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NEAR SURFACE SPENT FUEL STORAGE - ENVIRONMENTAL ISSUES

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INTRODUCTION

Present U.S. policy regarding spent light water reactor fuel emphasizes alternatives to reprocessing of spent fuel, particularly the alternatives of interim storage and/or ultimate disposal of spent fuel as waste. In any event, interim storage of spent fuel apppears inevitable, because reprocessing plants or spent fuel repositories are not currently available to receive spent fuel.

The spent fuel storage capacity at nuclear plants has been conventionally designed to accommodate one full core plus one discharge or essentially 1-1/3 cores. The basis for this design was the assumption that the spent fuel from a given discharge would be shipped offsite for reprocessing before the next annual discharge took place and that additional storage capacity of one fuel core would be maintained should it become necessary to unload the whole reactor. Most reactor storage basins were equipped with storage racks that because of conservative design did not fully utilize the available space and as a consequence, in many cases the spent fuel storage basin capacity may be increased by a factor of up to about 2.5.(1) Thus better use of existing facilities through reracking of storage basins is one route to additional spent fuel storage capacity. Discontinuance of the full core reserve policy by utilities would also permit additional spent fuel storage

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(1) Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Reactor Fuel, NUREG-0404, U.S. Nuclear Reg. Comm., Wash., D.C., March 1978.

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capacity without construction of additional facilities. However, this would seem advisable only in an emergency since the full-core reserve space is prudent for flexibility of plant operation.

Additional near term independent spent fuel storage facilities could be built either near to or remote from a reactor. The former is representative of the so called At Reactor Storage concept, and the latter has been referred to as Away From Reactor storage or as an Independent Spent Fuel Storage Facility. These options are illustrated in Figure 1. Also illustrated in Figure 1 is the concept of transshipment, where fuel from a reactor that has an inadequate storage capacity is moved to another reactor which has excess storage capacity.

Building spent fuel storage facilities that could extend the storage period for many decades is also technically feasible. The movement of spent fuel in this option is illustrated in Figure 2. In this case, spent fuel,

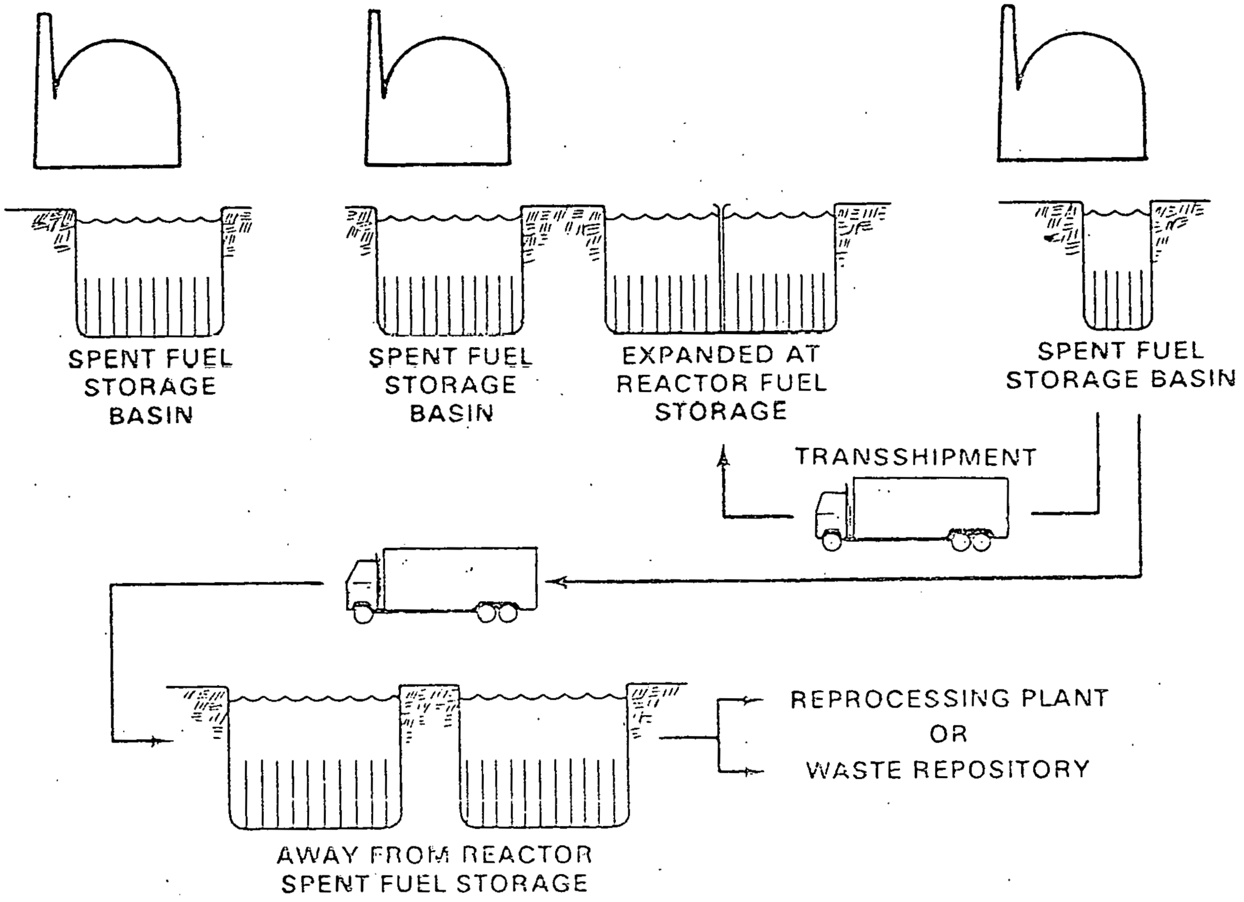

FIGURE 1. Near Term Spent Fuel Storage

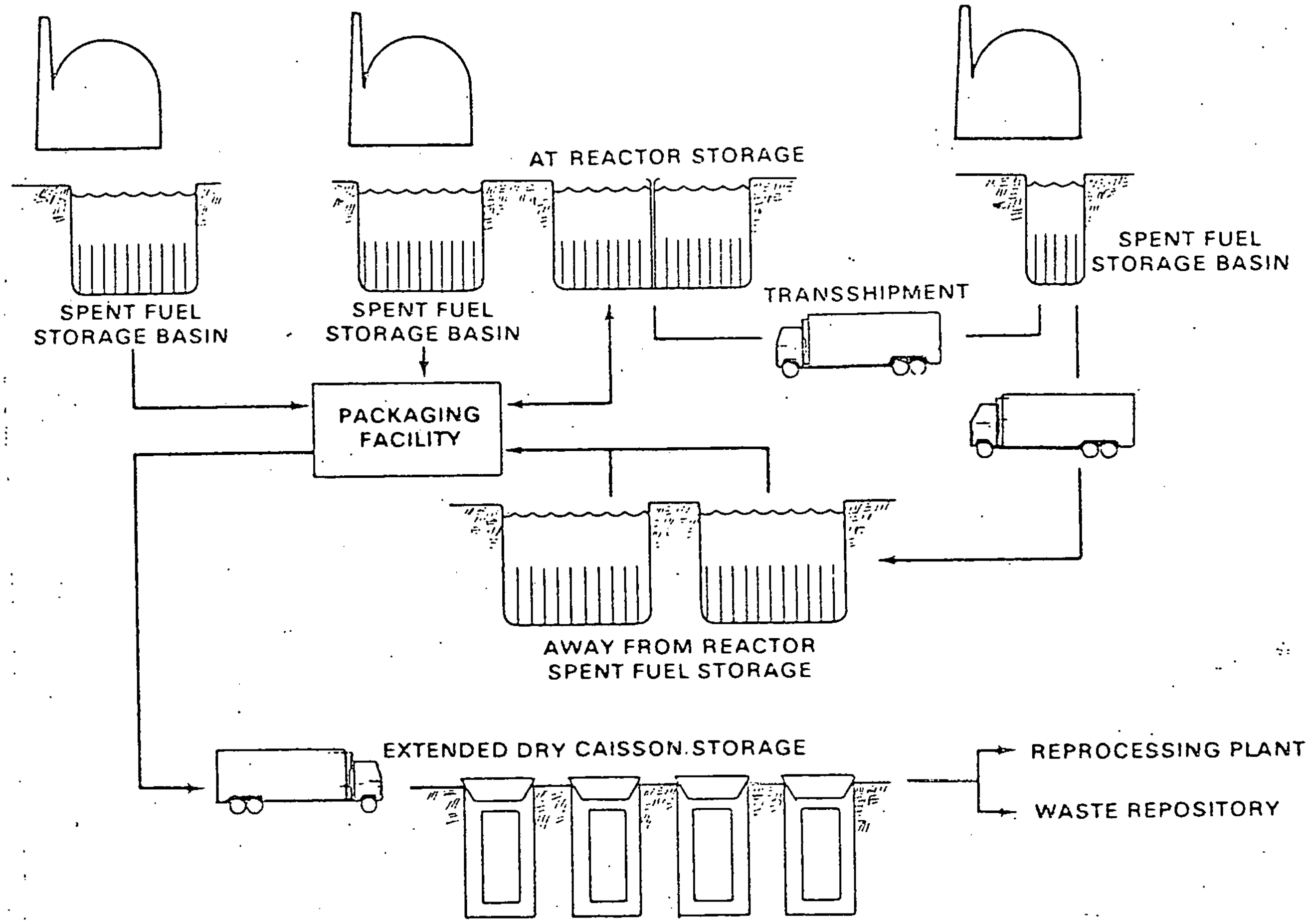

FIGURE 2. Extended Term Spent Fuel Storage

whether stored in reactor basins, at an expanded storage at the reactor, or at an independent spent fuel storage facility (Away From Reactor Storage) is sent to a packaging facility which most likely would be built in conjunction with an independent spent fuel storage facility. After packaging, the fuel is transported to an Extended Term Fuel Storage Facility. Several storage concepts are available.

This paper presents results of an examination of the environmental issues potentially associated with management of spent fuel before disposal or reprocessing. Whether for short term or extended term, this storage is referred to, in general, as interim near surface storage of spent fuel.

REFERENCE POWER SCENARIO

The nuclear power growth scenario used for reference in this paper is that used in the Generic Environmental Impact Statement on Management of Commercially Generated Radioactive Wastes (CWM-GEIS), DOE/EIS-0046D, April 1979.(2) The light water reactor nuclear power industry was postulated to grow from present capacity of about 55 GWe to 400 GWe in the year 2000 and then the plants phased out such that no power was produced by these LWRs by about 2040. The total energy production for the 70-yr period was about 10,000 GWe-year. The total amount of spent fuel handled in this power scenario was 379,000 t(HM) (heavy metal). The rate of discharge of this fuel peaks in 2010 and decreases to zero in 2040. Spent fuel intended for extended storage is packaged in canisters.* To avoid overheating, the fuel is aged for 6-1/2 years prior to packaging. In any event, spent fuel is cooled for a minimum of 6 months before shipping. For the purposes of this analysis, it was assumed that three-fourths of all fuel would stay at the reactor from which it was discharged for 6-1/2 years. The remaining one-fourth of the fuel would remain in reactor basin storage for 1/2 year and would then be sent to an Away From Reactor Storage Facility for 6 years. At that time the fuel would be sent to either an Extended Term Spent Fuel Storage Facility, a reprocessing plant or to a waste repository. In the event that reprocessing is permitted, fuel might be processed as soon as one year after discharge from reactor. Once at an Extended Term Spent Fuel Storage Facility the fuel is assumed to remain there for 30 years. (Thirty years is an arbitrary period chosen to place some bound on the period of analysis.) The simplifying assumption is made that all 379,000 t(HM) requires the 6-1/2 years short term water basin storage somewhere followed by 30 years storage at Extended Term Storage Facilities.

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* Extended interim storage of unpackaged spent fuel in water basins is also feasible.

SUMMARY AND CONCLUSIONS

As stated in several recent documents pertaining to spent fuel storage(1,2,3) and as developed in this paper the environmental impacts associated with the storage of spent fuel are small. As a consequence there appear to be no serious issues related to near surface interim spent fuel storage per se (sociological, institutional or political issues are not treated). The radiological impacts of spent fuel storage are limited to low-level releases of noble gases and halogens (principally iodine), which even in the most serious design basis accidents would not have a significant impact on the health and safety of the public (accidents envisioned here would be the drop of a fuel bundle, rupture of fuel elements as a result of a tornado striking the unpackaged fuel storage area, or criticality).

Other environmental impacts are mainly related to the construction of storage facilities. Land use, resource commitments, and socioeconomic effects are expected to be reasonably in line with the needs of other industrial undertakings of similar size. A possible but manageable issue would be related to the water required for water basin storage of spent fuel. In the CWM-GEIS a reference environment was developed on which comparisons of resource use could be made. There, the nearby river flowed at a rate of about 4×10^9 m^3/yr. On the order of 3×10^5 m^3 of water is required annually for process needs and cooling tower makeup. Thus, so long as streams of at least that size are available for spent fuel storage needs, no significant effect on aquatic life or other downstream uses would be expected.

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(2) Generic Environmental Impact Statement on Management of Commercially Generated Radioactive Wastes, DOE/EIS-0046D, April 1979.

(3) Storage of U.S. Spent Power Reactor Fuel, DOE/EIS-0015D, DS, December 1978.

In relation to licensing applications for expanded storage, the environmental issues voiced by concerned citizens deal principally with impacts associated with severe transportation accidents and sabotage of spent fuel, again principally during shipment. Although shipment is not storage, the location of spent fuel storage facilities will govern in a large part the amount of shipping required, the distances travelled and consequently the likelihood of involvement in an accident. Contentions seem to be focused on severe accidents. In the CWM-GEIS the worst accident postulated for spent fuel shipment involved loss of cavity coolant from a spent fuel rail cask but where no immediate remedial action was taken. This resulted in overheating and release of radioactive material at ground level over a six-hour period. The dose to the maximum individual was calculated to be 120 rem the first year and the population (2.6 million people) dose over 70 years was calculated to be 140 man-rem. At a dose of 120 rem the individual exposed has a small chance of experiencing symptoms of acute radiation sickness and may develop radiation related health problems in the long term. The population dose is equivalent to the population being exposed for about 6 additional hours of natural background radiation.

There is, however, another argument in favor of minimized transport and that relates to the frequency of injuries and fatalities not related to radioactive cargo but based simply on accidents as a function of distance travelled. In the CWM-GEIS an injury rate of about 0.4 injuries and 0.04 fatalities/million km travelled were used. Shipment of all fuel (379,000 t(HM) in the GEIS scenario) just to an ISFSF for storage and/or packaging would result in about 560 million km travelled (by both rail and truck) with an expectation of about 220 injuries and 22 fatalities. Thus minimizing distances spent fuel must be shipped would reduce traffic related injuries and fatalities and is an important consideration. Minimizing transport would call for maximizing storage at reactors until it is to be sent to a reprocessing center or waste isolation repository. Where the independent spent fuel storage facility is to be used it should be located centrally for a given group of reactors. If extended storage is to be elected it too should be at a location that will minimize transport of fuel.

NEAR TERM SPENT FUEL STORAGE

The facility described in conjunction with near term storage is the independent fuel storage facility (ISFSF) with packaging capability.(4) Variations between the ISFSF and an At Reactor Storage Facilities (ARSF) are taken to be sufficiently small that the environmental effects(5) associated with the ARSF could be estimated by ratio of amount of spent fuel stored to that of the ISFSF. Thus for example, radiological effects are summarized based on the estimated ISFSF releases but include all fuel stored in water basins, regardless of location.

FACILITY DESCRIPTION AND ENVIRONMENTAL EFFECTS OF CONSTRUCTION AND OPERATION

In the reference scenario eight ISFSFs are to be built and operated for 30 years. For purposes of impact estimates of these facilities on land and water use, facilities were assumed to not be colocated. For purposes of conservative estimates of radiological impact, all facilities were assumed to be colocated for routine operations. Resource commitments were combined for the 8 plants.

The ISFSF in the reference system uses storage in water basins for 3000 t(HM) of unpackaged fuel. The packaging facility is rated at

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(4) Technology for Commercial Radioactive Waste Management, DOE/ET-0028, May, 1979.

(5) Environmental Aspects of Commerical Radioactive Waste Management, DOE/ET-0029, May, 1979.

2000 t(HM)/year. For purposes of environmental analysis, the water basin storage facility and the packaging facility are treated as one unit.

Resource Commitments

A single ISFSF will require an area of about 400 ha and eight will occupy a total of about 3200 ha. Resources committed for construction and operation of eight ISFSFs and packaging facility are listed in Tables 1 and 2, respectively.

TABLE 1. Materials Committed for Construction of Eight Independent Spent Suel Storage Facilities

	Storage	Packaging	Total
Resource			
Concrete, m^3	1.8×10^5	1.8×10^5	3.6×10^5
Steel, t	8.8×10^4	3.6×10^4	1.2×10^5
Stainless Steel, t	4.9×10^4		4.9×10^4
Copper, t	2.2×10^2	1.4×10^2	3.5×10^2
Zinc, t	5.2×10^2		5.2×10^2
Lumber, m^3	1.0×10^4	1.5×10^4	2.5×10^4
Water, m^3			1.0×10^5
Energy			
Propane, m^3	4.6×10^3	3.0×10^3	7.6×10^3
Diesel Fuel m^3	4.6×10^4	3.0×10^4	7.6×10^4
Gasoline, m^3	3.0×10^4	2.1×10^4	5.1×10^4
Electricity			
Peak Demand, kW	1.2×10^4	1.0×10^4	2.2×10^4
Total Consumption	2.2×10^7	1.4×10^7	$3/7 \times 10^7$
Manpower, man-yr	2.0×10^4	1.2×10^4	3.2×10^4

TABLE 2. Utilities and Materials Required for Planned Operation of Eight Independent Spent Fuel Storage Facilities

Resource	Average Annual Use Storage	Packaging	Total
Electricity, kWh	2.1×10^8	7.0×10^7	2.7×10^8
Water Consumed, m^3	2.0×10^6	2.4×10^4	2.0×10^6
Coal, t	2.0×10^4	3.2×10^4	5.2×10^4
5% NaOH, m^3	4.6×10^3		4.6×10^3
5% HNO_3, m^3	3.0×10^3		3.0×10^3
Detergent, m^3	1.2×10^2	1.0×10^2	2.2×10^2
Helium, m^3		8.8×10^3	8.8×10^3
Steel (packaging canisters and overpacks), t		1.0×10^4	1.0×10^4
Manpower, man-yr	6.4×10^2	6.2×10^2	1.3×10^3

Effluents

In the event of radioactive releases to the ventilating air, a standby atmospheric protection system for the ISFSF can be activated which consists of a high-efficiency particulate air (HEPA) filters with a decontamination factor (DF) of 1×10^{3} and an iodine adsorber system (principally for ^{129}I) with a DF of 1×10^{3}. A separate process off gas system is used to treat air in areas that have a high potential for release of gaseous fission products (such as cask venting and leaking fuel assemblies). The off gas is vented to the atmosphere through a stack 45 m high, which operates at a flow rate of 120 m^{3}/sec and a linear velocity of 15 m/sec.

Estimated amounts of radioactive materials released to the atmosphere from planned operation of a single ISFSF are given in Table 3. Radioactivity release originates principally from defective fuel rods, although a small quantity of activation products on the surface of spent fuel are also present and contribute to the release.

TABLE 3. Radionuclides Released to the Atmosphere During Planned Operation of the Independent Spent Fuel Storage Facility

	Releases, Ci/yr			
Radionuclide	Receiving	Storage	Packaging	Total
^{3}H	1.3	1.1	1.3	3.7
^{14}C	3.3×10^{-3}	1.9×10^{-5}	6.6×10^{-3}	1.0×10^{-2}
^{58}Co	6.3×10^{-4}			6.3×10^{-4}
^{60}Co	1.6×10^{-3}		6.3×10^{-4}	2.2×10^{-3}
^{85}Kr	8.7×10^{2}	1.7×10^{1}	8.1×10^{2}	1.7×10^{3}
^{90}Sr	2.0×10^{-4}	3.8×10^{-5}	9.9×10^{-5}	4.1×10^{-4}
^{91}Y	2.9×10^{-4}			2.9×10^{-4}
^{95}Zr	1.7×10^{-3}			1.7×10^{-3}
^{95}Nb	3.0×10^{-3}			3.0×10^{-3}
^{106}Ru	1.0×10^{-3}		2.6×10^{-4}	1.3×10^{-3}
^{125m}Te	1.4×10^{-5}			1.4×10^{-5}
^{127m}Te	1.3×10^{-5}			1.3×10^{-5}
^{129}I	1.0×10^{-5}	8.9×10^{-7}	9.9×10^{-4}	1.0×10^{-3}
^{134}Cs	1.8×10^{-2}		7.2×10^{-3}	1.9×10^{-2}
^{137}Cs	9.9×10^{-3}	2.4×10^{-3}	5.4×10^{-3}	2.3×10^{-2}
^{144}Cs	1.8×10^{-3}	2.5×10^{-5}	3.9×10^{-4}	2.2×10^{-3}

About 5×10^8 MJ/yr of waste heat from the radioactive decay process will be rejected to the atmosphere through a mechanical-draft cooling tower during operation of the ISFSF.

About 3.5×10^4 m^3/yr of water at 17°C above ambient will be released from the cooling tower as blowdown. About 1.0×10^2 m^3/yr of water at 28°C above ambient will leave the cooling tower as drift.

Radiological Effects

Doses from radionuclides released to the atmosphere have been calculated for workers, the regional population, and the worldwide population. For planned operation of the ISFSF, the only exposure pathway to man is via airborne releases; there are no planned releases to ground or water. Doses to workers and population include doses from routine releases and minor accidents. Doses are summarized in Table 4.

TABLE 4. Summary of 70-Year Total-Body Doses Received from 30-Year Operation of Eight Colocated Independent Spent Fuel Storage Facilities and from Naturally Occurring Sources

	Dose, man-rem
ISFSF	
Process work force (30 years)	29,000
Population (within 80 km)	13
Worldwide population (30 years of operation)	560
Naturally occurring sources	
Population (within 80 km)	14,000,000
Worldwide	4,000,000,000

A range of upper values of 100 to 800 "health effects"* million man-rem was used in the CWM-GEIS. If these values are used with these doses,

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* A range of some of the commonly used conversion factors between dose and somatic health effects (such as fatal cancers) is 50 to 500 such effects per million man-rem, and between dose and genetic health effects, 50 to 300 such effects over all generations per million man-rem. Other suggested conversion factors would indicate more effects and others less, not excluding zero effects.

about 29 to 230 health effects might be expected among spent fuel storage workers; none among the regional population and none among the worldwide population. If the relationship of health effects to dose is correct then 1,400 to 11,000 health effects would be expected among the regional population from naturally occurring sources. Similarly, 400,000 to 3,200,000 health effects would be expected in the worldwide population from naturally occurring sources.

Non-Radiological Affects

Statistics from the construction industry suggests a disabling injury rate of 13.6 per million man-hours of construction effort. Based on that rate and the labor needed to construct eight ISFSFs, about 110 disabling injuries can be expected. Similarly, at a fatal accident rate of 0.17 fatalities per million man-hours,one fatality (or permanently disabling injury) may be expected as a result of an accident during construction of 8 ISFSFs.

Postulated Radiological Accidents

Minor, moderate, and severe accidents were examined for each component within the reference ISFSF for the release of radioactive material. The worst-case severe accident in the spent fuel storage facility was postulated to occur in the event of a criticality accident.

Doses received by the maximum individual (1.5×10^{-1} rem to the thyroid is the largest 70-year dose commitment) as a result of this accident are from one-half to one and one-half times the nominal annual dose caused by naturally occurring sources. In terms of accidental exposure these doses are considered to be insignificant.

EXTENDED TERM SPENT FUEL STORAGE-FACILITY DESCRIPTION

If the decision is made to store fuel for long periods it maybe sent to an Extended Term Storage Facility (ETSF). The four concepts for extended storage of spent fuel considered here are: dry caisson storage, water basin storage, air-cooled vault storage, and surface cask storage. Each ETSF will have a receiving facility which will be substantially the same regardless of ETSF option chosen.

A conclusion of the CWM-GEIS was that only two extended term storage facilities would be needed because of deferred availability of repositories or reprocessing facilities. That implies that 40,000 t(HM) of longer term storage would be required.

Dry Caisson Storage of Packaged Spent Fuel

The caisson concept for storage of packaged spent fuels relies upon the soil to conduct the radiogenic heat from the spent fuel to the earth's surface, where it is dissipated to the atmosphere. The canistered fuel is placed in an underground steel caisson that is closed with a concrete plug. This concept for fuel storage is similar to that being used to store high-temperature gas reactor fuel and to a technique being used to store Canadian reactor fuel. This approach has not been used for storage of commercial light-water reactor fuels, but it is a direct application of available technology and has been studied for this use.

Figure 3 shows the details of the caisson-construction and the caisson field arrangement. Carbon steel pipe caissons 1 m in diameter by 7.6 m long are placed in drilled holes and concrete is poured between the pipe and the soil to provide corrosion protection. A precast concrete collar and a matching shielding plug are placed on top of the caisson, and a concrete slab is poured around each hole to provide the foundation for the shielding cask. The caissons are placed in square arrays 7.6 m on center. Figure 4 shows a flow diagram of the storage facility. Operations at this facility consist of fuel transfer from an adjacent independent spent fuel receiving facility to the storage area, fuel placement in a caisson, and monitoring of

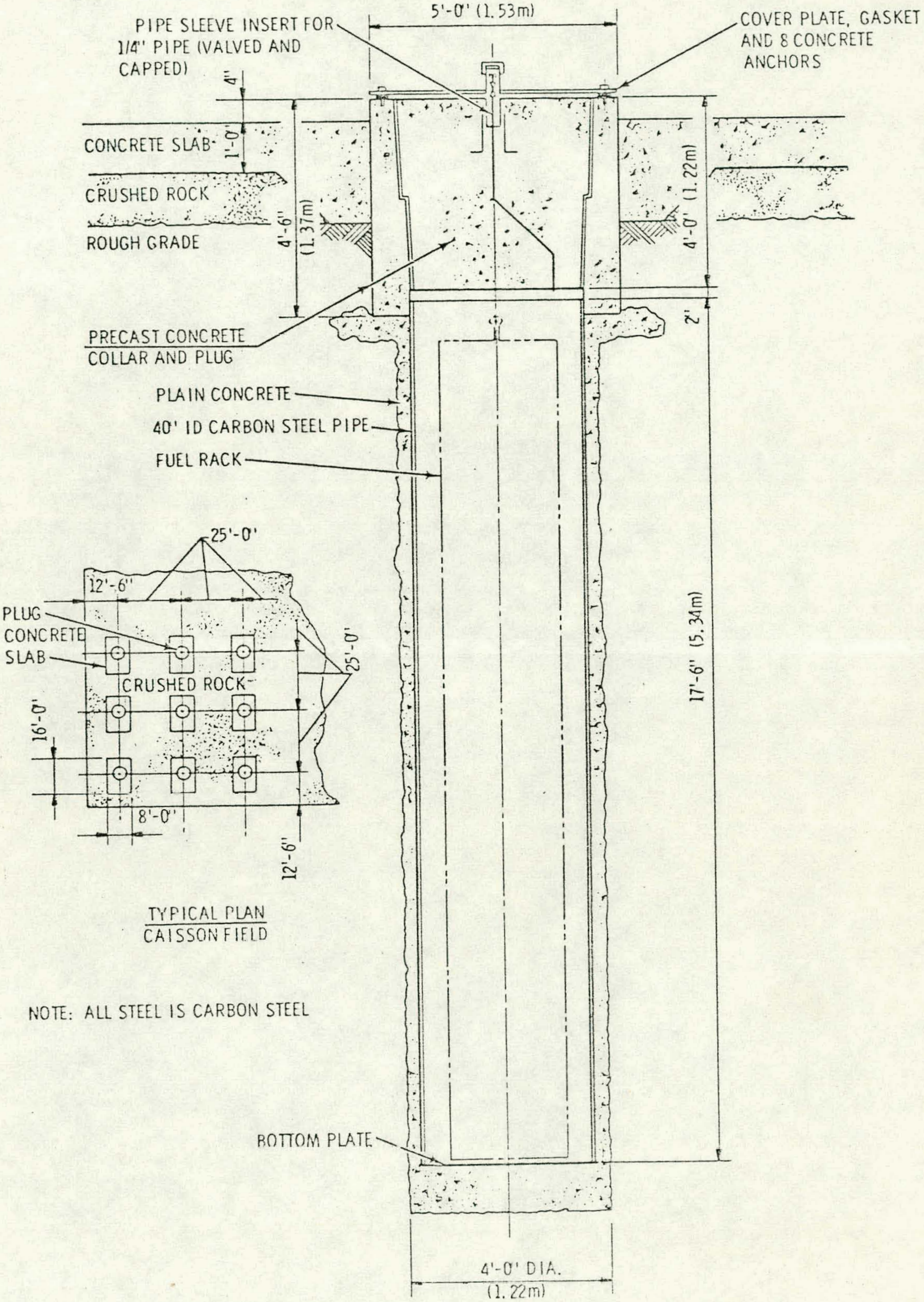

FIGURE 3. DCSF Caisson, Detail

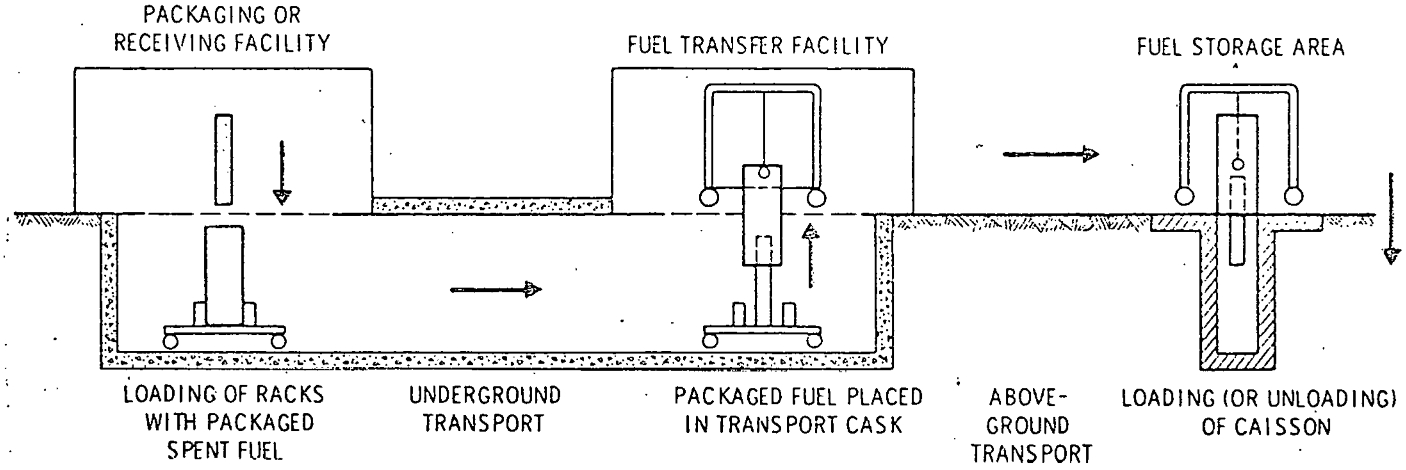

FIGURE 4. Operations Flow for the Dry Caisson Storage Facility for Packaged Spent Fuel

the filled caisson and storage area. In the unlikely event that fuel package integrity is compromised during these operations, the package would be returned to the packaging facility for inspection and repackaging or overpacking if necessary. All caissons are identical and will store either three PWR or six boiling water reactor (BWR) assemblies. A carbon steel rack supports the fuel assemblies in each caisson. The dry caisson facility will have the capacity to receive and store packaged fuel elements at a rate of 2000 t(HM)/yr (2690 PWR assemblies and 4030 BWR assemblies.) This requires about 1570 caissons per year, of which 900 will be for PWR elements and 670 for BWR elements. The design capacity provided is 1570 caissons per year for 10 years for a planned storage capacity of 15,700 caissons or about 20,000 t(HM).

Water Basin Storage of Packaged Spent Fuel

The concept of storing packaged spent fuel in a water basin is the same as that for unpackaged spent fuel except that the fuel is placed in a stainless steel canister that provides additional fuel protection, radionuclide containment barriers, and contamination control. The packaged fuel is stored under water in a reinforced concrete pool lined with stainless steel. The water provides shielding for operating personnel and a medium by which the radionuclide decay heat can be removed.

The storage of packaged spent fuel has not been practiced routinely. However, fuel has been overpacked and stored when leaking fuel elements have been detected. The technology is considered to be reasonably well established, based on water basin storage of unpackaged fuel.

Figure 5 shows a simplifed operations flow diagram of a water basin storage facility. Packaged spent fuel is transferred from an independent spent fuel receiving facility to a water basin for storing packaged fuel. Demineralized water is circulated within the water basin storage building through a heat exchanger, a filter, and an ion exchanger for removal of heat and radioactive contamination. Cooling towers are provided as a secondary cooling water circuit for heat dissipation. Each basin module is covered by an insulated building that houses a crane for handling the storage baskets and the basin water cooling and treating equipment.

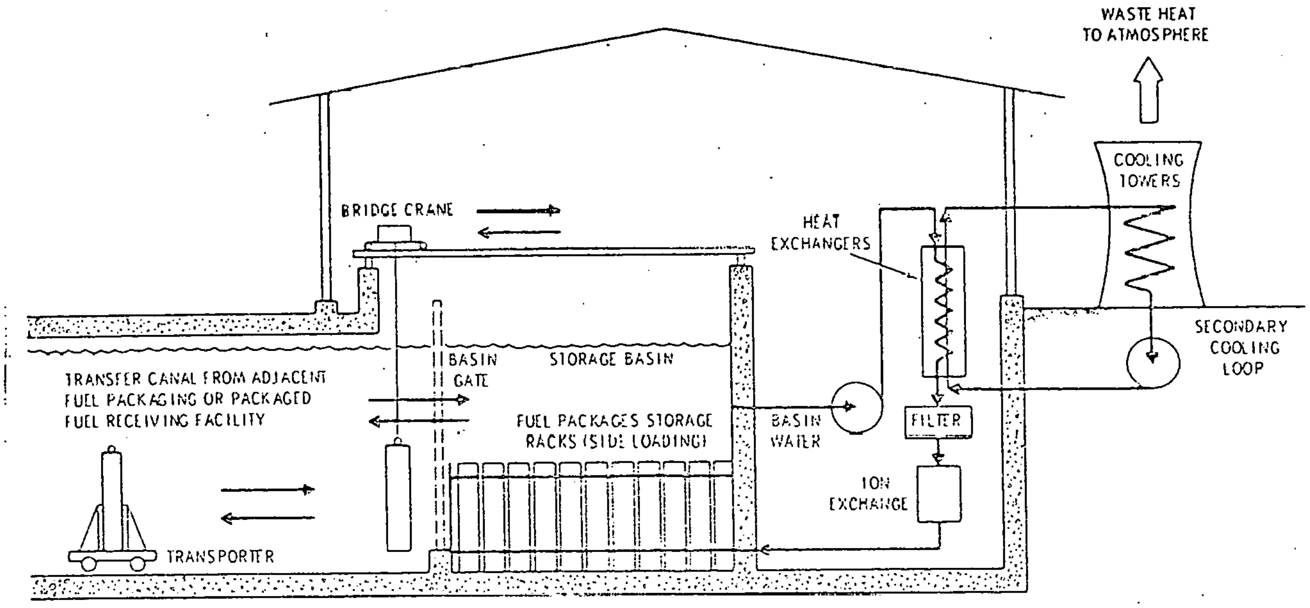

FIGURE 5. Simplified Operations Flow Diagram of the Water Basin Storage Facility for Packaged Spent Fuel

Spent LWR fuel assemblies, packaged in stainless steel containers, are received at a rate of 2000 t(HM)/yr. The assumed annual storage rate of spent fuel is 680 PWR baskets containing 2720 PWR fuel assemblies in canisters plus 450 BWR baskets containing 4050 BWR fuel assemblies. Storage basin modules of 2000 t(HM) capacity are added as needed up to a total capacity of 20,000 t(HM). In the reference facility it is assumed that these storage modules are constructed at the rate of one per year for ten years.

Air-Cooled Vault Storage of Packaged Spent Fuel

In the air-cooled vault storage concept, spent fuel assemblies are packaged in carbon steel canisters and placed vertically in carbon steel sleeves. The sleeves are part of near-grade structures containing storage cells covered with concrete shielding plugs. Cooling air enters the sleeves through side inlets in the structure and a bottom distribution plenum. The air passes upward through annuli formed by the storage units and sleeves. This concept uses the decay heat of the waste and the engineered design of the vault to induce air flow by natural draft to maintain permissible temperatures. The heated air is discharged through a short exhaust port to the atmosphere. The structure provides for biological shielding and protection from natural phenomena. To date, this concept has not been used for fuel storage, but the technology is based on established engineering practice. This concept is illustrated in Figure 6.

The storage vaults are modular units each of which has a storage capacity of 2000 t(HM). It is assumed that additional vaults will be built at the rate of one per year for ten years for a total capacity of 20,000 t(HM). A system is provided to monitor the exit air for helium and fission products. A standby forced-air cooling system with provision to filter the exhaust air is also provided in the event airborne radioactive material is detected. The vault design provides for ready retrieval of the fuel packages at any time. Packaged fuel

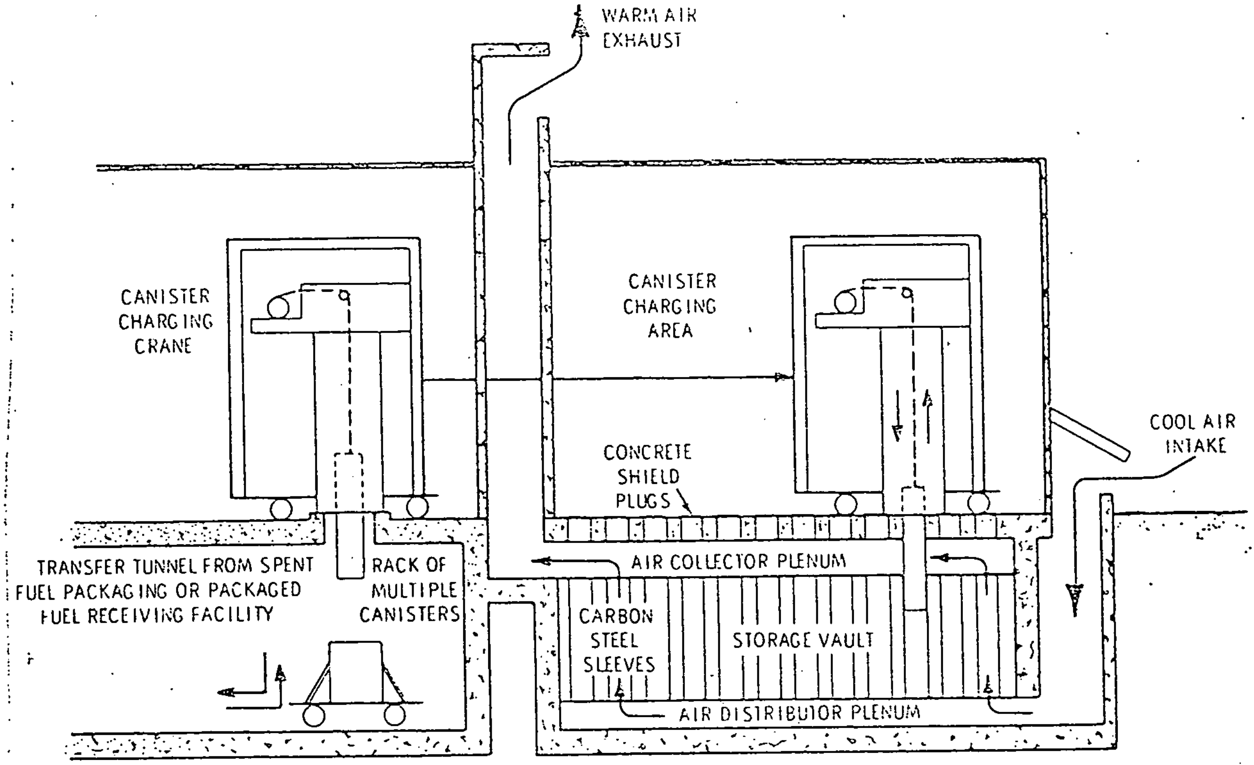

FIGURE 6. Operations Flowsheet for Air-Cooled Vault Storage of Packaged Spent Fuel

assemblies are stored in racks of four assemblies for PWR and nine for BWR fuel at a maximum rate of 2000 t(HM)/yr. The assumed annual storage rate of spent fuel is 2690 PWR fuel assemblies and 4030 BWR fuel assemblies packaged in canisters.

Surface Cask Storage of Packaged Spent Fuel

In the reference surface cask storage concept, spent fuel assemblies in carbon steel canisters are placed in vertical concrete radiation shields located outdoors on concrete pads. Heat is removed from the casks by natural convective air flow through the annulus between the cask and the radiation shield. The storage units furnish both radiation protection and confinement of waste. To date the concept has not been used for storage of spent reactor fuels or high-level waste, but the concept is an extension of existing technology. A similar concept is being used in Canada to store reactor fuels. The major difference between the concepts is that in the Canadian concept the heat generated from the fuel is conducted through the concrete shield instead of being removed by air convection.

The surface cask storage facility can receive the packaged fuel elements from the associated packaging or receiving facility at a rate of 2000 t(HM)/yr (2690 PWR fuel assemblies and 4030 BWR fuel assemblies); it has the capacity to store a total of 20,000 t(HM) of spent fuel. The storage facility is designed to handle storage cask units about 3.3 m in diameter and 7.6 m high. Each unit provides a storage envelope about 1 m in diameter by 5 m high and contains either four PWR or nine BWR fuel assemblies (1.6 t(HM)). Figure 7 illustrates the surface storage cask. The initial storage area provides for the storage of 1120 such units and has provisions for incremental expansion of the storage area up to the total of 11,200 storage units.

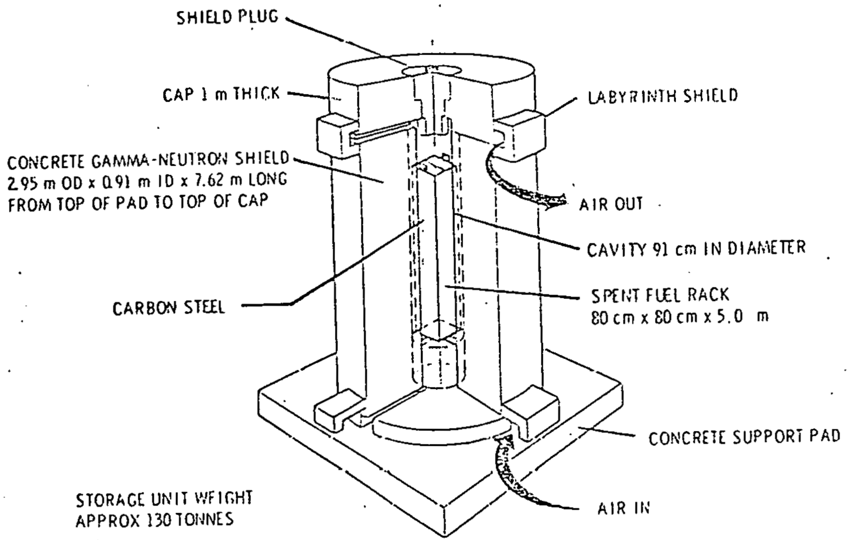

FIGURE 7. Storage Unit Used in the Surface Cask Storage Facility for Spent Fuel

The storage system is completely passive. The heat generated from the fuel is conducted and radiated to the air flow channel between the packaged fuel and shield. The heat is then transferred to the air flowing through the channel by convection. Radiation is prevented from streaming through the inlet and exit air ports by use of a labyrinth arrangement of air channels.

Environmental Effects Related to Facility Construction

Resource commitments for construction and operation of the alternative facilities for long term storage of packaged spent fuel are given in Table 5 and 6 respectively.

The resources listed are those committed for construction of facilities that will have a storage capacity of 20,000 t(HM).

TABLE 5. Resource Commitments for Construction of Alternatives for Storing Packaged Spent Fuel (20,000 t(HM) capacity)

Resource	Water Basin Storage	Air-Cooled Vault Storage	Surface Cask Storage	Dry Caisson Storage
Land, ha	6.4	1.3×10^{1}	1.1×10^{2}	1.3×10^{2}
Water, m^3	1.1×10^{5}	2.0×10^{5}	8.2×10^{4}	3.9×10^{4}
Concrete, t	3.9×10^{4}	1.3×10^{5}	8.4×10^{3}	2.7×10^{4}
Steel, t	1.2×10^{4}	3.8×10^{4}	2.8×10^{3}	
Copper, t	1.4×10^{2}	2.5×10^{1}	4.5×10^{1}	
Zinc, t	3.6×10^{1}			
Lead, t		1.0×10^{1}		6.3×10^{1}
Lumber, m^3	3.1×10^{3}	8.6×10^{3}	3.1×10^{2}	1.9×10^{2}
Propane, m^3	9.0×10^{2}	1.6×10^{3}	8.0×10^{2}	7.6×10^{2}
Diesel fuel, m^3	8.9×10^{3}	1.6×10^{4}	7.8×10^{3}	8.0×10^{3}
Gasoline, m^3	6.0×10^{3}	1.1×10^{4}	5.3×10^{3}	5.2×10^{3}
Electricity, kWh	4.4×10^{6}	8.1×10^{6}	3.9×10^{6}	3.9×10^{6}
Manpower, man-yr	3.8×10^{3}	6.5×10^{3}	3.5×10^{3}	3.4×10^{3}

TABLE 6. Resources Needed for Annual Operation of Alternative Faciltiies for Storing Packaged Spent Fuel

Resource	Water Basin Storage	Air-Cooled Vault Storage	Surface Cask Storage	Dry Caisson Storage
Water, m^3				
Cooling tower -makeup	3.8×10^{5}			
Coal, t	2.3×10^{3}			
Gasoline, m^3		4.0×10^{1}	6.0×10^{1}	
Diesel fuel, m^3				1.2×10^{2}
Electricity, kWh	2.6×10^{7}	5.3×10^{6}	5.3×10^{6}	5.3×10^{6}
Manpower, man-yr	5.0×10^{1}	2.3×10^{1}	6.0×10^{1}	3.2×10^{1}

About 7×10^{8} MJ/yr of waste heat would be released to the atmosphere regardless of concept used; the largest effect will be a temperature increase of <1°C at 1 km downwind. Water use during facility operation would be greatest for the water basin storage facility. The other storage facilities (air-cooled vault, surface cask, and dry caisson) would require water only for sanitary uses. Thus in areas of abundant water no operating requirements clearly favor one option over the others. In areas without abundant water, the water basin storage concept may be precluded.

There are no identifiable releases of radioactive material for normal operation of these storage facilities. The estimated annual occupational doses are presented in Table 7. There are no clear choices to be made on the basis of occupational dose (uncertainties in the estimates probably exceeds the apparent factor of 2 in dose in Table 7).

TABLE 7. Annual Occupational Doses Received During Operation of the Alternative Facilities for Storing Packaged Spent Unreprocessed Fuel

Facility	Occupational Dose, man-rem/yr
Water basin storage	98
Air-cooled vault storage	49
Surface cask storage	78
Dry caisson storage	41

Environmental Effects Related to Postulated Accidents

Postulated minor accidents for spent extended term fuel storage facilities include loss of normal elecrtrical power, loss of normal cooling water supply, failure of ventilation system, loss of cooling air, and flooding of storage vault. However, none of these accidents are expected to result in release of radioactive material to the environment.

The credible severe accident leading to the highest doses was a design basis tornado at the water basin storage facility. The first-year total-body dose to the maximum indivudal was determined to be 0.02 rem which may be compared with 0.1 rem received from naturally occurring sources over the same period. A dose of 2 rem to the lung of the maximum individual was calculated for a severe accident at the water basin storage facility, this dose is less than one-half of the permissible annual dose to radiation workers and is believed to be insignificant in terms of accidental exposure.