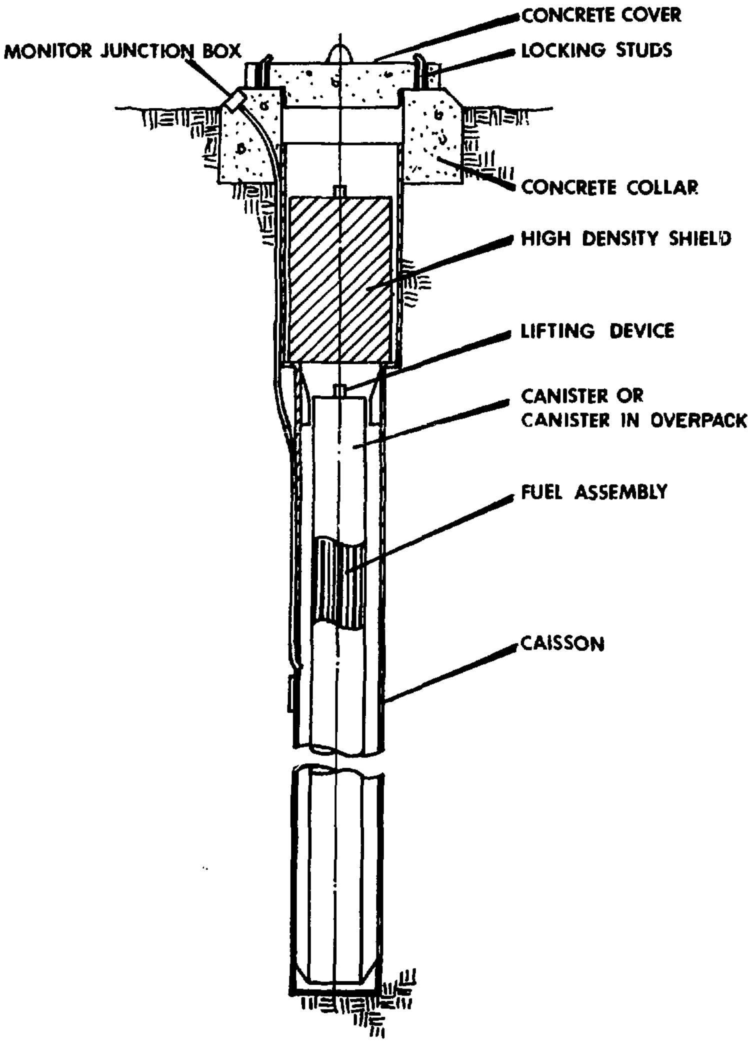


Figure 21. Closed Caisson Concept

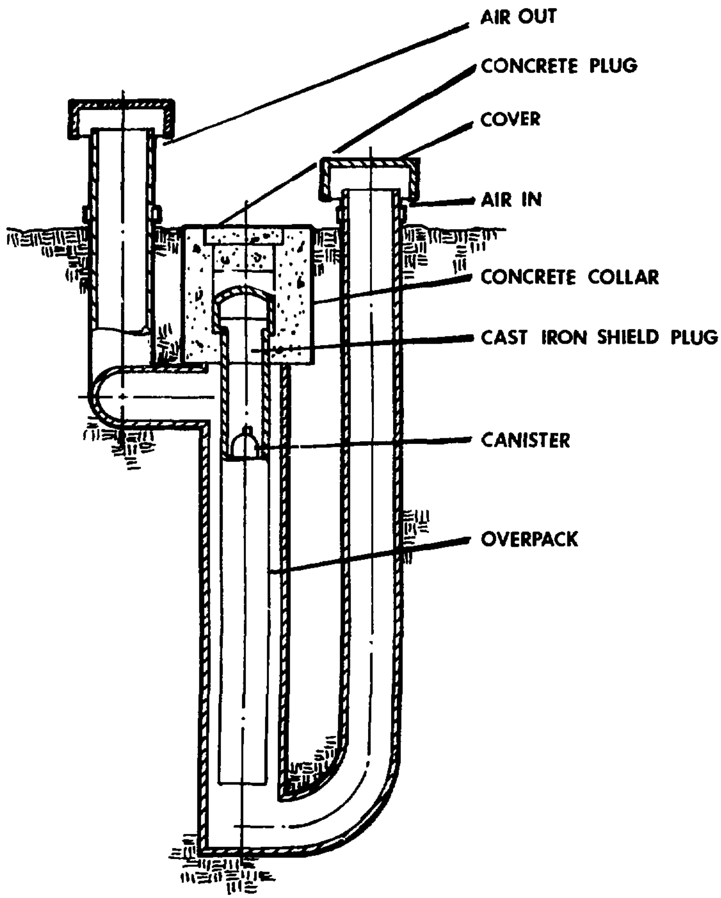


Figure 22. Natural Draft Caisson Concept

DSSF, provisions are made for adding canisters, for adding overpacks to previously canistered fuel, if required, and for handling the resultant assemblies.

The simplest canister is that designed to hold a single BWR or PWR fuel assembly (see Figure 23). More economical alternatives involve storage of multiple assemblies per canister; however, their use is constrained by the higher heat loads involved. Canister material will depend on the chosen storage mode and the need for corrosion resistance. Stainless steel is typical. Overpack design is similar to that of the canister.

Thermal Limits -- Representative heating rates for spent fuel are given in Section II. These heating rates and resulting temperatures impact the thermal limits of materials present in the DSSF. Zircalloy clad assemblies will react with air at temperatures above 200° C. Stainless steel clad assemblies have low oxidation rates at much higher temperatures. As noted in Figure 23, provision is made for evacuating and backfilling canisters and overpacks with helium. This limits corrosion problems and improves thermal conductivity. Zinc or powdered aluminum have also been considered as fillers.

Other critical process materials are carbon steel, used in construction and storage casks and as a possible overpack material, and concrete, used structurally and in some proposed storage units. Carbon steel corrodes only about 0.05 mm/year at 260° C when shielded from the weather. Above 430° C the carbon steel creep rate as a result of dead-load stresses may become a factor and carbides may decompose, subjecting the assembly to brittle fracture. Ordinary concrete is adequate at temperatures below 100° C but may require additional support or reinforcement in uses at temperatures above this point.

Radiation -- Fuel cladding is the initial contamination barrier for confinement in spent fuel. A second barrier is provided by the

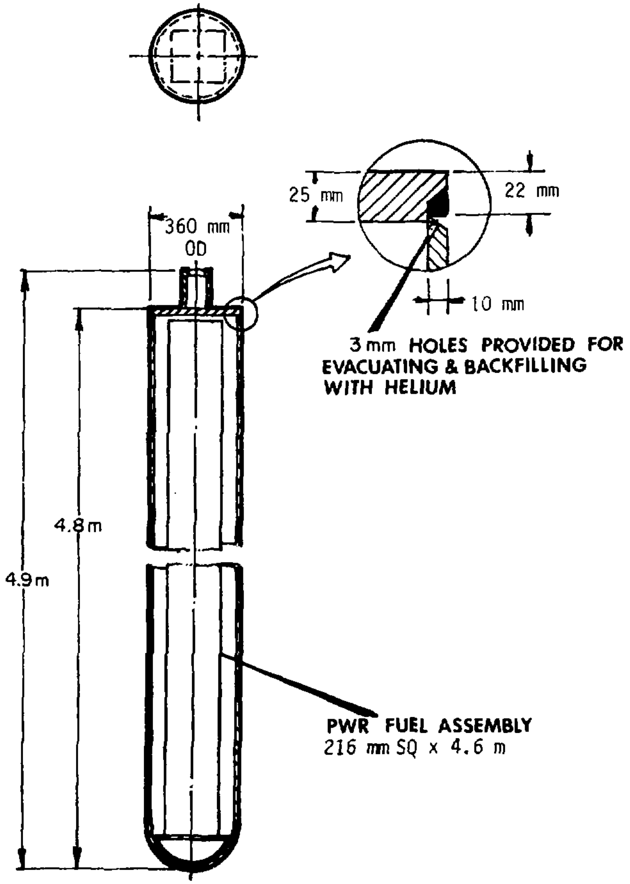


Figure 23. Canister Design

canister. Canisters may be supplemented by overpacks if the fuel canister and/or cladding are damaged. Protection from spent fuel radioactivity may be provided by a combination of a low carbon steel storage cask and a concrete gamma-neutron shield. During receiving, preparation, and handling, building containment systems, such as cells and ventilation, provide barriers against release.

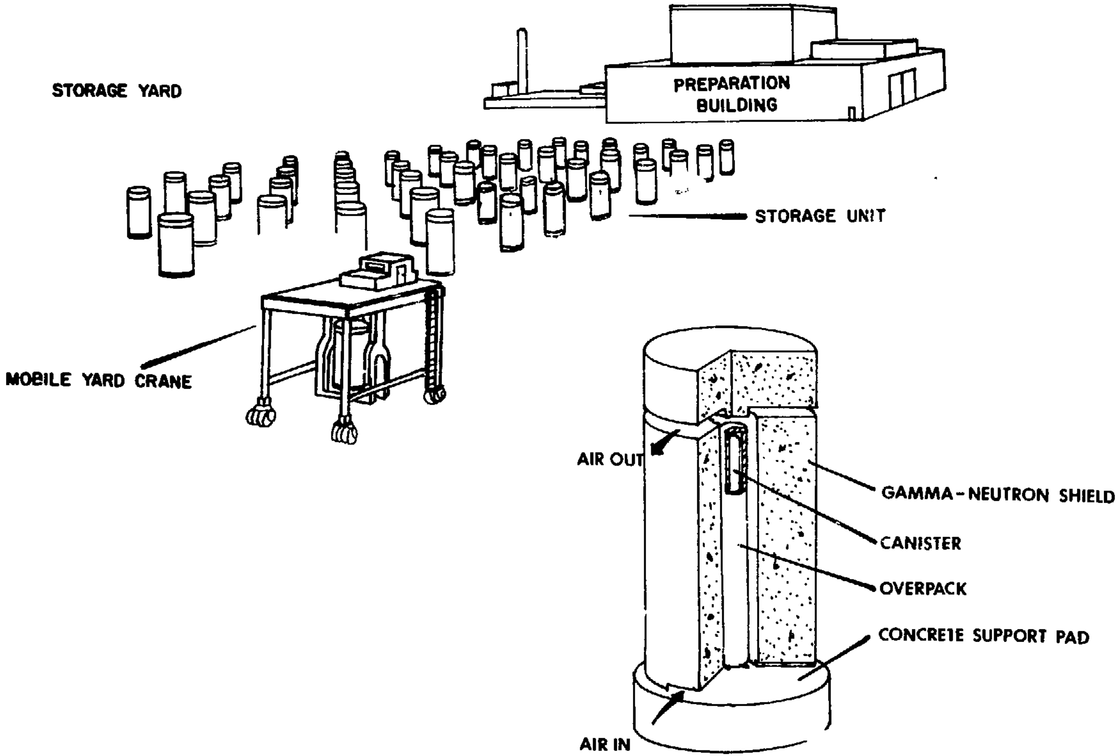
Operating personnel are shielded from the assemblies at all times. Process operations in the DSSF are designed for remote or manual control with no direct operator contact required except during controlled maintenance activities.

Facility Description

The baseline DSSF is designed to receive spent fuel assemblies in shipping casks by truck and rail. Unloading and preparation of the assemblies for storage is done in a building which contains equipment and areas for inspection, decontamination, canning and weld sealing, and transfer between preparation operations prior to storage. A storage area adjacent to the preparation building is equipped to receive and store the packaged spent fuel and to provide long term surveillance and testing for quality assurance. The facility also accommodates spent fuel removal from storage and shipment off-site.

Site Layout -- The facility site layout is shown in Figures 24 and 25. The site covers an area of approximately 1 km^2. It is located on flat land which has good water drainage and no flooding potential. Soil must be well compacted to provide good foundation loading. The site is seismically inert. Under these design conditions, spent fuel can be stored in excess of 100 years.

Site construction consists of access roads and a rail line for trucks and trains, respectively, a building complex at which spent fuel is received and prepared for storage, a storage area, and auxiliary structures and areas for support services and equipment.



Facility Layout -- Sealed Storage Cask Concept

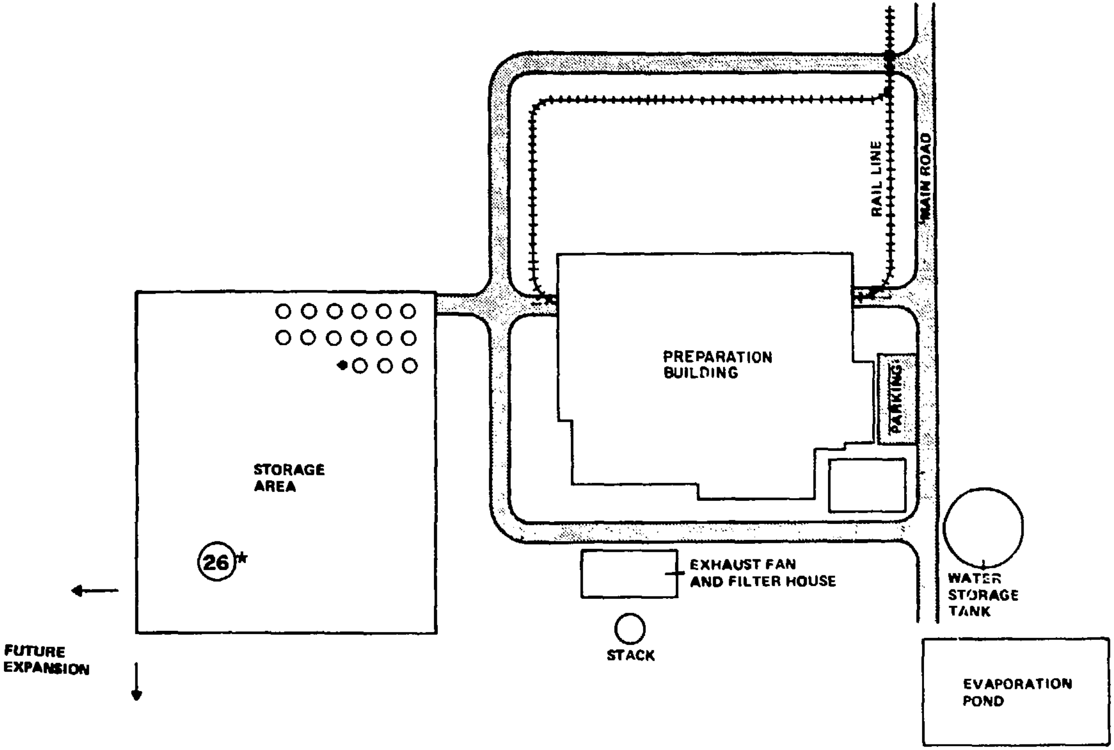


Figure 25. Plot Plan -- Dry Surface Storage Facility

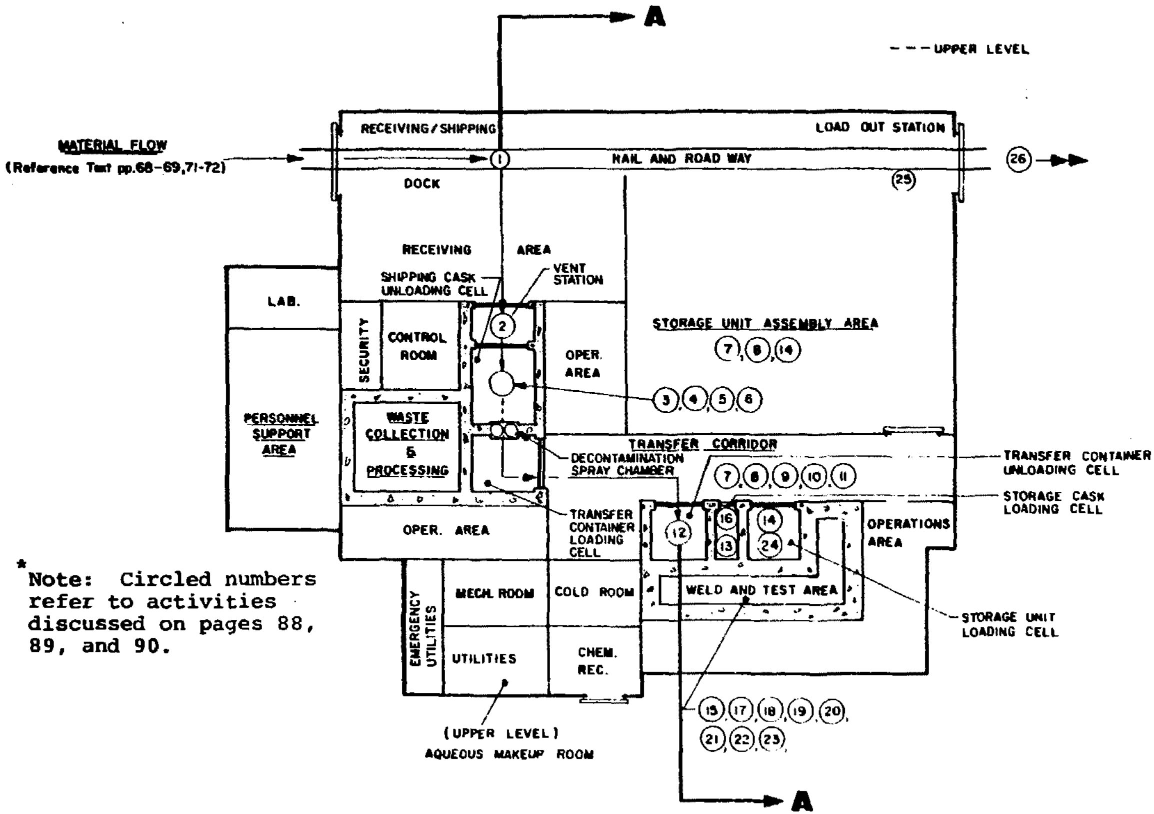
Receiving, Handling and Preparation -- The receiving, handling, and preparation areas of the DCSF are shown in Figures 24 through 27. A rail/roadway runs through the receiving shipping high bay. There are portals at both ends of the bay. An unloading/loading dock runs the complete length of the bay. A 120-tonne crane services the bay and a receiving area.

A two-level hot room contains ground level cells for venting, decontamination, and unloading the fuel assemblies from the shipping casks and loading them into transfer containers. A 30-tonne crane services the cells from an upper level transfer bay. An operations control and visual monitoring area is separated from the hot cell by a thick concrete wall pierced by leaded glass windows. A storage unit assembly area contains space for storage of empty transfer containers, overpacks, transfer carriages, storage casks, and concrete storage units. A 50-tonne crane services the area.

A transfer corridor services the transfer container loading cell, the storage unit assembly area, and the weld and test operation control and monitoring area. Tracks in the floor provide for transfer carriage movement by overhead monorails and a 50-tonne crane which services the corridor.

A two-level hot room contains ground level cells for loading and unloading operations between transfer containers, canisters, storage casks, and storage units, and an upper level preparation area for weld sealing, cutting and testing loaded canisters. Cell preperation areas can be used reversibly for shipping operations.

Basic building construction is steel framing with insulated metal siding. Cells are constructed of 1- to 2-metre-thick high-density (3.7-MT/m^3) concrete. Cell floors and walls are lined with stainless steel to 0.5 metre above the floor level and finished for easy decontamination above that point.



*Note: Circled numbers refer to activities discussed on pages 88, 89, and 90.

Figure 26. Preparation Building
Dry Surface Storage Facility

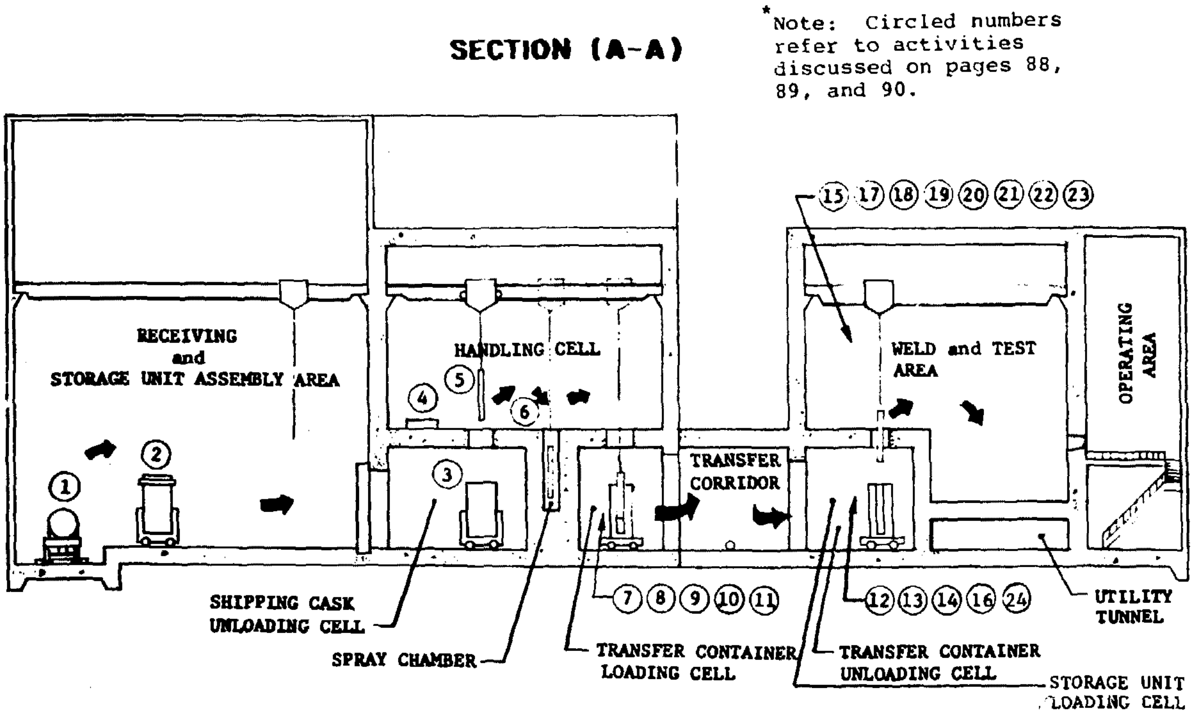


Figure 27. Preparation Building
Dry Surface Storage Facility
(Section A-A)

Storage -- An access roadway runs between the preparation building and the 0.2 km^2 surface storage area to accommodate the mobile crane (Figure 24) which transfers storage assemblies between the preparation building and the storage yard. The yard is serviced by underground monitor system cable ducts.

Facility Operations

Operation of the DSSF is summarized in Figure 28. The individual operations noted are detailed in the following sections with the exception of "Operations Central Control" which was described for the AFR. Depending on facility size to meet receipt requirements, several operations could occur in parallel.

The following definitions are used in discussions of the DSSF operations:

1. Canister--a welded stainless steel container (Figure 28) covering the fuel assembly and serving to ensure structural integrity and to act as a containment barrier to the release of fission products.
2. Overpack--welded stainless steel container applied over a canister to ensure containment if the canister leaks.
3. Transfer Container--an unsealed, temporary container used for transferring fuel assemblies between operations in the DSSF.
4. Storage Cask--a massive low carbon steel container applied over the canister or overpack to provide an additional containment barrier and assure protection for storage periods up to 100 years.
5. Storage Unit--the storage cask mounted in its concrete shield.

Assembly Receipt and Unloading and Preparation for Storage -- The DSSF has receiving and unloading facilities suitable for either road or rail transportation of the incoming spent fuel. After verification of shipping papers, the shipment is moved to the receiving area. For

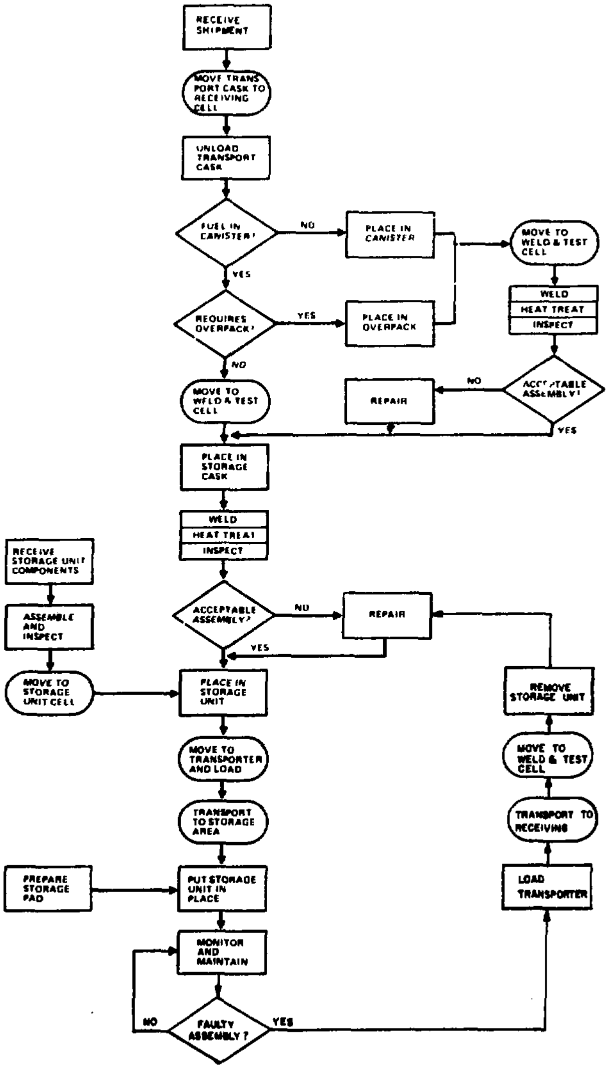


Figure 28. DSSF Receiving, Handling, and Storage Flow

rail delivery, a dedicated site engine is used. The fuel cask and transporter are examined for external contamination and washed down at the receiving dock. When washdown is completed, the operations identified and numbered in Figures 25, 26, and 27 and flow-charted in Figure 28 take place as the shipment of spent fuel is prepared for storage. These operations are defined below.

(1) The receiving area crane upends the cask from its horizontal shipping orientation and places it on a transfer carriage.*

(2) The cask is moved to a venting station where it is monitored for radioactivity and then vented.

(3) The shipping cask is then moved to the shipping cask unloading cell. Operations are conducted remotely from this point.

(4) The cask cover is removed by the crane and stored in the handling cell.

(5) One canister or bare assembly at a time is raised into the handling cell.

(6) The canister or bare assembly is decontaminated in a spray chamber and checked for leaks.

(7) If the assembly is bare, the transfer container is loaded with an empty canister at the storage unit assembly area and then moved to the transfer container loading cell.

(8) If the assembly is in a leaking canister, the transfer container is loaded with an empty overpack at the storage unit assembly area and moved to the transfer container loading cell.

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*Transfer carriages are used throughout the DSSF. They are remotely operated and move along tracks. They eliminate much of the need for overhead cranes and consequently limit the potential for dropping. Transport carriages designed for moving canisters once they are removed from the shipping cask include transfer containers (Figure 29). The transfer container is designed to cool the fuel assembly or canister with water or gas. It provides shielding and maintains confinement even in the maximally credible tipping accident. Options to the use of transfer carriages include use of cranes or air movers.

(9) If the assembly is in a nonleaking canister, the transfer container is moved directly to the transfer container loading cell.

(10) The assembly or canister is lowered from the handling cell into the transfer container at the transfer container loading cell.

(11) The transfer container cover is put in place.

(12) The transfer container is moved through the transfer corridor door to the transfer container unloading cell beneath a hatch of the weld and test cell.

(13) An empty low carbon steel storage cask is moved on another transfer carriage to the storage cask loading cell beneath a second hatch of the weld and test cell.

(14) A concrete storage unit gamma-neutron shield and cover is moved by a third transfer carriage to the storage unit loading cell beneath a third hatch of the weld and test cell.

(15) The cast iron storage cask is raised into the weld and test cell.

(16) The transfer container cover is removed.

(17) The canister or overpack with the contained assembly is raised into the weld and test cell from the transfer container.

(18) The canister or overpack is moved to one of the two remotely operated welding stations. Each station is capable of completing a continuous full penetration weld on a canister overpack or carbon steel storage cask.

(19) The canister or overpack is evacuated, backfilled with helium, and welded.

(20) The sealed canister or overpack is annealed, the weld is tested, and the canister is inserted into the carbon steel storage cask.

(21) The storage cask is mounted in the rotary weld positioner and the cap is welded.

(22) The storage cask is heat treated to relieve stress and the weld is tested.

(23) Storage casks with uncorrectable flaws are moved to the decask station where a cutting tool separates the cap from the cask. The canisters are removed and repackaged and the defective storage casks are scrapped.

(24) The welded storage cask is lowered into the concrete storage unit.

(25) The storage unit is moved to the loadout station where it is grappled, raised, and transported to the storage area.

(26) Storage units are placed in a symmetrical array on prepared concrete pads. Lifting heights are limited to protect operating personnel from radiation shine from the bottom of the assembly. The storage units are typically 6 to 9 metres on centers.

Area symmetry allows easy movement of storage yard cranes and access to all units. Area expansions are completed modularly, as required. Emplaced storage units are continuously monitored for radioactivity and component integrity as part of the quality control program. Any suspect units are removed from storage and returned to the operating facility for inspection and repair or replacement, if required.

Removal Operations -- All facility operations are reversible. When removing stored fuel, flow through the facility is reversed. The decask stations in the welding and test cell may be used to remove the storage casks or the storage unit may be shipped intact in specially designed shipping casks. Detailed inspection is performed in the storage area before the storage unit is disturbed, and further inspections are required as each containment barrier is removed.

Essential Support Services

This section addresses the common support areas and processes required for operation of the DSSF.

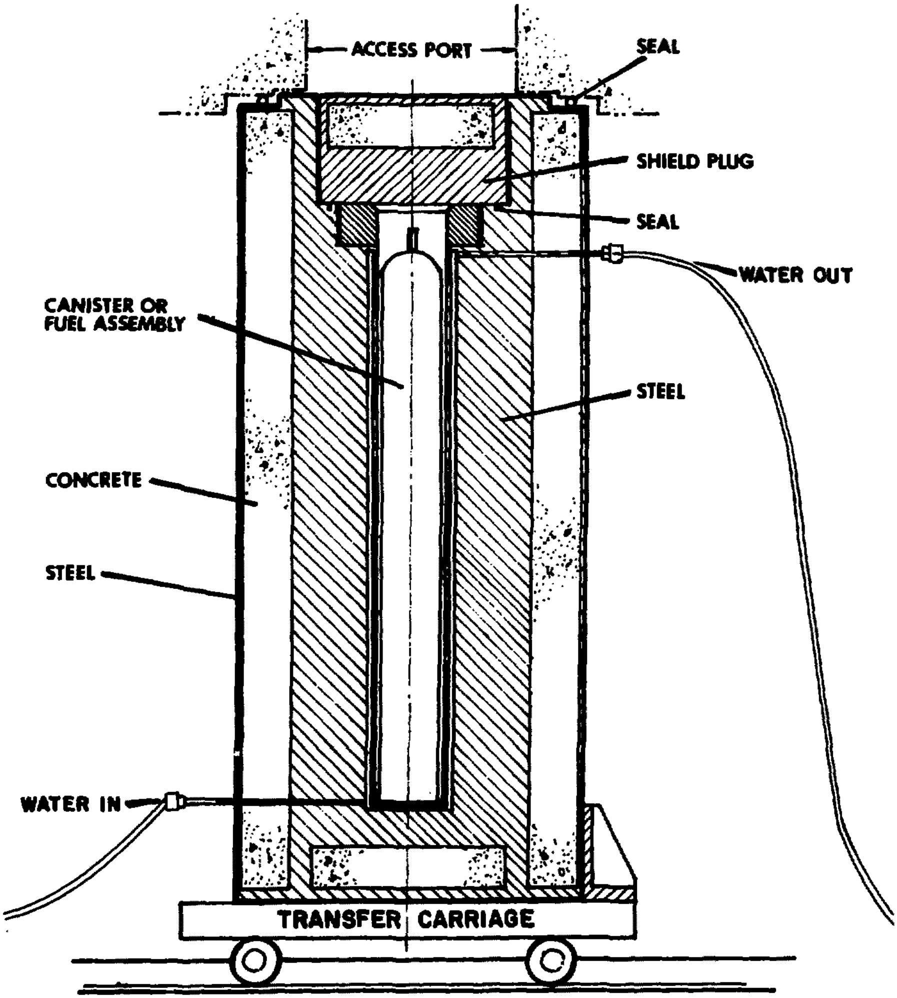


Figure 29. Transfer Container on Transfer Carriage

Waste Collection and Processing -- The function of the waste system is to collect, reduce in volume, and dispose of waste resulting from normal or abnormal operation of the DSSF. All radioactive waste will be solidified on-site prior to shipping to a repository, if required.

Contaminated waste may be generated in the receiving area, cask and fuel decontamination stations, the weld and test area, transfer corridors, the laboratory, and hot maintenance areas. Uncontaminated liquid wastes are jetted to surface disposal. Mildly contaminated liquids are circulated through an ion exchanger and reused within the process. Liquids with significant contamination are transferred to a hot waste tank for feed to a fluidized bed calciner.*

Noncombustible solid wastes are compacted in suitable drums. Large failed process equipment is packaged separately. Combustible wastes are incinerated and the ash immobilized.

HVAC System -- The heating, ventilating, and air-conditioning (HVAC) system is designed to limit radioactivity to specific areas of the DSSF. Additionally, the HVAC system removes fuel assembly decay heat and prevents the accumulation of explosive or toxic gases.

Ventilation maintains air flow towards areas of increasing contamination potential. Air from all potentially contaminated areas is exhausted through two sets of HEPA filters in series. Remote centralized indication, alarm, and control are provided for all ventilation system components.

Monitoring and Control -- The function of monitoring and control systems is to ensure the safety of operating personnel and the continuity of plant operations.

*Other potential disposal methods include: (1) direct casting with cement in vermiculite, (2) casting with cement plus sodium silicate, (3) extrusion - evaporation as asphalt mixture, or (4) crystallization.

Utilities -- The utilities provide services necessary to maintain continuity of operation. Essential systems receive power from diesel or turbine generators and uninterruptible battery power supply systems.

The water system is supplied by water pumps feeding a reservoir and a fire water storage tank. Connections which can supply once-through emergency cooling water are made to the raw water main.

Normal three-phase power is received from off-site utility sources and supplied to a distribution station located outdoors near the process building. The distribution station sends power to substations in the utilities area and other plant areas.

Standby power consists of two redundant diesel or turbine generators and auxiliary equipment which can restore power to essential loads within 30 seconds. Generator fuel is delivered by truck to two 30,000-liter buried storage tanks and is distributed by pump. An uninterruptible battery power supply is provided for critical instrumentation and alarms as a further backup.

The compressed air system consists of two small air compressors to supply instrument air for any process requirements. Each instrument air compressor is fed from redundant ac sources. A backup compressor and controls are provided with the emergency utilities. All are connected to standby diesel or turbine generators.

SECTION IV

DEEP GEOLOGIC STORAGE FACILITIES

This section describes a deep geologic spent fuel storage facility including material characteristics, operations, and essential systems.

The facility described is designed to meet many of the criteria under consideration for the permanent storage of solidified high-level and transuranic wastes. Spent fuel storage may be accomplished in conjunction with the storage of these wastes.

Another deep geologic spent fuel storage concept which is currently being investigated involves placing spent fuel beneath deep seabeds. While this concept is not addressed in this study, the Bibliography contains references to deep seabed high-level waste storage concepts that are presently being investigated and could provide an alternative consideration for spent fuel storage.

Site Characteristics

The basic concept of geologic storage of spent fuel involves the use of a natural barrier to separate the spent fuel from the biosphere. Mine caverns can be constructed for use as repositories in which spent fuel can be either stored or permanently entombed.

To date, all effort in the U.S. directed toward establishing these repositories has been of a conceptual nature. No actual detailed engineering designs of such facilities have been prepared. The main feature, which is unique to the most recent efforts to dispose of spent fuel, is that in the early stages of the operations of these repositories, the spent fuel is retrievable.

At this early stage of development, many rock types are being considered as possible storage and/or disposal media, with emphasis on bedded and dome salt sedimentary formations. Also, interest has been shown in other sedimentary rocks, such as shale, and in igneous rocks, such as basalt and granite.

The physical and chemical characteristics of each of the rock types under consideration for repository sites are quite different. Because of this wide variation in physical and chemical characteristics between rock types, it is reasonable to assume that these characteristics will dictate significant variations in both surface and underground designs, but particularly in underground designs.

Material Characteristics

BWR and PWR spent fuel assemblies, bare or in sealed containers, arrive in shipping casks from the LWR reactor sites, AFR facilities, or DSSFs by rail and truck. These assemblies are unloaded from the shipping casks, prepared, and moved to the designated subsurface storage compartment. Bare spent fuel assemblies are canned and any faulty canisters are overpacked in a surface facility on site before transfer into storage. During all operations the bare and canned assemblies are in contact with ambient air for short periods of time during unloading and canning operations. At all other times they are cooled by forced air or other cooling gas prior to storage.

Spent fuel assemblies that normally arrive at the site have been aged 5 years or more; related material properties are discussed in Section II.

Facility Description

In this baseline design a mine is constructed (see Figures 30 and 31) below a spent fuel surface receiving and handling facility at a depth of between 300 to 900 metres in a geologic formation such as salt, granite, shale, or basalt. The mine consists of a large number of chambers excavated within the layer of suitable rock mass and is connected to the surface facilities through access shafts. These excavated chambers are interconnected by various corridors. The corridor and shaft designs ensure separation of the mining and spent fuel assembly emplacement operations.

The support surface complex consists of a spent fuel preparation building, utilities, roads, railroad tracks, mine tailing storage, administrative buildings, and other support structures.

The placement of facilities has been arranged for efficient mining, storage, and retrieval operations, and the layout could be implemented in many different geologic media.

Surface Site Layout

The surface site layout (Figure 31) occupies an area of approximately 0.8 km^2. The major surface facilities are

1. Preparation Building,
2. Radwaste Treatment Building,
3. Supply Ventilation Building,
4. Exhaust Ventilation Building,
5. Site Control Building,
6. Mechanical Assembly,
7. Refrigeration and Boiler Plant, and
8. Surface Mine Operations, Personnel, Materials, and Miscellaneous Buildings.

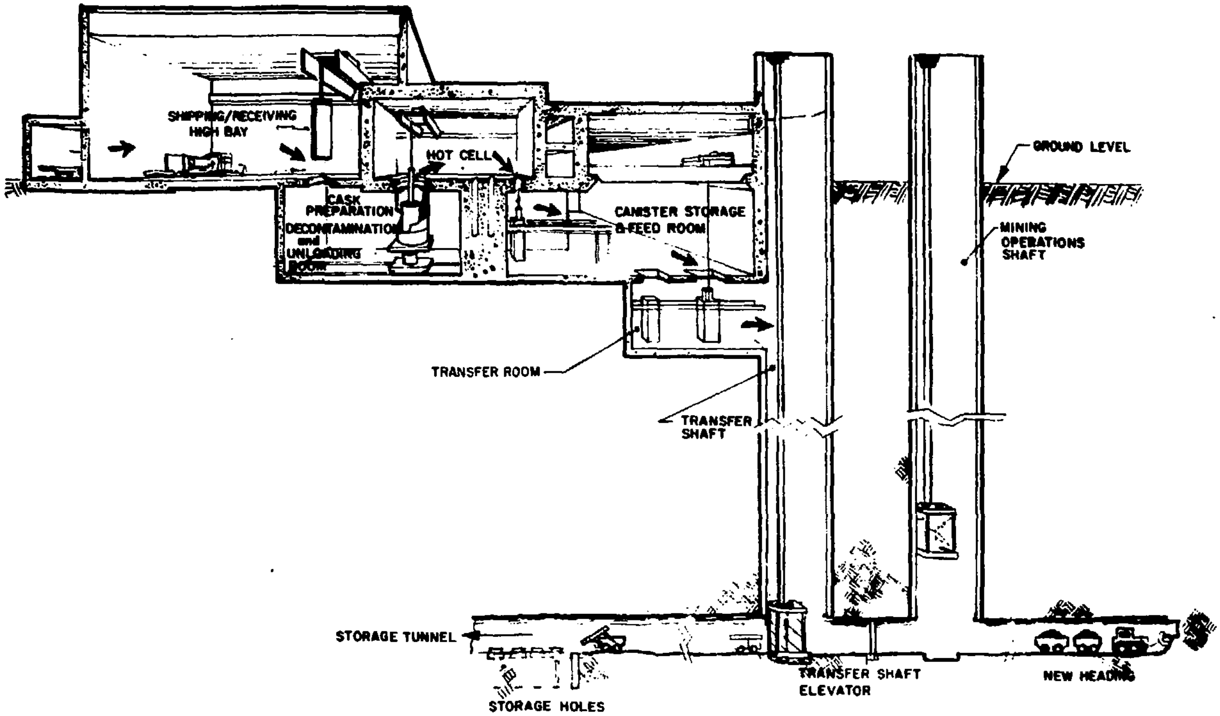


Figure 30. Deep Geologic Storage Facility -- Cutaway Perspective

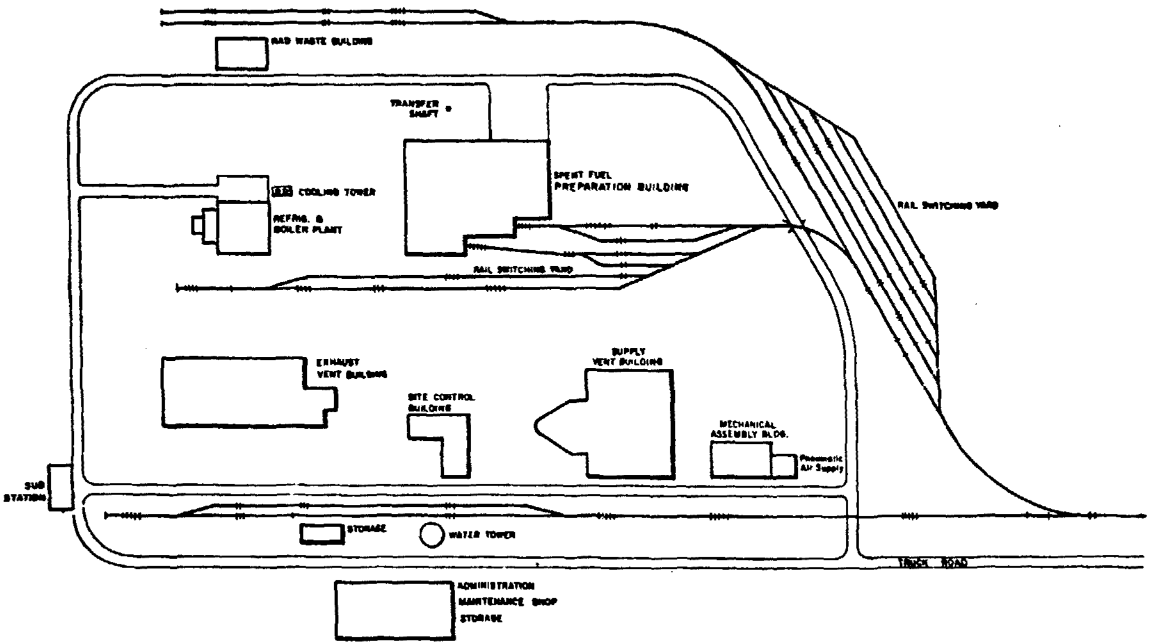


Figure 31. Deep Geologic Storage Facility -- Surface Site Plan

Subterranean storage areas which could encompass as much as 9 km^2 are protected from inadvertent penetration because the facility holds title to the overlying areas and perpetual subterranean rights to an area that extends considerably beyond the site proper.

Spent Fuel Preparation Building

The Spent Fuel Preparation Building provides the capabilities necessary to receive and handle spent fuel that was shipped via truck or rail in shielded casks. Space is provided for support functions such as control and monitoring, counting rooms, laboratories, a health physics office, personnel, service areas, maintenance, storage, heating/ventilation/air-conditioning, and electrical and mechanical equipment rooms. Airlocks are provided for access between these areas and the operating galleries and cask unloading areas.

Specific stations involved in the handling of spent fuel in the surface facility as illustrated in Figure 32 include:

1. Shipping/Receiving High Bay,
2. Cask Transfer Gallery,
3. Cask Elevators to Hot Cells,
4. Bare Assembly Hot Cell/Canistering Station,
5. Canister Storage and Feed Room,
6. Mine Cage Transfer Station, and
7. Spent Fuel Mine Shaft.

Overhead cranes (18 to 120 tonne) or cask elevators service these stations. Airlocks are located between all spent fuel handling areas. Hot cells with heavy shielding and remote handling equipment are located in the spent fuel preparation building.

A spent fuel transfer room for transferring canned spent fuel to the mine transfer shaft connecting the spent fuel preparation building to the subsurface storage areas is an integral part of the spent fuel preparation building.

Subsurface Facilities

The initial shaft and tunnel excavations for the subsurface facilities are as illustrated in Figure 30. One shaft and tunnel complex is dedicated to the transfer and storage of canned spent fuel assemblies. Other shafts (represented as a single shaft in Figure 30) provide for: (1) removal of muck from the new heading of another storage tunnel, (2) transfer of materials and equipment between surface and underground operations, and (3) ventilation and utility air, water, and electricity for underground operations. The fully developed tunnel complex area for the facility is estimated to be about 10 km^2. The size and canister capacity of the storage rooms is highly dependent on rock type and radiation heating characteristics, i.e., present conceptual mining designs for repositories in salt use a conventional room-and-pillar design and incorporate the requirements of mine ventilation, mine opening stability, thermal effects, and efficient use of excavated space and of mining and hauling equipment. The modular approach to the mine development allows the simultaneous performance of mining activities and spent fuel storage operations. Excavation of several storage rooms can proceed without interference with the storage operations in the previously excavated rooms.

Facility Operations

Figure 32 charts the flow of facility operations. The spent fuel is received at the repository via railroad or truck, unloaded and inspected, placed in a canister, lowered into the mine, and transported to a burial location within the mine.

Operations Central Control

The operational control system and operational procedures are designed to monitor the critical operations and to ensure a high

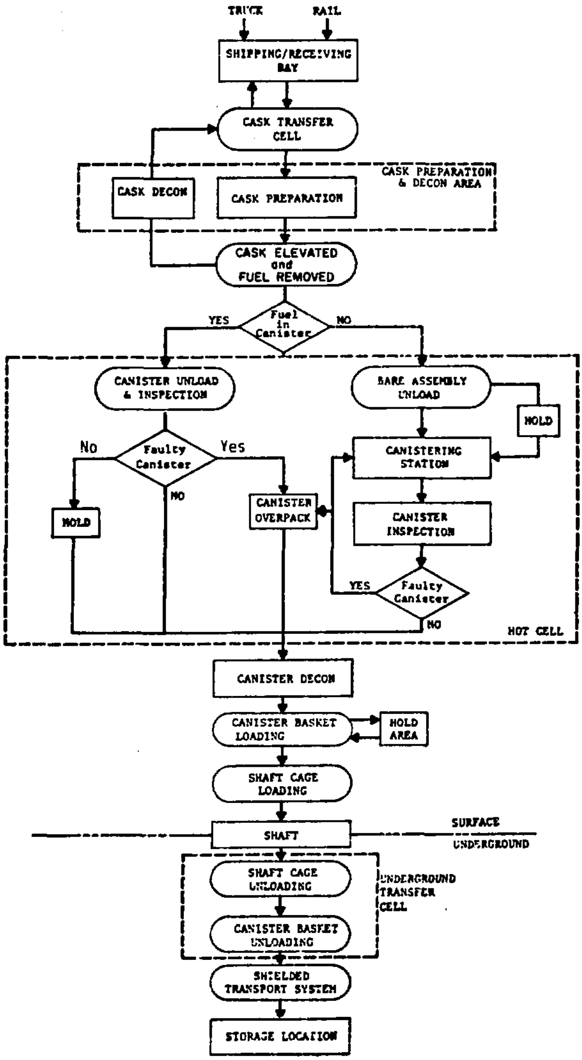


Figure 32. Receiving, Handling, and Storage Operations Flow Deep Geologic Storage

level of containment and radiation safety for the spent fuel from the time it arrives at the repository, during handling operations, and while it is in storage.

Receiving, Handling, and Preparation for Storage

Surface Operations -- All operations from receipt of shipping casks to loading of canisters into the transfer shaft are conducted in the spent fuel preparation building. All canisters and bare assembly operations within this building are done with remotely controlled manipulators and/or automated systems which are operated from adjacent rooms.

The sequence of surface operations is as follows:

1. Truck and rail shipments of spent fuel assemblies contained in shipping casks are unloaded from the trailer or railcars by a 120-tonne overhead crane in the shipping and receiving high bay shown in Figure 30.
2. The crane transfers a cask into a cask preparation and decontamination room where the cask is decontaminated, gas samples are taken for evidence of internal contamination, and the cask is cooled. It is then mated to the hot cell.
3. The cask cover is removed and the bare spent fuel assemblies are transferred to the hot cell for placement and sealing in canisters, and then decontamination, possible overpacking, and transfer to the canister storage and feed room.
4. Empty shipping casks are decontaminated and returned to the shipping and receiving high bay for subsequent maintenance, storage, and shipment.
5. Spent fuel assemblies in sealed canisters are transferred to the hot cell for inspection, decontamination, possible overpacking, and transfer to the canister storage and feed room.
6. Processed canisters are then placed into multicanister baskets for transfer to the spent fuel shaft.

7. If an overflow occurs, canisters are temporarily stored in holes in the floor of the transfer room and plugged; they are later retrieved and loaded as described.
8. The basket is placed into the transfer shaft and lowered to the storage level hot cell.

Shaft Operations -- In the storage level hot cell, the basket is removed from the cage and placed into a shielded transporter. This transporter can carry one to six canisters from the receiving area to a mine storage room for emplacement. The loading and unloading of the canisters from the shaft cage and subsequent loading of the shielded transporter is remotely controlled.

Subsurface Operations -- Shielded transporters move the canisters from the receiving area through a corridor to a designated storage room (Figure 30). In the storage room, steel sleeves, if required, are inserted into the appropriate number of storage holes. The transporter is positioned over each hole sequentially and the canisters are lowered into the appropriate storage hole. The holes are then plugged and the transporter returns to the subsurface receiving station.

As each room is filled to capacity, the room is partitioned off for ventilation efficiency.

Essential Support Systems

Support facilities of major concern in safe repository operation include surface and subsurface ventilation systems, radwaste treatment systems, normal and emergency power systems, and radiological monitoring systems.

Ventilation

The mine ventilation system provides an adequate supply of clean, fresh air to satisfy personnel breathing air supply needs. It controls the chemical and physical quality of the mine atmospheric environment by providing for the removal of contaminants such as engine exhaust gases, dust, heat, moisture, and smoke generated by equipment and mining processes. The ventilation system also satisfies the need for air during spent fuel assembly placement operations in which transporter operators and other personnel are involved. It is likely that the ventilation system for the mining activities will be kept separate from the ventilation system serving spent fuel storage activities.

Waste Management

Treatment systems are available for on-site generated radioactive wastes (solid, liquid, or gaseous forms). A separate building contains all the necessary equipment for collecting, treating, and packaging the waste. Liquid wastes generated mainly by decontamination operations and mine seepage flow (if any) are collected, solidified, packaged, and placed in the mine. The ventilation system traps fine suspended radioactive particulate matter from the mine vent.

Monitoring and Control

The facility would be designed so that any release of contamination is monitored and controlled. Radiation alarm systems are provided to warn facility personnel of significant increases in radiation levels in normally accessible areas and of excessive radioactivity released in plant effluents. Systems are designed with redundance and with the capability to permit monitoring during operation.

Electrical

Normal three-phase power is received through physically separated redundant lines at a distribution station on site. Standby power is provided from diesel or turbine generators plus auxiliary equipment which can restore power to essential loads. Shedding nonessential loads and transferring to standby power is accomplished automatically with provision made for manual override. An uninterruptible battery power supply is provided for critical instrumentation and alarms as a further backup.

SECTION V

TRANSPORTATION OF SPENT FUEL

Spent fuel assemblies packaged in heavy transportation casks are shipped between nuclear reactor sites and storage facilities, and potentially to reprocessing facilities. Figure 33 shows the reactor-to-storage transportation alternatives considered in this document. The quantities currently transported are relatively small but are expected to increase rapidly both in the U.S. and in and between foreign countries. The transportation of spent fuel is further impacted by the U.S. offer to accept and store limited quantities of spent fuel generated in foreign countries.

This section describes the spent fuel transportation operations, including the shipping casks, land and water transportation vehicles, and typical transportation modes.

Shipping Containers for Spent Fuel

The general characteristics of representative U.S. and foreign spent fuel shipping containers are given in Tables III and IV, respectively. The containers are designed to prevent the release of radioactive material, protect handling personnel and the public from exposure, and prevent criticality or loss-of-coolant accidents under severe impact conditions. They contain heat transfer media to dissipate heat produced by radioactive decay. They are cooled externally by natural air flow over external fins, by forced air, or by recirculating fluid systems to assure adequate temperature conditioning.

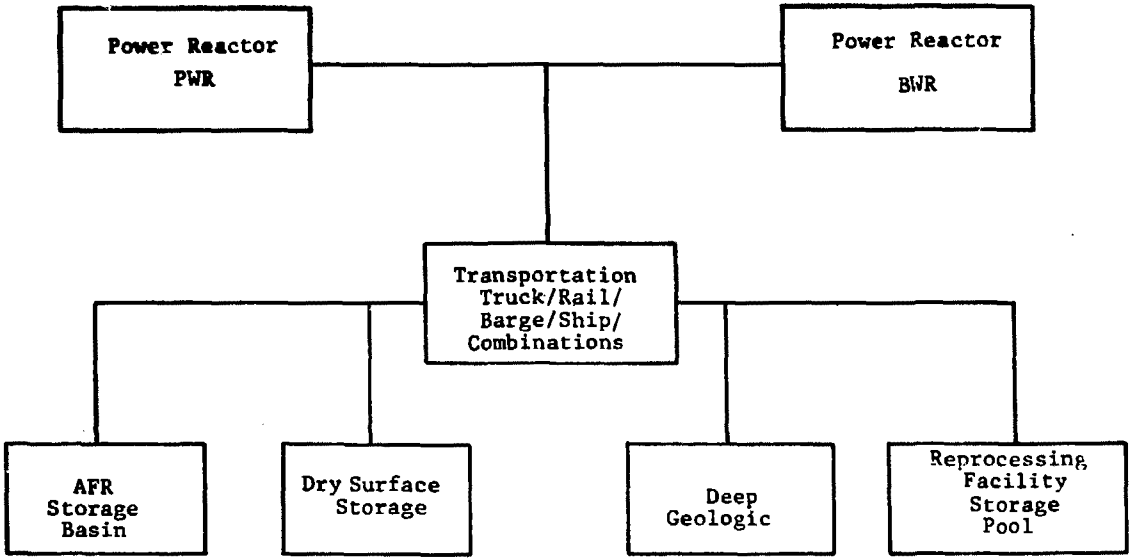


Figure 33. Spent Fuel Storage and Transportation Modes

TABLE III

Characteristics of U.S. Spent Fuel Casks

Cask Type	Primary Transport Mode	Weight Loaded (tonnes)	Capacity In Elements (PWR/BWR)	Fluid in Cavity	Cavity Length/Dia (cm)	Thermal Capacity (kW)	Major Shielding	Neutron Shielding
NAC-1	Truck	22.25	1/2	Water/ Air	452/34.2	11.5	Lead and Steel	Borated Water Antifreeze
NFS-4	Truck	22.25	1/2	Water/ Air	452/34.2	11.5	Lead and Steel	Borated Water Antifreeze
NFS-5	Truck	24.1	2/3	Water	452/24.3x 46.2	24.7	Uranium and Steel	Borated Water Antifreeze
NLI-1/2	Truck	21.4	1/2	Helium	452/32	10.6	Lead, Uranium, and Steel	Water/Glycol
NLI-10/24	Rail	86.6	10/24	Helium	464/114	70	Lead, Uranium, and Steel	Water/Glycol
TN-8	Truck/Rail	35.7	3 PWR	Air	427/170	35.5	Lead and Steel	Borated Solid Resin
TN-9	Truck/Rail	33.9	7 BWR	Air	452/170	24.5	Lead and Steel	Borated Solid Resin
TN-12	Rail	95.5	12/32	Air	465/249	135	Steel	Borated Solid Resin
GE IF-300	Rail	60.7	7/18	Water/ Air	458/95.2	61.5	Uranium and Steel	Water/Glycol

NAC Nuclear Assurance Corp.
NFS Nuclear Fuel Services
NLI National Lead Ind.
TN Transnuclear
GE General Electric
IF Irradiated Fuel

TABLE IV

Characteristics of Western European Spent Fuel Casks

Type	NTL 2	NTL 3	NTL 4	NTL 5	NTL 8	NTL 9	NTL 10	NTL 11	NTL 12	NTL 14	Exl 13/3A	Exl 14	SGHWR
Competent authority approval No.	F 59	1106	1132	1124		F 136 A		1146		1154	1126/1141	1147	1120
Owner	NTL	NTL	NTL	NTL	NTL	NTL	NTL	NTL	NTL	NTL	BNFL	BNFL	UKAEA
Capacity													
PWR (assemblies/mm)	4/200	7/200	7/200	7/200	3/215	-	12/230	7/215	12/215	5/230	5/215	5/215	2/197
BWR (assemblies/mm)	9/114	-	19/114	12/140	-	7/140	-	17/140	30/140	-	14/140	14/140	10/127
Thermal capacity (kW)	15	30	35	35	35	25	100	42	100	50	30	40	20
Total weight (t)	32	52	65	69	36	34	104	75	95	82	72/72.5	100	45
Payload (t U)	1.1	2.0	2.3	2.3	1.4	1.4	6.2	3.3	5.7	2.7	2.7	2.7	1.8
Cavity length (mm)	3875	3380	4370	4675	4280	4520	5050	4630	4580	5160	4674/4776	4887	4420
Cavity diameter (mm)	440	864	864	864	3x230	474	1220	914	1220	914	864	914	610
Primary coolant	Air	Water	Water	Water	Air	Air	Air (water)	Water	Air (water)	Water	Water	Water	Water
Primary mode of transport	Road	Rail	Rail	Rail	Road	Road	Rail	Rail	Rail	Rail	Rail	Rail	Railroad
Approval status	Licensed	Licensed	Licensed	Licensed	Licensed	Licensed	Pending	Licensed	Pending	Licensed	Licensed	Pending	Licensed
Flasks operating	2	3	1	1	2	2	-	-	-	-	3/4	-	1
Flasks under construction ordered	-	1	-	-	-	-	1	2	1	2	-	Pending	-

BNFL British Nuclear Fuels Limited
EXL Excellox
NTL Nuclear Transport Limited
SGHWR Steam-Generating Heavy-Water Reactor
UKAEA United Kingdom Atomic Energy Authority

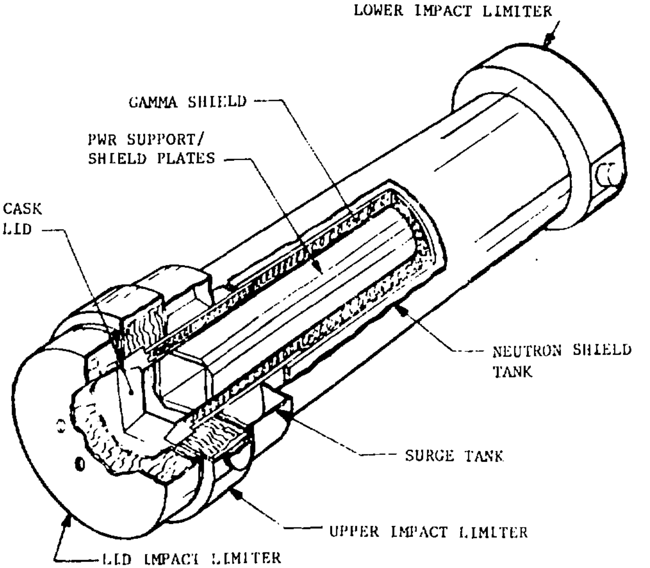
For the purposes of this baseline document, detailed cask descriptions will be limited to one representative cask for road transport and one for rail transport.

Baseline Truck Cask

The baseline truck cask is shown in Figure 34 together with fuel data when loaded with PWR or BWR assemblies.

The fuel is supported by interchangeable fuel baskets inside of a cylindrical inner cavity. The cavity is filled with air when shipping assemblies with a thermal power below 2.5 kW and it is filled with water when the power is between 2.5 and 11.5 kW; the upper limit for this cask is 11.5 kW. By convection, heat is transferred from the spent fuel assembly surface through water or air to a stainless steel inner liner, a lead gamma-ray shield surrounded by stainless steel, and a borated-water antifreeze neutron shield solution. This shield is designed with surge tanks to assure uniform water shielding thickness. The heat is conducted through the shields and transferred to the atmosphere by radiation and convection. No active cooling system is used.

The inner cavity is closed by a stainless steel cask lid which seals and shields the cask cavity. It is attached to the cask by six high-strength bolts. Two Teflon O-rings, arranged so that each may be pressure tested, provide the head seal. The sides of the cask are protected against impacts by permanently installed balsa wood structures encased in stainless steel, which are located at the cask trunnions. Similar impact limiters protect the cask base and cask head. The head impact limiter is removable and normally is unbolted from the cask before it is removed from the truck. Two sets of trunnions are used for normal cask handling and for transport tiedown purposes. The upper set is used for lifting the cask in conjunction with a special "swing arm" type yoke. The lower trunnions provide a gravity pivot for lowering the cask from the vertical loading position into the horizontal transport position.



Capacity	1 PWR Type or Fuel Assembly	2 BWR Type Fuel Assemblies
Fuel Data	1 PWR	2 BWR
Envelope Section, m	0.22 x 0.022	0.14 x 0.14
Envelope Length, m	4.50	4.50
Enrichment, % U-235	3.6	2.6
Weight Uranium, kg	447	358
Maximum decay heat, kW	11.5	11.5
Cask weight (loaded), tonnes	24	
Cask Envelope, m	1.2 diameter 6.0 length	

Figure 34. Baseline Spent Fuel Shipping Cask - Road Transport

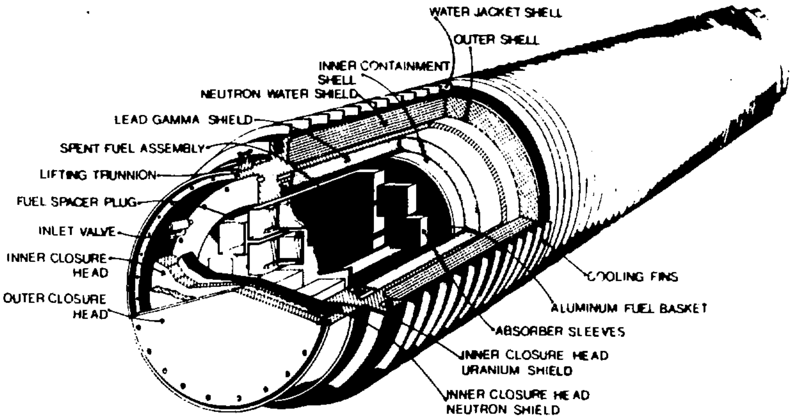
Baseline Rail Cask

The fuel is shipped "dry" in this cask in a closed helium system. Water cooling outside the inner cavity is used to lower fuel temperatures and reduce cool-down time at receiving facilities. Figure 35 shows the cask and gives a brief summary of its characteristics together with fuel data when loaded with PWR or BWR assemblies.

The inner cavity liner is a stainless steel cylinder surrounded by axial cooling channels. These are grouped into two independent systems which are filled with water and connected to independent diesel-powered cooling systems.

Outside the inner cylinder and its cooling channels is a lead gamma-ray shield and an annular neutron shield of water contained between stainless steel walls. Expansion tanks are provided to maintain integrity of the water shield under varying temperature conditions.

The cask is sealed by inner and outer closure heads with one penetration through the head end forging into the space between the closures. This penetration is used to drain water from between the inner and outer closures during loading operations. The inner closure head consists of a stainless steel forging, the center section of which is filled with depleted uranium and covered by a stainless steel plate welded to the forging. The bulk of the required gamma shielding is contained in the inner head to provide operator protection during handling of the loaded cask. The inner closure head is held in place by 20 bolts. The inner head seal is a metallic ring. There are four penetrations through the inner flange which are used for servicing the cavity of the cask. These penetrations are equipped with globe-type angle valves that are designed for maximum leak tightness under accident conditions. The outer closure head is a flat stainless steel plate held in place by 24 bolts. The single necessary service penetration is made through the end forging.



Capacity	10 PWR Type Fuel Assemblies or	24 BWR Type Fuel Assemblies
Fuel Data	10 PWR	24 BWR
Envelope Section, m	0.22 x 0.22	0.14 x 0.14
Envelope Length, m	4.36	4.48
Enrichment, % U-235	3.35	2.65
Weight Uranium, kg	4,470	4,300
Maximum decay heat, kW	97.2	88.8
Cask weight (loaded), tonnes	89.0	
Cask Envelope, m	2.2 diameter 5.2 length	

Figure 35. Baseline Spent Fuel Shipping Cask - Rail Transport

The outer closure head, which is the secondary containment boundary, also serves as a rugged valve box cover for the four service penetrations in the inner flange.

Road Transportation

The economics of roadway transport make high payload vehicles important for spent fuel shipping, but practical and regulatory constraints limit the usable gross combination weights of the transporter. As a result, road transportation of spent fuel represents a compromise in which specialized semitrailers become important. This section describes salient features of the vehicle loads, support systems, and operations for road transport of spent fuel assemblies.

Load Characteristics

Spent LWR fuel assemblies are packaged in the special shipping casks described earlier in this section. The loaded weight for these casks is about 22 tonnes.

Vehicle Description

The vehicle is powered by a standard lightweight tractor weighing about 6 tonnes. Gross weight limits imposed by state load laws permit combination weights of 33 tonnes for normal operations. Because cask weights run upwards from 20 tonnes, special trailers are used that have high strength-to-weight ratios and allow normal hauling. Figure 36 shows the baseline trailer.

The baseline design trailer uses a weight efficient truss structure of square tubing together with aluminum wheels, tubeless tires, single leaf springs, an aluminum fence and roof, and aluminum support legs. Overall unloaded weight is about 3.4 tonnes. Tubing welds on high tensile stress members comply with pressure vessel standards, and gussets are used to prevent fatigue cracks. The

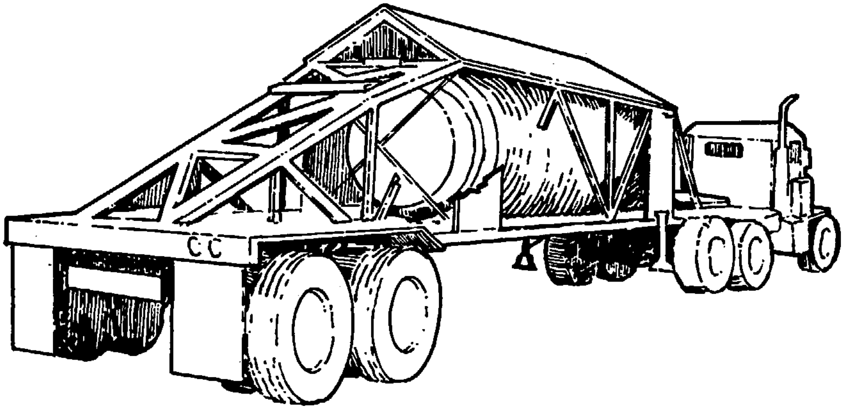


Figure 36. Road Transport Configuration

truss tubing is pressurized to 17,600 kg/m^2 and fitted with a valve to permit periodic monitoring of pressure. Loss of pressure indicates cracks or weld failure.

Vehicle Loading and Unloading

Since the cask for the baseline road transportation system has restrictions specifying the maximum permissible decay heat generation rate of the material to be shipped, this rate is determined by measuring the coolant temperature shortly after the cask has been loaded with the spent fuel. Pressure checks are also made and correlated with test data. These checks include a 10-minute pressurization of the annulus between the double O-ring seals and pressurization of the inner cask cavity. The pressure of these regions is raised to about 62,000 kg/m^2 and then monitored for 10 minutes and vented. Should a leaky O-ring or cavity valve be detected, the cask is repaired using a parts kit furnished by the manufacturer; replacement of valve seals, seats, and O-rings normally requires about 1 hour.

When the cask is cleared for shipment, it is loaded into its shipping cradle on the road transporter following the sequence of steps given below. The unload procedure follows similar steps in the reverse order. The loading operations flow is shown in Figure 37; these operations include:

1. The transporter trailer is positioned in the loading area at a predetermined location accessible by an overhead crane of at least 30-tonne capacity.
2. The trailer is prepared to receive the cask. The cask shed is removed, holddown mechanisms are checked, cradle locks are released, and trunnion bearing points made ready to receive the cask.
3. The crane is positioned above the lifting yoke storage rack, lowered, and the crane hook is mated to the eye of the yoke.
4. The yoke is secured to the crane hook, lifted, and moved to a position above the cask.

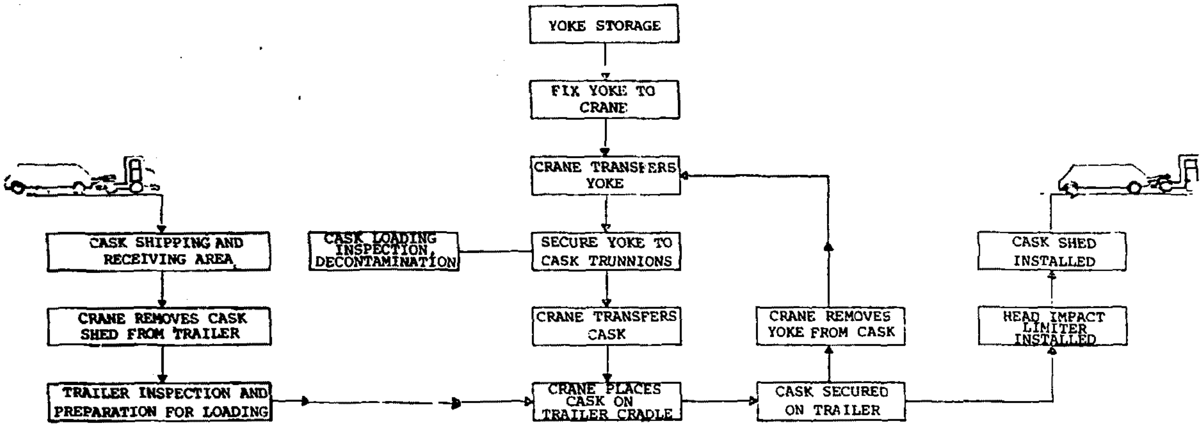


Figure 37. Loading Operations Flow -- Road Transportation Vehicle

5. The yoke is lowered to the cask and the yoke arms are positioned to contact the cask trunnions for lifting.
6. The yoke is secured to the cask and the cask is raised and moved to a position above the trailer.
7. The cask is lowered to a position just above the base trunnion bearings of the cask cradle.
8. The lower cask trunnions are mated to the base trunnion bearings and secured.
9. The cask is lowered to the horizontal shipping position and the top trunnions are secured in their cradle bearings.
10. Cradle position locks are engaged.
11. The yoke arms are removed from the cask trunnions and the yoke is moved to storage in its support rack.
12. The cask head impact limiter is bolted to the cask.
13. The transporter cask shed is put in place.

Essential Support Systems

No essential support systems are carried on the vehicle.

Rail Transportation

Rail transport is particularly well suited to shipment of large quantities of spent fuel in the multiple fuel assembly casks described earlier. A flatbed rail car can be adapted to carry one rail cask and its associated cooling systems (see Figure 38).

Load Characteristics

Using the baseline cask, each rail car will carry 10 PWR or 24 BWR assemblies. The fully loaded baseline rail cask and associated cooling systems represent a gross load of about 106 tonnes.

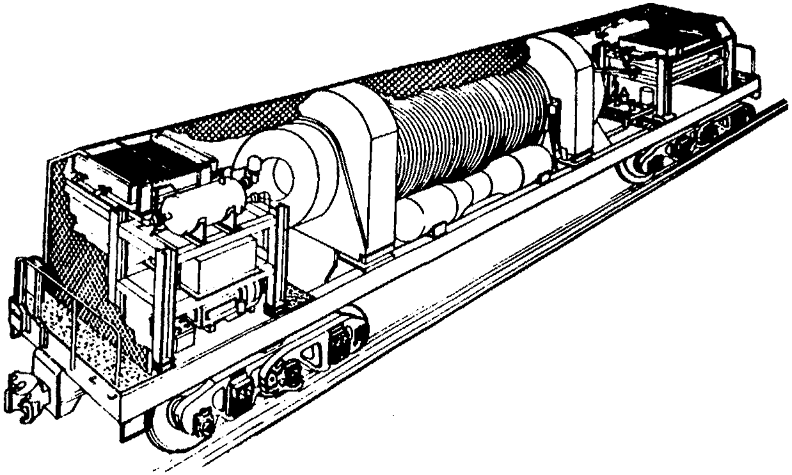


Figure 38. Rail Transport Configuration

Vehicle Description

While some casks are shipped in a special skid mounted enclosure which adapts them to ordinary 90-tonne capacity flat cars, the baseline rail cask is shipped on a rail car with a cask tiedown arrangement built into the car frame. The 18-metre rail car, using 6-wheel trucks, has two redundant water circulation systems with water-to-air heat exchangers. Power is supplied by diesel generators. An aluminum mesh shed covers both cooling systems and the cask. A tilting cradle is part of the holddown mechanism.

Vehicle Loading and Unloading

As licensed, the baseline rail cask requires pretransportation checking of the pressure integrity of the head closure. The pressure integrity is checked by pressurizing the space between the inner and outer head closures. The pressure is vented after 10 minutes. Operational checks of the cooling system are performed before and after the cask is loaded, as indicated in the following sequence of loading operations. Unloading operations follow analogous steps in the reverse order. The loading operations flow is shown in Figure 39; the operations include:

1. The rail transport car is positioned for access by a crane of 110 tonnes or greater lifting capacity.
2. The rail car shed is removed by the crane and set aside.
3. The cooling systems and diesel generators fixed to the rail cars are tested and diesel fuel levels are checked.
4. The car is decontaminated as necessary.
5. The crane is positioned above the yoke storage rack and lowered to mate the crane hook with the lifting yoke eye.
6. The lifting yoke is secured to the crane hook, raised, and positioned over the cask.
7. The lifting yoke is lowered to the cask and the yoke arms are secured to the upper cask trunnions.
8. The cask is raised and positioned over the rotatable support cradle base.

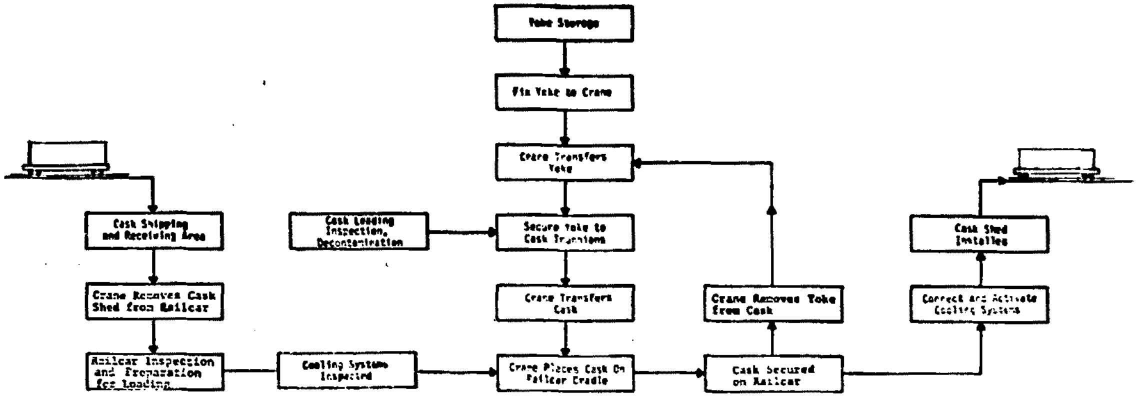


Figure 39. Rail Transportation Vehicle -- Loading Operations Flow

9. The cask is lowered and the bottom cask trunnions are guided into position in the support cradle and secured.
10. The cask is lowered to the horizontal shipping position and the upper cask trunnions are secured to the support cradle.
11. Support cradle position locks are engaged.
12. The yoke arms are removed from the cask trunnions and the yoke is moved to the yoke storage rack.
13. The cooling system water lines are attached to the cask through the service penetration of the end forging.
14. The cooling system is activated and the water temperature monitored until it stabilizes.
15. The aluminum shed is raised by crane and returned to its mounts on the rail car and secured.

Essential Support Systems

No essential support systems are carried on the rail car. The forced convection cooling systems referred to above are only provided to minimize cask cooldown time at receiving facilities.

Barge Transportation

The transport of spent fuel by barge/tug combinations is a potentially attractive alternative to long distance hauling by road or rail, especially for shipments between facilities that have private property access to inland waterways. The spent fuel can be loaded to or from the barge by two fundamentally different techniques, one using heavy cranes and the other using roll-on/roll-off transfer methods. The paragraphs that follow describe barge transportation systems for both these alternatives. Representative barge transport configurations correspond to the two types of loading procedures and are shown in Figures 40 and 41.

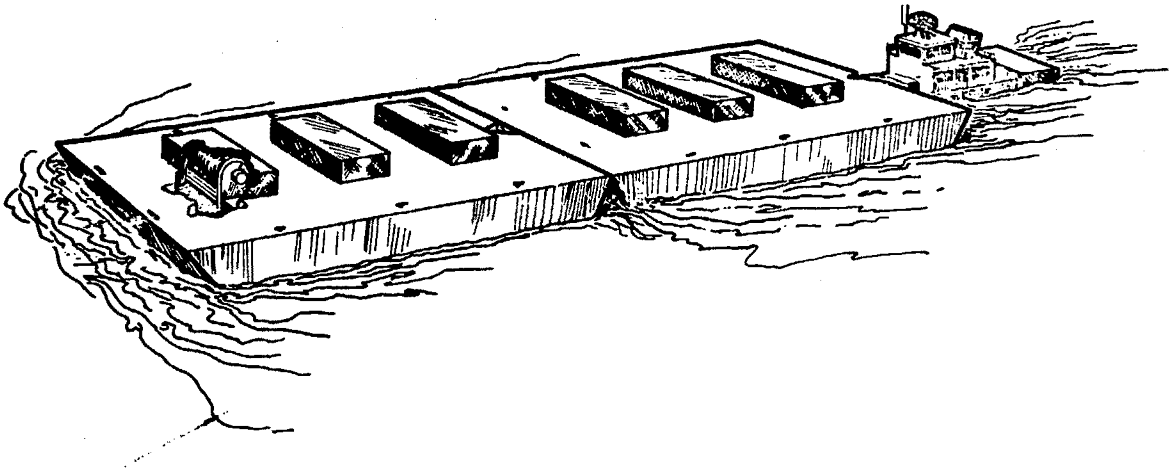


Figure 40. Barge Transport Configuration
(crane loaded)

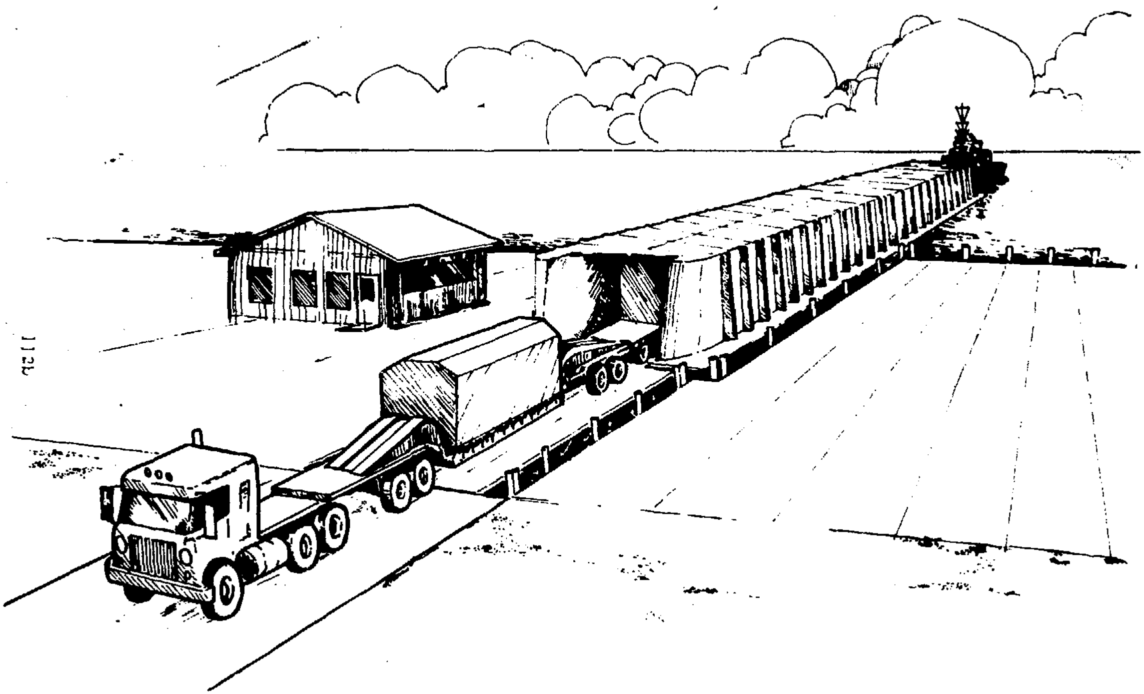


Figure 41. Barge Transport Configuration (roll-on/roll-off)

Characteristics of the Barge Load

A typical barge load will consist of three large rail casks mounted in support cradles, together with their associated cooling systems. For a crane-loaded barge the support cradles and cooling systems are integral to the bed of the barge and only the cask is handled by the crane. For a roll-on/roll-off barge the casks, support cradles and cooling systems are integral to road or rail vehicles which are moved over a leveling bridge to the barge, and remain on board during shipment.

Description of the Barge

Existing Class I barges are suitable for either type of barge transportation system. Such a barge would be steel, double hulled, have individually ballastable compartments, and outside dimensions of about 13 metres width, 30 to 50 metres length, and 4 metres at the side with a fully loaded draft of 2 to 3 metres. For increased stability and maneuverability the barge could be notched or fitted with a semirigid tug linkage. The barge would be enclosed to provide protection from salt spray and fully ventilated to allow continuous operation of the diesel-powered cask cooling systems. The barge would normally be pushed by the tugboat.

Barge Loading and Unloading

Dockside procedures for a crane-loaded barge are described in the following paragraph. Roll-on/roll-off procedures are also summarized.

Crane Loading and Unloading -- Crane loading of a barge begins with normal pier procedures in which the barge is pushed into a barge slip by a tugboat. A dockside crane is used for loading; a similar sequence is used for unloading, with the principal steps reversed. The loading operations flow is shown in Figure 42; the loading operations include:

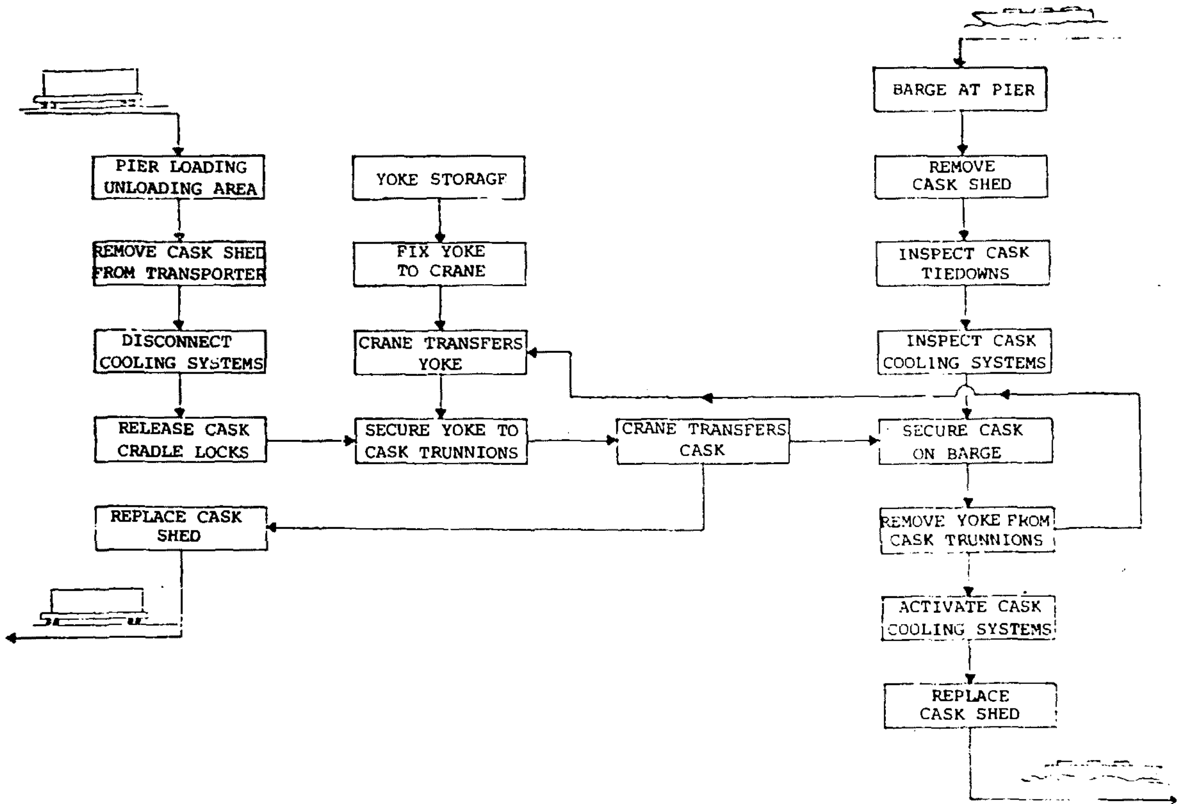


Figure 42. Barge Crane Loading Operations Flow

1. Incoming transport vehicles have their cask sheds removed by a crane and placed out of the way on the pier.
2. The cask cooling systems on the incoming transporters are turned off.
3. Cask cradle locks are released.
4. The cask lifting yoke is secured to the crane hook.
5. The yoke is positioned at the cask and the yoke arms secured to the upper cask trunnions.
6. The cask is raised to the vertical position and lifted from the incoming transporter.
7. The cask is moved to a position above one of the cargo areas of the barge.
8. The cask is guided into a support cradle in the cargo area.
9. The lower cask trunnions are secured to the cradle trunnion bearings.
10. The cask is lowered to the horizontal position and the upper trunnions are secured.
11. The cask cradle locks are engaged.

Roll-on/Roll-off Loading and Unloading -- Roll-on/roll-off procedures involve transferring a road or rail vehicle to the barge across a leveling bridge. A variety of techniques can be used depending upon facilities available at the barge slip. The vehicle may be pushed onto the barge while the bridge span is adjusted to the level of the barge deck. When a rail car is transferred to a barge fitted with rails, extra rail cars are used for spacing so that the weight of the switch engine is not carried by either the bridge or barge. Alternatively, the rail car bed may be put on large wheeled dollies and moved by a heavy hauling tractor or the rail car can be positioned using a winch on board the barge. After the transfer, the mobile transporter is secured to the barge with tie downs.

Essential Support Systems

The redundant cooling systems for barge transport of casks are similar to those of the rail transport system.

Ship Transportation

This section contains a discussion of the load characteristics, vessel, loading and unloading operations, and essential support systems for the baseline ship transportation system for spent fuel -- a small dedicated commercial freighter fitted with cask support cradles, venting facilities, and cask cooling systems.

Load Characteristics

The vessel load consists of spent LWR fuel assemblies contained in road or rail casks. This ship has provisions for a cargo load of 3 road casks and 12 rail casks. Since cooling facilities are included aboard the ship, the auxiliary cooling systems that travel with rail casks on their rail cars need not be transshipped.

Vessel Description

The vessel is a low tonnage freighter of approximately 3000 to 5000 tonnes dead weight. The main hold is fitted with tanks of demineralized water which are refrigerated to 12° C to provide coolant for water cooled casks. A second hold near the bow of the ship is served by a refrigerated ventilation system for air cooled casks. Ventilation systems for the holds are separate from those servicing other areas of the ship. A vessel of this general type is currently used in foreign international shipments of spent fuel. This type of ship is shown in Figure 43.

Vessel Loading and Unloading

The vessel will dock at the port nearest the reactor, storage, or reprocessing facility being served. Normal refueling and all

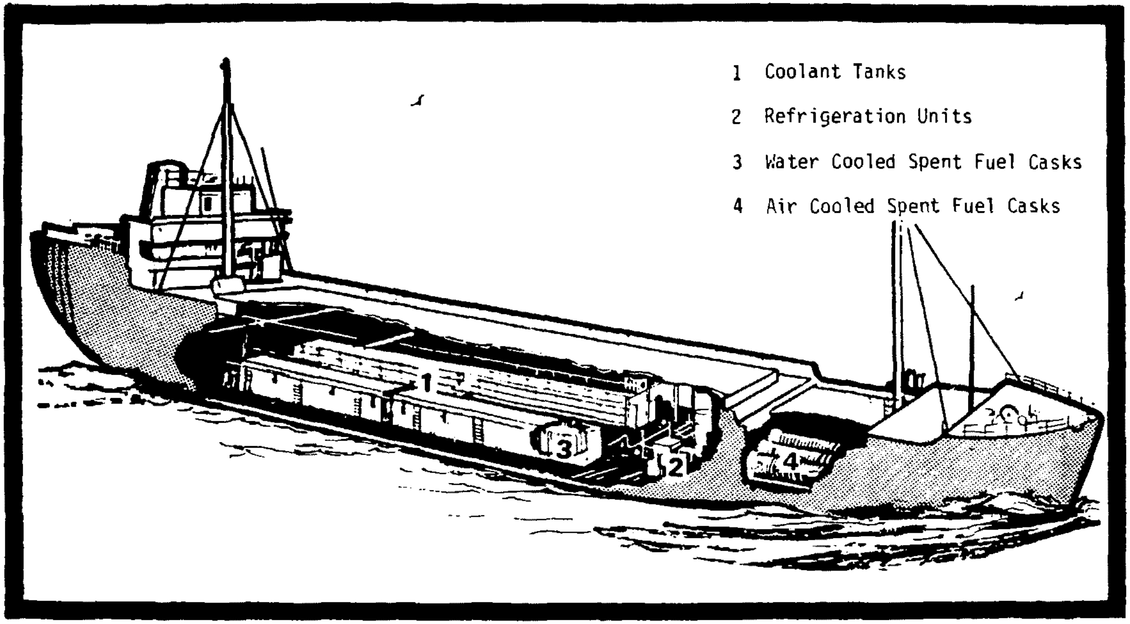


Figure 43. Ship Transport Configuration

necessary ship maintenance is performed before the spent fuel is brought aboard. The following loading procedure is then followed using dockside cranes of suitable capacity. Unloading is done similarly with the sequence of steps reversed. The loading operations flow is shown in Figure 44 and includes:

1. Hatch covers above the holds are removed from their intransit positions and cask sheds are removed from the transporters.
2. Cask cooling systems on the incoming transporters are turned off and disconnected from the cask.
3. Cradle locks are released.
4. The crane's hook is positioned above the cask handling yoke storage rack at the rear of the main hold.
5. The yoke is positioned at the cask and the yoke arms are secured to the upper cask trunnions.
6. The cask is raised from the transporter and moved to a position above one of the onboard cask cradles.
7. Casks cooled by immersion are positioned in cradles within the demineralized water tanks. Casks cooled by internal flow through coolant channels within the cask are positioned in cradles external to the tanks, after which they are connected to the water circulation system by flexhose connectors.
8. Casks cooled by internal air flow are positioned in cradles in the forward refrigerated hold.
9. Yoke arms are released from the cask trunnions, and the yoke is moved to the next cask to be transferred.
10. When all casks are onboard, the yoke is returned to storage and the hatch covers are refitted above the holds. Transporter sheds are replaced and secured.
11. The ship is moved by tugboat to open water.

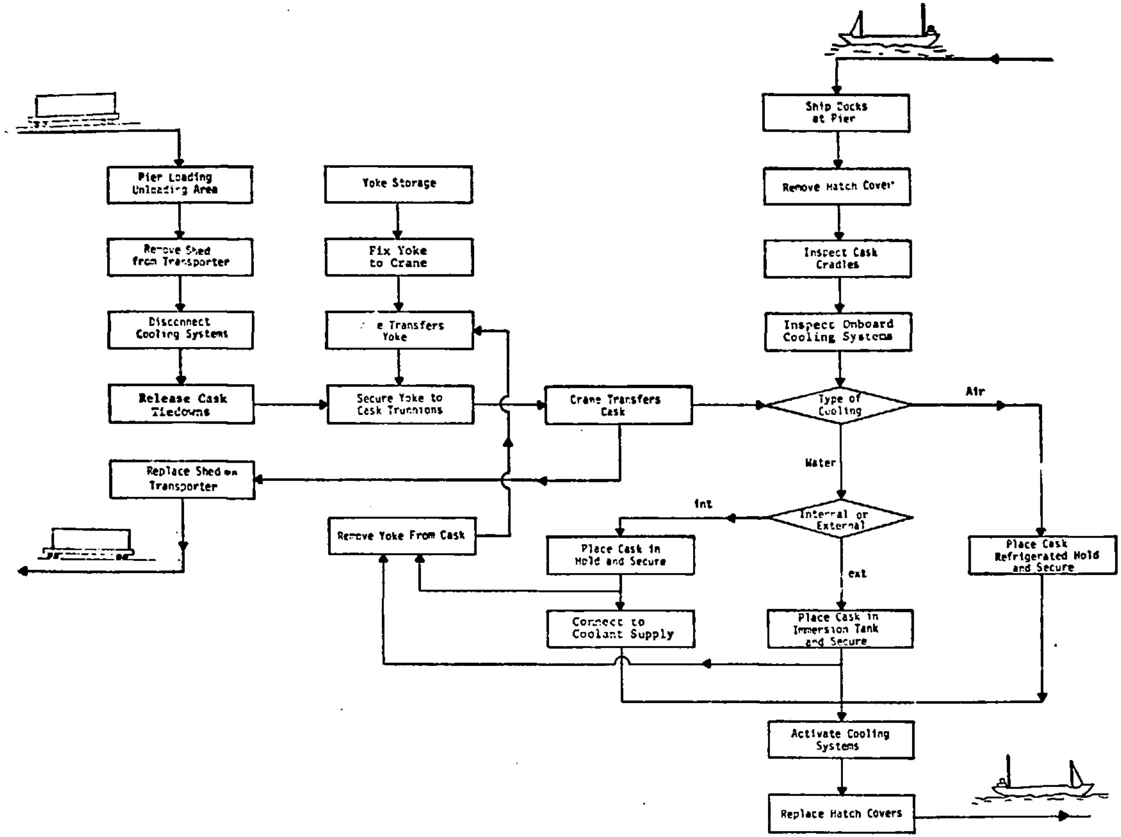


Figure 44. Ship Loading Operations Flow

Essential Support Systems

The essential support systems for ocean transport of spent fuel are the demineralized water system that provides heat transfer between the spent fuel and the cask wall, the refrigeration systems servicing the coolant tanks and the refrigerated hold, and the onboard electrical system. Standby diesel generators are provided to supplement the ship's primary electrical generation system, and supplemental refrigeration equipment is available to ensure continuous operation of the cask cooling equipment. The ship's machine shop has the capability of performing emergency repairs for all critical ship's systems.

The hold is also provided with facilities for venting gas produced by radiation hydrolysis within casks. If it is necessary to release a buildup of pressure in one of those casks, vented gas is passed through an HEPA absolute filter and is discharged through a vent pipe which extends from the hold to the top of the ship's mast.

Intermodal Transfer Alternatives

This section outlines methods for intermodal transfer which could be used to facilitate loading and unloading of spent fuel when the shipment is changed between road, rail, barge, or ship carriage. The methods presented include a range of concepts, some of which are in current use for the transportation of spent fuel. The remaining concepts are based upon transportation industry practices that are either currently in use for other kinds of freight shipments or have been specifically proposed within the nuclear transportation industry as reasonable intermodal transfer concepts.

Road/Rail Transfers

Characteristics of road/rail transfers include:

1. Three road casks could be transferred by crane to or from a single standard rail car outfitted with compatible cask cradles.
2. Casks and cradles could be transferred as a unit to or from the rail car. The cradles could be integral to steel shipping skids.
3. Two truck trailers with their loads of one truck cask each could be piggybacked onto a single rail car.
4. Special road permit hauling of loaded rail casks on heavy duty trailers could be used for short distances when a rail head is located near enough to the facility.
5. For use in special situations, a rail car could be made with its wheel trucks replaceable to multiaxle road dollies as shown in Figure 45.

Road/Barge Transfers

Characteristics of road/barge transfers include:

1. The crane loading procedures given for the dedicated barge could be used.
2. Casks with cradles integral to steel shipping skids could be transferred by crane to conventional barges outfitted with auxiliary cooling systems to service the casks.
3. Road trailers could be transferred by a roll-on/roll-off method through the use of an elevator leveling bridge connecting the loading dock with the barge.

Road/Ship Transfers

Characteristics of road/ship transfers include:

1. Conventional spent fuel ship loading procedures could be used.

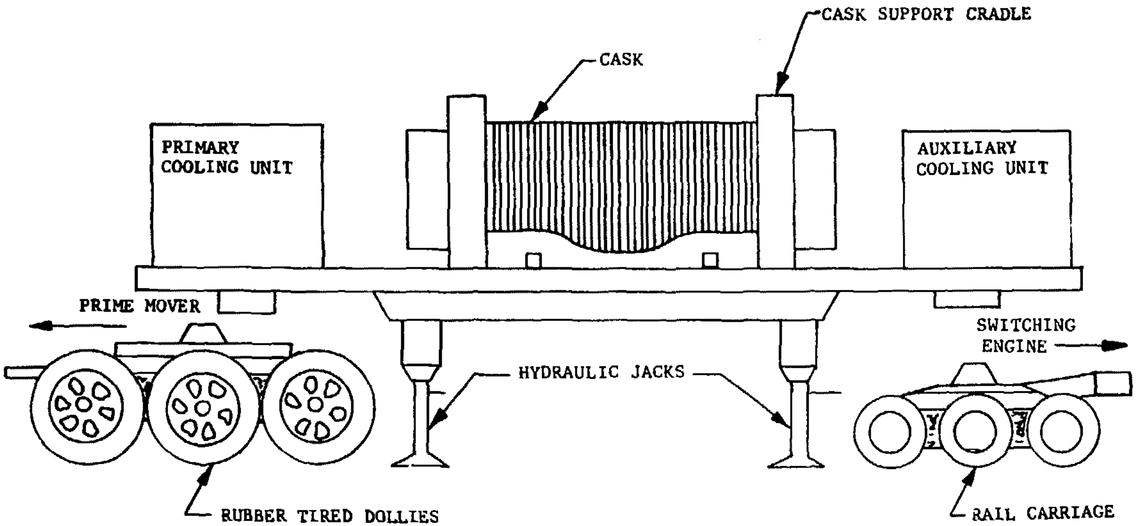


Figure 45. Road/Rail Intermodal Alternative Concept

2. The casks could be left on their trailers if sufficient capacity cranes were available at both ends of the ship's voyage. Road casks would require auxiliary cooling when enclosed in the hold of a ship.
3. Roll-on/roll-off procedures could be used with larger ships.

Rail/Barge Transfers

Characteristics of rail/barge transfers include:

1. The barge transfer procedures described earlier could be used.
2. A roll-on/roll-off procedure could be used by providing rails on the barge and leveling bridge between the pier and barge. A winch cable could be used to move the rail car across the bridge and onto the barge.
3. A road/rail transfer could be combined with a roll-on/roll-off procedure by heavy haulers to and from the barge.

Rail/Ship Transfers

Characteristics of rail/ship transfers include:

1. The ship loading procedures could be used.
2. The transshipment alternatives described under rail/barge transfers have analogs which could be adapted for rail/ship transfers.
3. When the rail car has removable wheel trucks and sufficient capacity cranes are available, the rail car bed could be used as a shipping pallet to transfer the cask and its cooling systems to the ship.

Barge/Ship Transfers

Characteristics of barge/ship transfers include:

1. Loading and unloading procedures could be combined to effect the transfer.

2. Smaller barges holding one or two casks could be used directly as shipping containers and lifted aboard special ships having large capacity on board gantry cranes, as is currently done for some types of bulk cargos.

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