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STUDIES AND RESEARCH CONCERNING BNFP

SPENT FUEL DRY STORAGE STUDIES AT THE BARNWELL NUCLEAR FUEL PLANT

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ABSTRACT

Conceptual designs are presented utilizing the Barnwell Nuclear Fuel Plant for the dry interim storage of spent light water reactor fuel. Studies were conducted to determine feasible approaches to storing spent fuel by methods other than wet pool storage. Fuel that has had an opportunity to cool for several years, or more, after discharge from a reactor is especially adaptable to dry storage since its thermal load is greatly reduced compared to the thermal load immediately following discharge. A thermal analysis was performed to help in determining the feasibility of various spent fuel dry storage concepts. Methods to reject the heat from dry storage are briefly discussed, which include both active and passive cooling systems. The storage modes reviewed include above and below ground caisson-type storage facilities and numerous variations of vault, or hot cell-type, storage facilities.

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GLOSSARY

AFR - Away-From-Reactor
AGNS - Allied-General Nuclear Services
BNFP - Barnwell Nuclear Fuel Plant
BWIP - Basalt Waste Isolation Project
BWR - Boiling Water Reactor
CPF - Caisson Packaging Facility
CSFSA - Caisson Spent Fuel Storage Area
CUP - Cask Unloading Pool
EUA - Emergency Utility Area
FRSS - Fuel Receiving and Storage Station
GVOS - Grade Viewing and Operating Station
HEPA - High Efficiency Particulate Air
HILC - High-Intermediate-Level Cell
HLC - High-Level Cell
HTGR - High-Temperature Gas Reactor
ILC - Intermediate-Level Cell
INEL - Idaho National Engineering Laboratory
LWR - Light Water Reactor
MTU - Metric Tons of Uranium
MW - Megawatt
MWd - Megawatt-day
NNWSI - Nevada Nuclear Waste Storage Investigations Program
PNC - Plutonium Nitrate Cell
PPC - Plutonium Product Cell
PWR - Pressurized Water Reactor
RMSC - Remote Maintenance and Scrap Cell
RPC - Remote Process Cell
SFDSV - Spent Fuel Dry Storage Vault
UPC - Uranium Product Cell
WIPP - Waste Isolation Pilot Plant

1.0 INTRODUCTION

Two policy decisions made by President Carter in 1977 have had a major impact on the storage and processing of spent nuclear fuel assemblies:

- On April 7, the reprocessing of spent fuel from commercial reactors was indefinitely deferred.
- On October 18, the Federal Government offered to take title to spent reactor fuel.

These policy changes stopped commercial development of reprocessing, and, as a result, currently available spent fuel storage space (utility storage pools) will be filled within a few years, as reactors continue to discharge spent fuel. Additional near-term storage capacity can be provided by modifying commercial spent fuel storage basins, such as installing closely spaced storage racks, but by the mid-1980's, some basins will have inadequate capacity to handle the fuel being discharged.(1) Additional storage could be provided by either an Away-From-Reactor (AFR) storage facility or a disposal facility.

Studies previously conducted by Allied-General Nuclear Services (AGNS) have already addressed converting the Barnwell Nuclear Fuel Plant (BNFP) to an AFR underwater storage facility.(2) This report will address the feasibility of converting the BNFP to an AFR dry storage facility for the interim storage of spent nuclear fuel.

There are potentially at least four general concepts for dry storage of spent fuel from light water reactors (LWR): (1) a new Federal repository, (2) storage at existing facilities within the United States, (3) conceptualized vault storage, and (4) conceptualized caisson storage.(5, 6)

Repository storage would entail placing LWR spent fuel directly into geologic burial for permanent disposal (although a 10- to 50-year retrieval duration would probably be engineered into the repository design). The repository could be located in underground formations of salt, basalt, granite, shale, or some other stable geologic media. This repository is envisaged to be owned and regulated by the Federal Government and would be similar to those proposed for New Mexico (WIPP-salt media), Washington (BWIP-basalt media), and Nevada (NNWSI-tuff, granite, and shale media). It is estimated that the first government repository will not be on-line until at least 1990.* Since a resolution of the disposition of LWR fuel needs to be made prior to 1990, near-term storage in a Federal repository is not a viable solution. Repository storage will not be discussed any further in this report.

*In February of 1980, President Carter established a comprehensive radioactive waste management program that set the goals of a repository site selection by about 1985 and an operating facility by about 1995.

The second means considered for storage of spent fuel is utilization of existing facilities, i.e., facilities throughout the United States. Storage facilities outside the United States have been excluded from this study. Existing sites, generally nuclear production facilities and laboratories operated by the Federal Government, include hot cells, vaults, production canyons, and decommissioned pools. Essentially, the storage mode in these existing facilities are all variations of the vault and caisson storage modes discussed in this report. The use of existing facilities could be valuable from a timing standpoint, i.e., they could be modified to accept LWR spent fuel faster than building new dedicated facilities.

This report deals with various vault and caisson concepts and applications of existing BNFP facilities for the dry storage of spent fuel. Each concept is presented separately; and in the case of the caisson concepts, it is assumed that each caisson contains the equivalent of one intact fuel assembly or up to four assemblies that have been compacted by disassembly. Some of the concepts for heat removal could be combined. For instance, cooling fins and forced convection cooling could be combined in a vault, or heat pipe cooling and natural convection could be combined in caisson storage. There are many such combinations; but to simplify the discussion, only the basic concepts are discussed individually. Likewise, caissons could probably store more than one to four fuel assemblies (becoming mini-vaults) but this has not been addressed.

2.0 METHODOLOGY

The objective of this study was to review ways to store LWR spent fuel in a dry environment, and specifically how BNFP could be utilized to meet this objective. The following steps were performed to accomplish the above objective:

- A literature search was performed to procure information concerning the dry storage of spent fuel.
- Criteria and design bases were established to assist in determining the feasibility of the various concepts and also in comparing one concept with another.
- The BNFP was analyzed for all possible facilities or sites that could be used for spent fuel dry storage.
- Design concepts were developed in general, and for specific applications to the BNFP site.
- Conceptual drawings were prepared illustrating the various dry storage concepts.
- Comparisons were made among the concepts, and about half of the potential sites at BNFP were rejected from further consideration.
- Thermal and shielding analyses were performed on vault and caisson storage concepts.
- This report was written documenting the findings of the spent fuel dry storage studies.

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3.0 DESIGN BASES

The LWR spent fuel characteristics used for dry storage analyses are shown in Table 2-1. It is assumed that the dry storage capacity is 2000 MTU unless physical constraints of the concepts and existing facilities under review limit this capacity to a lesser amount. Fuel receipt and retrieval rate is assumed to be 5 MTU per day over 300 operating days per year. The remainder of the calendar year may be used for repairs, maintenance, testing, and similar necessary operations. For purposes of this report it is assumed that reprocessing of spent fuel would never be permitted at BNFP and, therefore, any of the existing facilities could be used, or modified for use, for interim dry spent fuel storage.

The fuel content (kilograms uranium, nominal) in a BWR and PWR assembly is assumed to be 190 and 480 kilograms, respectively. It is also assumed that 70% BWR assemblies and 30% PWR assemblies are received at the storage facility. A simple calculation, utilizing the above fuel ratio, demonstrates that 7220 assemblies (5054 BWR and 2166 PWR) are required to yield 2000 MTU of storage capacity. An intact BWR assembly would be placed in a storage container whose outside dimensions would be 6 1/16-inch square. An intact PWR assembly would be placed in a 9 1/4-inch square container.

In the case of disassembled fuel, it is assumed that 4 BWR assemblies and 2 PWR assemblies will each fill a metal storage container 9 1/4-inch square. For the 2000 MTU case, this would require 1264 containers for BWR assemblies and 1083 containers for PWR assemblies, or a total of 2347 containers.

All of the storage concept drawings in this report show the disassembled (compacted) and containerized form of spent fuel storage. The fuel containers (4 BWR assemblies or 2 PWR assemblies) are assumed to be placed in racks that space the containers 15 inches apart, center to center. This allows approximately 6 inches between the outside surfaces of the containers for operational ease, thermal cooling, and criticality considerations. A preliminary criticality review shows that intact fuel should be spaced 4 to 5 inches apart (outside surface) and disassembled fuel may be spaced slightly less, about 3 inches apart. An array of fuel containing both BWR and PWR assemblies will, therefore, have a fuel density of about 0.55 MTU per square foot of storage area. A 60-foot by 60-foot storage area would contain about 2000 MTU (assuming 70% BWR assemblies and 30% PWR assemblies).

TABLE 3-1

FUEL CHARACTERISTICS[22]

		BWR	PWR
1.	Enrichment (% U-235)		
	Initial (maximum)	3.2	4.1
	Final (nominal)	0.9	0.9
*2.	Average fuel burnup (MWd/MTU)	29,000	29,000
*3.	Average fuel specific power (MW/MTU)	32	32
*4.	Maximum fuel burnup (MWd/MTU)	33,000	33,000
*5.	Maximum fuel specific power (MW/MTU)	35	35
6.	Cooling time prior to receipt (years)		
	Case 1	5	5
	Case 2	10	10
7.	Assembly cross-section (inches, nominal)	5.26	8.55
8.	Active length (feet, maximum)	12.5	12.5
9.	Overall length (feet, maximum)	15	15
10.	Fuel content/assembly (kilograms uranium, nominal)	190	480
11.	Assembly weight (pounds, maximum)	700	1,600
12.	Removable nonfuel bearing items included with assemblies	None	None
13.	Number of assemblies received (%)	70	30
**14.	Leaking assemblies (% of fuel received)		
	Shipped by the utility	No	No
	Failure during shipping	0.01	0.01
15.	Rail/truck receiving mix (%, MTU basis)	60/40	60/40

*Average values should be used for evaluation of the mixture of fuels (both BWR and PWR) that will be placed in storage. Such evaluations would include matters such as dry storage cooling requirements, normal operation, source terms, etc.

The maximum values will be used only for assessments involving a discrete amount of fuel. An example is development of source terms from a cask drop accident.

**Canned leakers from the utilities may be handled on a case-by-case basis.

4.0 SPECIFIC USES OF THE BNFP FOR DRY STORAGE OF SPENT NUCLEAR FUEL

There are at least eight ways (with many variations) of utilizing the BNFP for the dry storage of spent nuclear fuel. The specific uses of the BNFP are to store fuel in: (1) the Remote Process Cell (RPC), (2) the contact cells, (3) the Fuel Receiving and Storage Station (FRSS) pool without water, (4) the high-level waste tanks, (5) the Emergency Utilities Area building, (6) new facilities built for above or below ground caisson storage, (7) new facilities built for vault-type storage of spent fuel, and (8) the Plutonium Nitrate Cells (PNC) Nos. 1 and 2. Potential or actual location of facilities employing each of these concepts is shown on Drawing 533D-A-5001.

4.1 Remote Process Cell

The storage of spent fuel within the RPC would require that most of the equipment now in the cells (a shear, dissolvers, concentrators, etc.) be removed. New equipment associated with fuel storage, such as storage racks, would be added. Sketches of the RPC and Remote Maintenance and Scrap Cell (RMSC) used for dry spent fuel storage are shown in Drawings 533D-A-5002 and 533D-A-5003.

The in-cell cranes, the viewing windows, the ventilation system, and the cell itself are already existing and would be used for this dry storage concept. These existing facilities obviously represent a substantial savings over building a new dedicated facility. The use of the RPC for spent fuel storage, however, hinders the potential use of the BNFP for the reprocessing of LWR fuel at some later date. It would also inhibit the use of the RPC for the disassembly of spent nuclear fuel.

4.2 Contact Cells

The contact cells at the BNFP consist of five shielded process cells that were to be employed for chemical processing during the reprocessing of LWR fuel. If these cells were to be used for the dry storage of spent fuel, the existing tanks and piping would need to be removed. In addition, the walls between the cells would have to be at least partially removed to allow installation of an overhead crane to transfer stored fuel containers to any of the contact cells (see Drawings 533D-A-5004 and 533D-A-5005).

Another modification to the cells would require that an access opening for introduction of spent fuel be made in at least one location. This opening would logically be into the RPC. The RPC could be utilized to package spent fuel assemblies into storage containers. These assemblies could either be placed within a container intact or they could be disassembled (the nonfuel bearing components removed) and placed within a container. The disassembled process will compact the fuel rods by a volume reduction factor of two, i.e., two disassembled fuel assemblies will occupy the space of one intact assembly.

4.3 Fuel Receiving and Storage Station (FRSS) Pool Without Water

It is possible to utilize the BNFP spent fuel storage pool in a dry mode. Spent fuel would be stored in storage racks much the same as envisaged for wet storage. The fuel could be stored in a compacted form by using fixed neutron poisons to allow a closer spacing and/or by first disassembling the fuel by removing the nonfuel-bearing components.

A shielded cover would have to be constructed over the top of the pool which would essentially result in the pool being transformed into a large hot cell. Fuel would probably enter the pool area by first being introduced into one of the two existing Cask Unloading Pools (CUPS) while still within a cask. The fuel assemblies would be remotely removed from the cask (see Drawings 533D-A-5006 and 533D-A-5007).

If the fuel were to be disassembled, the cask would still be unloaded in a CUP and the fuel assemblies would be transferred to the RPC for disassembly. In the RPC, the fuel rods would be placed in a container and transferred back to the pool for dry storage in racks.

4.4 Waste Tank Storage

Spent fuel may be stored in any or all of the three existing waste tanks at the BNFP. All of the existing support equipment within the tanks such as air circulators and spargers, would need to be removed. The existing cooling coils could be employed to remove some of the heat generated from the spent fuel.

Since the tanks have already been designed to contain high-level radioactive wastes, the area around the tanks has been sufficiently shielded for storage of spent fuel. The double-walled tank construction and the existing monitoring system would assist in surveillance of the stored fuel.

The loading (and unloading) of the fuel into the waste tanks presents an operational problem with regard to worker exposure unless special measures are taken. It would be possible to transport casks directly to the waste tanks and dry unload the fuel and place it in the tanks. However, this would require the construction of a new facility to remotely perform these operations (necessary to protect workers from radiation exposure).

A more practical way would be to allow casks to enter the FRSS as normally envisaged, and to be unloaded in the CUP. The spent fuel would be transferred to the RPC where the fuel assembly could either be placed directly into a storage container, or it could first be disassembled (removal of nonfuel-bearing components) and then placed into storage containers.

These storage containers would be placed in an on-site transport cask similar to the cask originally proposed to transport hulls containers at the BNFP. The cask would be transported to the waste tank site and placed upon a special fixture above the tanks. Fuel containers would be lowered into the waste tank and remotely set in place (see Drawings 533D-A-5008 and 533D-A-5009).

4.5 PNC No. 1 and No. 2

Spent fuel storage in the plutonium nitrate cells (PNC) Nos. 1 and 2 would require substantial modifications. All of the slab tanks and shielding walls inside the cells would need to be removed and storage racks installed. The outside walls of the PNC's were designed for the storage of plutonium slightly contaminated with fission products. For this reason, some of the cell walls are only 18 inches thick and would need to be increased to about five feet thick for spent fuel storage. Load-in and load-out facilities would also need to be added, as would access roads and possibly a railroad spur (see Drawings 533D-A-5010 and 533D-A-5011).

4.6 Emergency Utility Area Building

To utilize the emergency utility area (EUA) building for the dry storage of spent LWR fuel, one would have to remove most of the existing equipment within the building. Since the remaining facility (after the utility equipment is removed) is only a building shell, a great deal of modifications would be required. A remote loading/unloading area would have to be added, as would cranes, viewing windows, storage racks, and other support equipment. The building has already been built to withstand tornados and seismic events, but may require additional materials for shielding (see Drawings 533D-A-5012 and 533D-A-5013).

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5.0 VAULT STORAGE CONCEPTS

The vault concepts considered for spent fuel storage consist of four possible designs. These four vault, or dedicated building, concepts include: (1) vault with forced air cooling, (2) vault using heat pipes for cooling, (3) vault cooled by a natural draft, open to the outside environment, and (4) vault with no cooling, sealed to the outside environment. There are numerous possible variations or combinations of these four concepts. For simplicity, only the four basic concepts are discussed.

All the vault concepts have many features in common, e.g., they store many unit quantities of packaged reactor fuel and protect these packages from accidents. They differ mainly in the method used to remove radiolytic decay heat.

The vault concept with forced air cooling is shown in Figure 5-1. This is typical of the design of most existing vaults and hot cells. It utilizes well-understood existing technology and dozens of existing facilities, particularly large hot cells, could be modified to store spent fuel in this manner. Nearly all nuclear facilities employ forced air ventilation utilizing High Efficiency Particulate Air (HEPA) filtration to remove radioactive particles from the air prior to its exhaust to the environment. Therefore, if existing facilities were to be used for fuel storage, they would probably employ some variation of the forced air cooled vault concept.*

The obvious disadvantage of the forced air concept is that it is an "active" system (versus "passive" systems) and requires the continuous effective operation of the ventilation and filtration systems. This disadvantage is reflected in yearly operating costs and safety considerations (an active ventilation system with HEPA filters may be considered a barrier in the containment system). The forced air system requires an accident analyses to determine what happens when components of the system fail, which often requires costly secondary backup ("fail-safe") systems or mechanisms.

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*Idaho National Engineering Laboratory (Idaho Falls, Idaho) has designed, built, and is operating two types of dry spent fuel storage facilities.(2) The two installations, the Peach Bottom Storage Vaults and the Irradiated Fuels Storage Facility, are both forced convection cooled storage vaults. Below ground dry storage is also provided for HTGR spent fuel at INEL.(23)

The vault concept shown in Figure 5-2 relies upon the natural convection of air to cool the fuel assemblies and is open to the outside environment.* One obvious advantage over the forced air concept is that the "natural draft" concept is passive. Loss of cooling due to the failure of mechanical equipment is impossible. The major disadvantage is in the area of safety. Since the air currents do not develop enough force to overcome the resistance of HEPA filters (due to the pressure drop across the filters), it is unlikely that absolute filters could be used. Therefore, to ensure the safety of the public, the radioactivity in the spent fuel must be protected by multiple barriers. A case can be made that the cladding of spent fuel elements cannot be classified as a barrier, since it may contain cracks, holes, etc. Therefore, to ensure a minimum of double containment of the spent fuel, the fuel rods (or entire assemblies) would be placed into a container and the container would be placed into an overpack. This multiple encasement of the fuel would require additional facilities, adding to the overall cost and also to the complexity of the operations.

The vault concept shown in Figure 5-3 relies on heat pipes to cool the fuel assemblies.** This method of storage has several advantages. The system is passive and does not require ventilation on a routine basis. A backup low capacity (low flow rate) ventilation system may be desirable to take air samples, allow major repairs/modifications to the heat pipes, provide clean airflow control for nonroutine-manned entry, and allow a degree of safety by providing the required differential air pressure for normal operations. This system would probably not contain its own backup systems, such as costly redundant secondary blowers, power supply, and HEPA filters, and it could also be a recirculating system. This ventilation system would provide perhaps 0.5 to 2 entire vault air changes per hour which is less than a typical hot cell ventilation system used for routine airflow and cooling.

A very similar concept to utilizing heat pipes is shown in Figure 5-4 in which metal fins are used to transfer heat, by conduction, out of the vault storage area. This cooling system is passive <u>inside</u> the vault. Forced convection is used to sweep the heat from the fins <u>outside</u> the vault storage area. The air from this sweep would be noncontaminated and HEPA filtration may be optional. In this design, the entire ceiling

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*Nukem GmbH of Germany[11] and Ontario Hydro of Canada[12] both have proposed a dry storage concept for spent fuel that utilizes a concrete vault cooled by natural convection.

**A heat pipe is a heat-transfer device consisting of a sealed metal tube with an inner lining of wicklike capillary material and a small amount of fluid in a vacuum. Heat is absorbed at one end by vaporization of the fluid and is released at the other end by condensation of the vapor. Fluid circulation is enhanced by the capillary action of the wick and gravity. The tubes are completely sealed and would provide no pathway for release of radioactive material from the vault to the environment. The tubes may be axially or radially finned to increase their heat transfer ability.

of the vault could be metal which would assist transferring heat out of the vault.

This vault concept would also be provided an air recirculation system that would cool and filter relatively small volumes of air, i.e., about 0.5 to 2 vault air changes per hour. This system would provide a negative air pressure inside the vault, perhaps -1.0 inch of water.

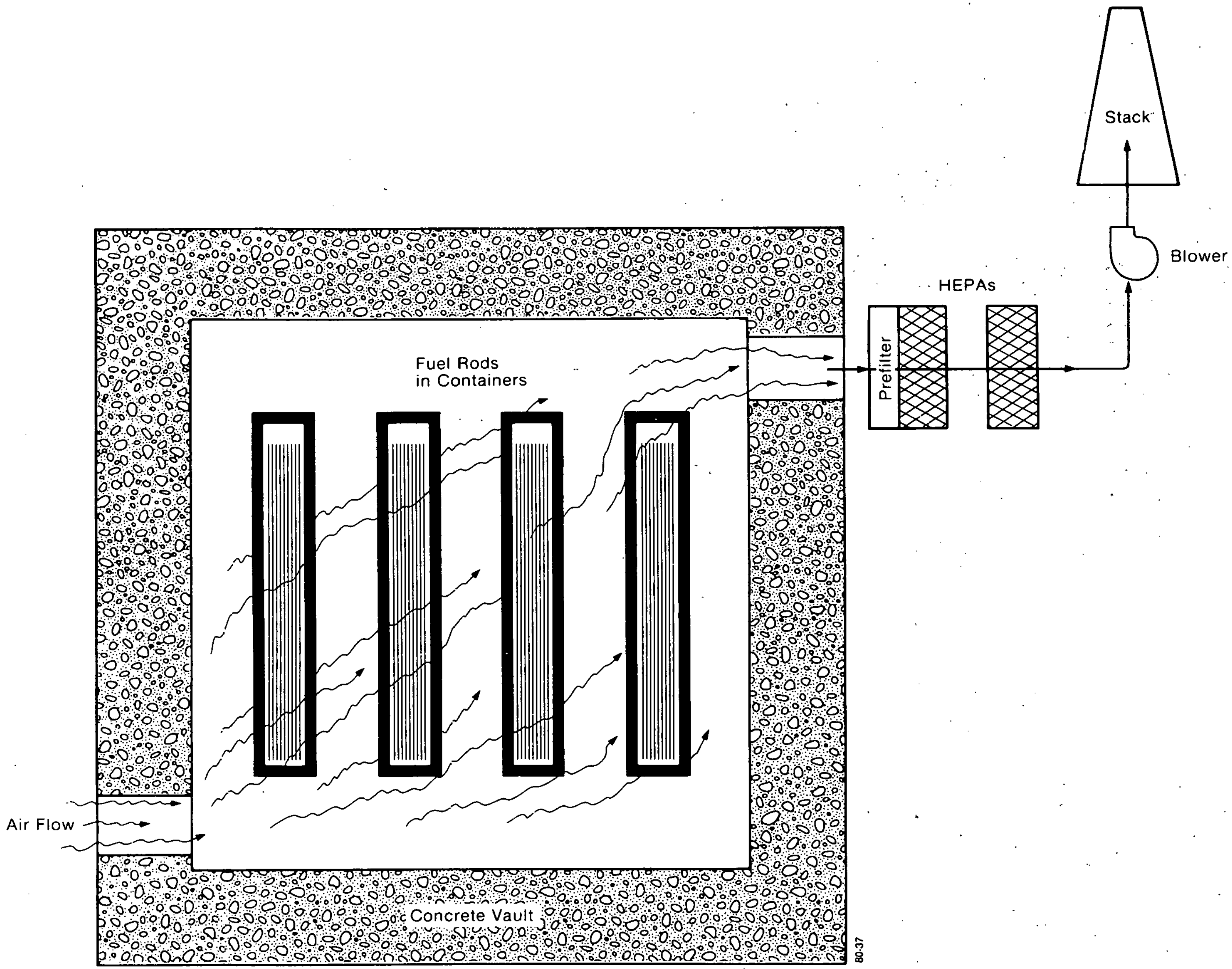
The vault design in Figure 5-5 assumes a "closed" vault with no cooling devices. The vault would only be open during placement or removal of spent fuel. Ventilation would be similar to that discussed in the heat pipe or metal fin storage concepts, i.e., a recirculating, low capacity ventilation system employed mainly to retain a negative pressure and not used for cooling.

The ability to use a vault design with no specific cooling devices (other than the heat sink provided by the vault's concrete structure) is only possible with spent fuel that has been cooled about 8 to 10 years after reactor discharge.

One possible location for a vault facility at the BNFP would be just west of the FRSS and south from the Separations Plant (see Drawing 533D-A-5001 and 533D-A-5018). This location would allow use of existing rail spurs, roads, and the FRSS Vehicle Unloading Bay.

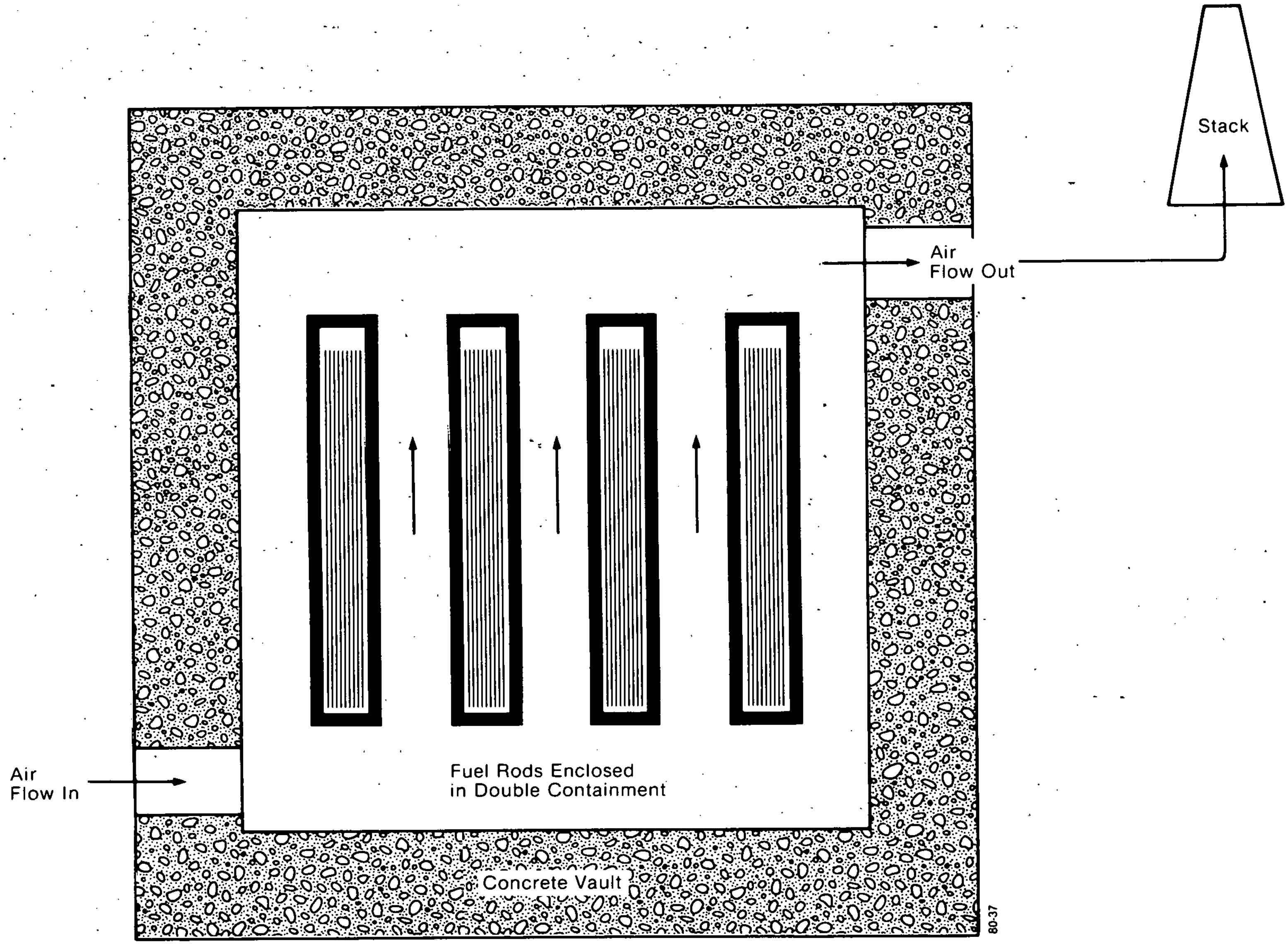
Spent fuel would enter the BNFP and be unloaded from transport casks in the FRSS. The fuel would be placed in the pool for temporary storage or go directly to the RPC for packaging into a storage container (either intact or disassembled). If the fuel were not to be disassembled, it would probably be possible to perform the container packaging in facilities adjacent to the Spent Fuel Dry Storage Vault (SFDSV).

Fuel would be stored on racks in the SFDSV and cooling could be provided by various means as discussed previously. The walls of the SFDSV would be concrete, thick enough to reduce the radiation exposure immediately outside the SFDSV to less than one-tenth mrem/hour.



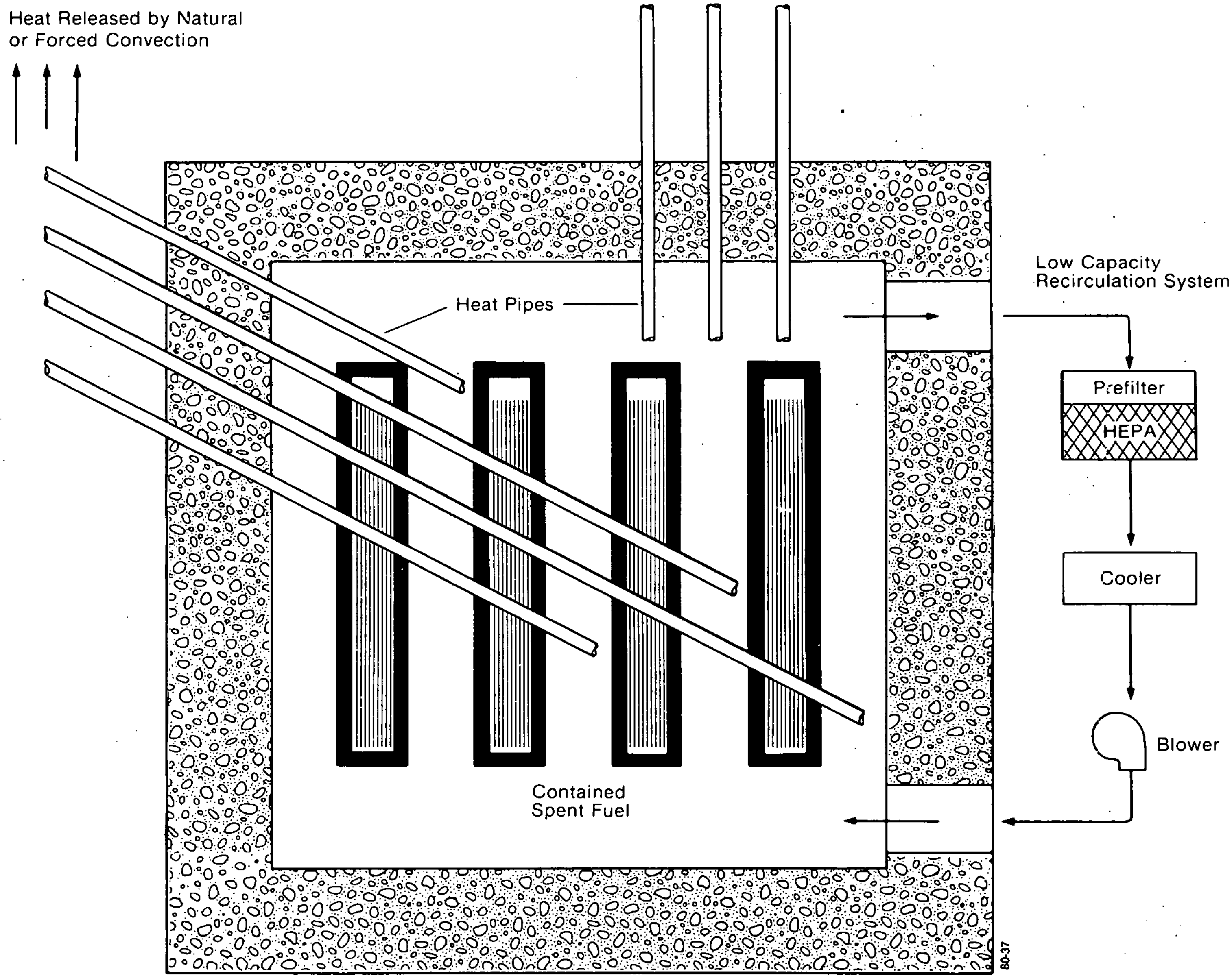
VAULT WITH FORCED AIR COOLING

FIGURE 5-1



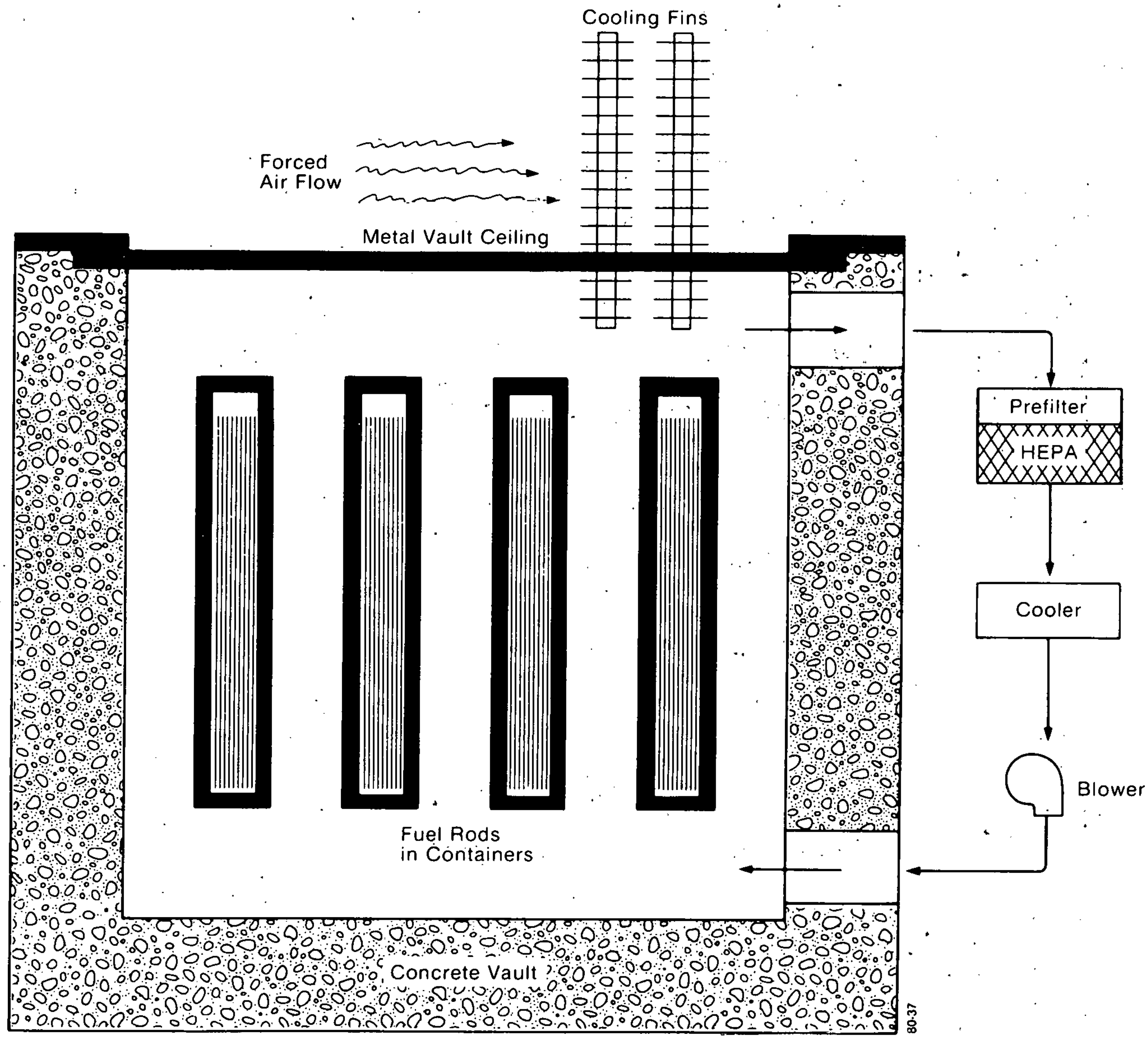
VAULT WITH NATURAL CONVECTION COOLING

FIGURE 5-2



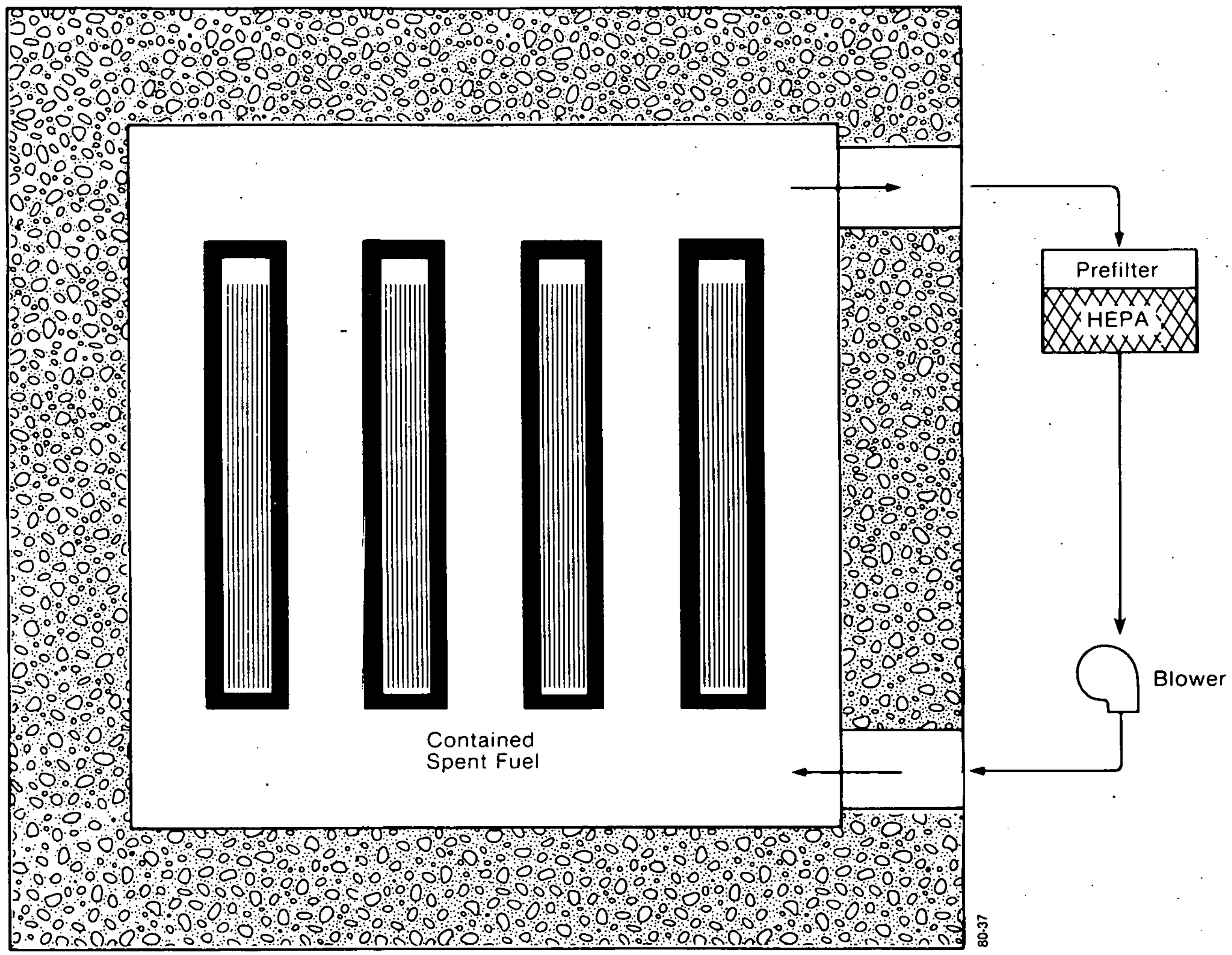
VAULT WITH HEAT PIPES

FIGURE 5-3



VAULT WITH COOLING FINS

FIGURE 5-4



VAULT WITH NO COOLING DEVICES

FIGURE 5-5

6.0 CAISSON (SILO) STORAGE CONCEPTS

The caisson concepts reviewed include: (1) caissons with natural convection cooling, (2) caissons with heat pipe cooling, and (3) caissons with no cooling. In addition, each of the concepts is reviewed on the basis of aboveground storage and below ground storage. The caisson, or silo, concepts of storing spent fuel are all similar in that only small quantities of packaged reactor fuel are stored in each caisson and that there are many caissons, in contrast to large vaults containing many fuel containers.

The caisson concepts with natural draft convection are shown in Figures 6-1 and 6-2. The aboveground storage concept, Figure 6-1, uses a large concrete structure for each caisson to provide shielding and protection from natural phenomena. Outside air is allowed to enter at the bottom of the concrete caisson and natural convection currents move the air upward and out openings provided at the top of the structure. A concrete plug is provided at the top of the caisson for insertion and removal of spent fuel. Since the heated air is vented to the outside environment without HEPA filtration, the spent fuel must be confined within at least two containment barriers. These barriers would probably consist of a metal container with a metal overpack.

If the caissons are placed underground, the soil would act as a radiation shield and missile barrier, therefore, the need for a massive concrete structure is eliminated. Figure 6-2 illustrates a potential design utilizing natural convection cooling for spent fuel stored underground. In this case, the spent fuel would be placed in double containment and placed into caissons within an engineered berm (see Section 7.0). Vents are provided at the top and bottom of the storage caisson and pass through the soil to the outside environment. No filtration is provided because of the secure containment of the spent fuel.

Caisson storage using heat pipes for cooling, both above and below ground, are shown in Figures 6-3 and 6-4, respectively. The concept of aboveground storage, Figure 6-3, is very similar to the natural convection aboveground storage shown in Figure 6-1. The relative size of the concrete structure and normal operations would be the same for both.*

The heat pipes could be provided through the upper concrete plug. If additional heat removal is required, heat pipes could also be introduced through the sides of the concrete shield. In either case, the heat pipes would be placed in orientations that would minimize the amount of

*A conceptual design combining natural convection (Figure 6-1) and heat pipes (Figure 6-3) for cooling stored spent fuel assemblies has been proposed by Electrowatt Engineering Services, Ltd.[1] Each concrete silo in the Electrowatt conceptual design would have the ability to store seven PWR fuel assemblies and could handle a maximum heat load of 40-kilowatt per silo.

radiation "shining" through the heat pipe access openings. The heat pipes would transfer heat from the stored spent fuel to the outside air where it would be dispersed by natural convection and forced convection (wind).

The use of heat pipes in underground storage of spent fuel is shown in Figure 6-4. This concept may or may not use an engineered berm. The concept is shown using a berm, which is likely to be more expensive than not using an engineered berm. However, it is assumed that storage of spent fuel underground can be operated safely without employing an engineered berm. A detailed engineering safety analysis would have to be conducted to support this assumption. The heat pipes are inserted into the concrete shielding plug and draw heat from the spent fuel to be dispersed by natural convection into the outside air.

The final caisson storage concepts reviewed are above and below ground storage with no auxilliary cooling. These concepts are shown in Figures 6-5 and 6-6, respectively. These concepts are probably the most simple and least costly designs assuming they can be operated safely and that the heat loads from the spent fuel is not too severe.

The aboveground caisson concept, shown in Figure 6-5, provides no cooling other than the heat sink effect of the large concrete structure, i.e., heat is lost out the sides of the caisson.* The outside wall of the concrete will become heated slightly once equilibrium is reached. A slight degree of cooling will take place on the outer concrete wall due to natural convection. If there is any wind or ventilation flow, the concrete will also be slightly cooled by forced convection. This caisson concept could work either outside or inside a building.

The concept shown in Figure 6-6, underground spent fuel storage without auxiliary cooling,** is almost the same as the caisson storage designed by AGNS for their proposed storage of hulls and general process trash.(7, 8, 9) It was demonstrated in the AGNS design that the use of an engineered berm would alleviate some of the design problems concerning earthquakes, floods, and heat removal. The details of such a berm are discussed in other parts of this report (see Section 7.0). It may be possible to fabricate caissons directly in the ground without a berm because of the low seismic classification. If this were possible, it would eliminate the expense of designing and building a berm.

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*Nukem of Germany,(11) Ontario Hydro of Canada,(12) and the Nevada Test Site(13, 14, 15) have proposed dry storage concepts for storing spent fuel that utilize the aboveground caisson concept with no auxiliary cooling.

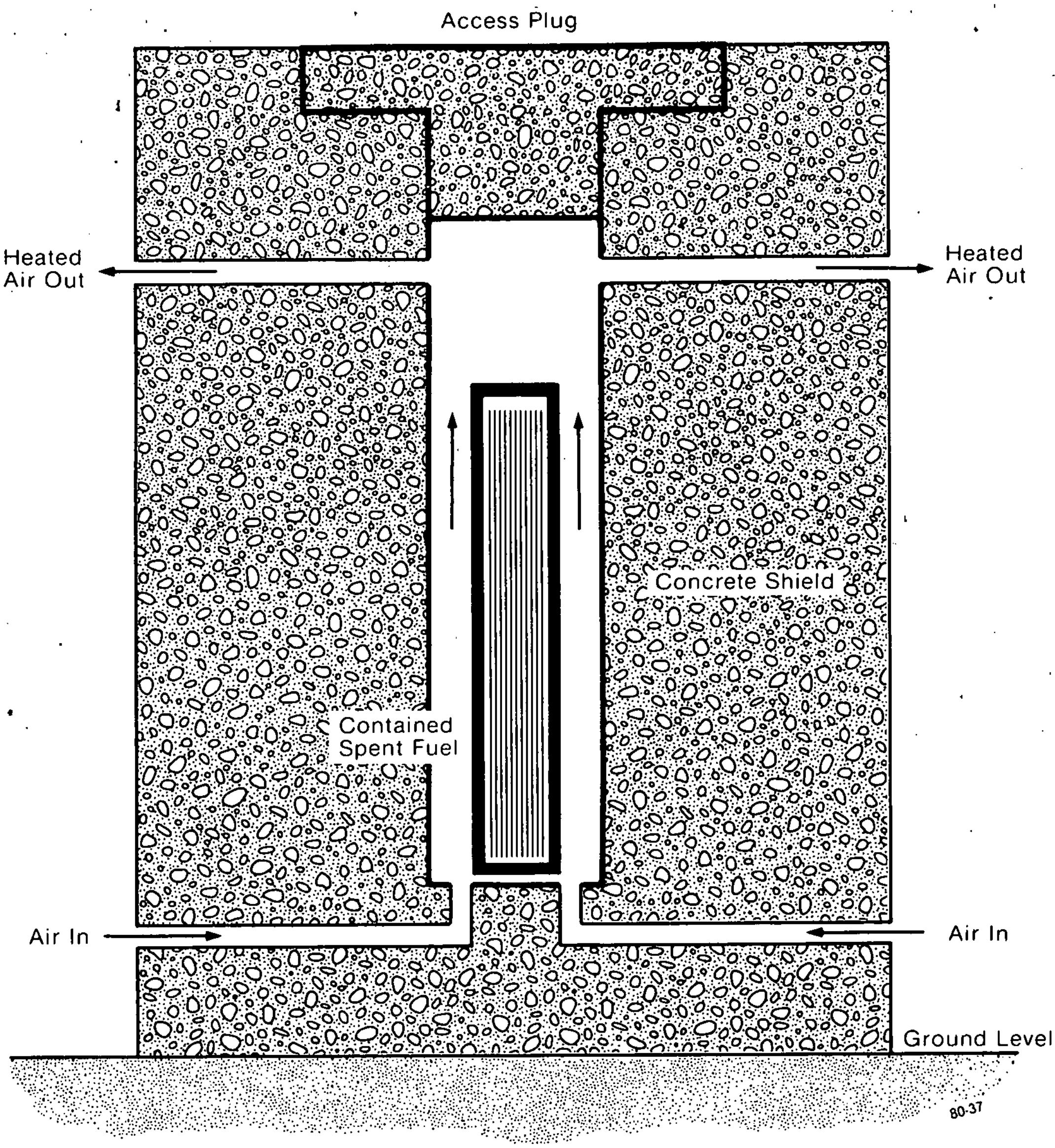
**The Nevada Test Site(13, 14, 15) and the Atlantic Richfield Company(16) have both proposed dry storage concepts for storing spent fuel that employ caissons, or silos, below ground with no auxiliary cooling.

The caisson concepts would require that spent fuel be placed within a storage container. This operation would be performed in the RPC and fuel could be either disassembled or left intact for storage. The spent fuel storage containers would be placed within a bottom-loading shielded cask and transported to the underground caisson facilities. For aboveground storage the containers would be moved to the Caisson Loading Facility for insertion into concrete caissons.

At the outdoor underground storage site, a platform is placed over the storage caisson to interface with the loaded spent fuel container. The loaded spent fuel cask is placed on the platform using a gantry crane. The cask doors and platform doors are opened and the loaded spent fuel container is lowered by a captive hoist into the caisson. Following disengagement from the container, the hoist cable retracts into the cask and the doors on both the cask and platform are closed. The cask is placed on its trailer and a shielding plug is placed on the caisson. The platform is then ready to be moved to the next caisson and the on-site spent fuel cask may be returned to the RPC to pick up another spent fuel container.

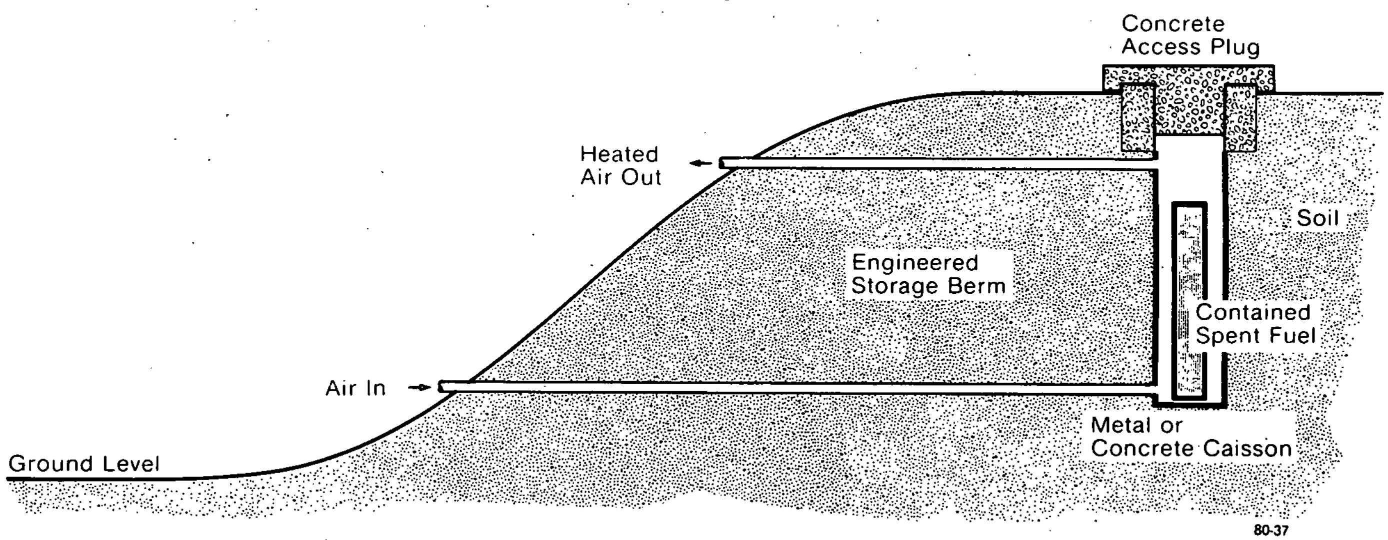
For aboveground caisson storage, the spent fuel will be placed into containers and then into concrete caissons in the RPC. This would eliminate the need of an on-site transport cask, but it would complicate the material handling problems within the RPC and the Caisson Loading Facility (see Drawings 533D-A-5014 and 533D-A-5015). The concrete caissons will be bulky and very heavy (about 100 tons).

An alternative to the Caisson Loading Facility would be to transport the spent fuel containers in a cask to the caisson storage area. A separate facility built specifically for loading the fuel containers into concrete caissons would be located adjacent to the outdoor storage area. A shielded mobile boom crane would be used to place the loaded concrete caissons in place aboveground.



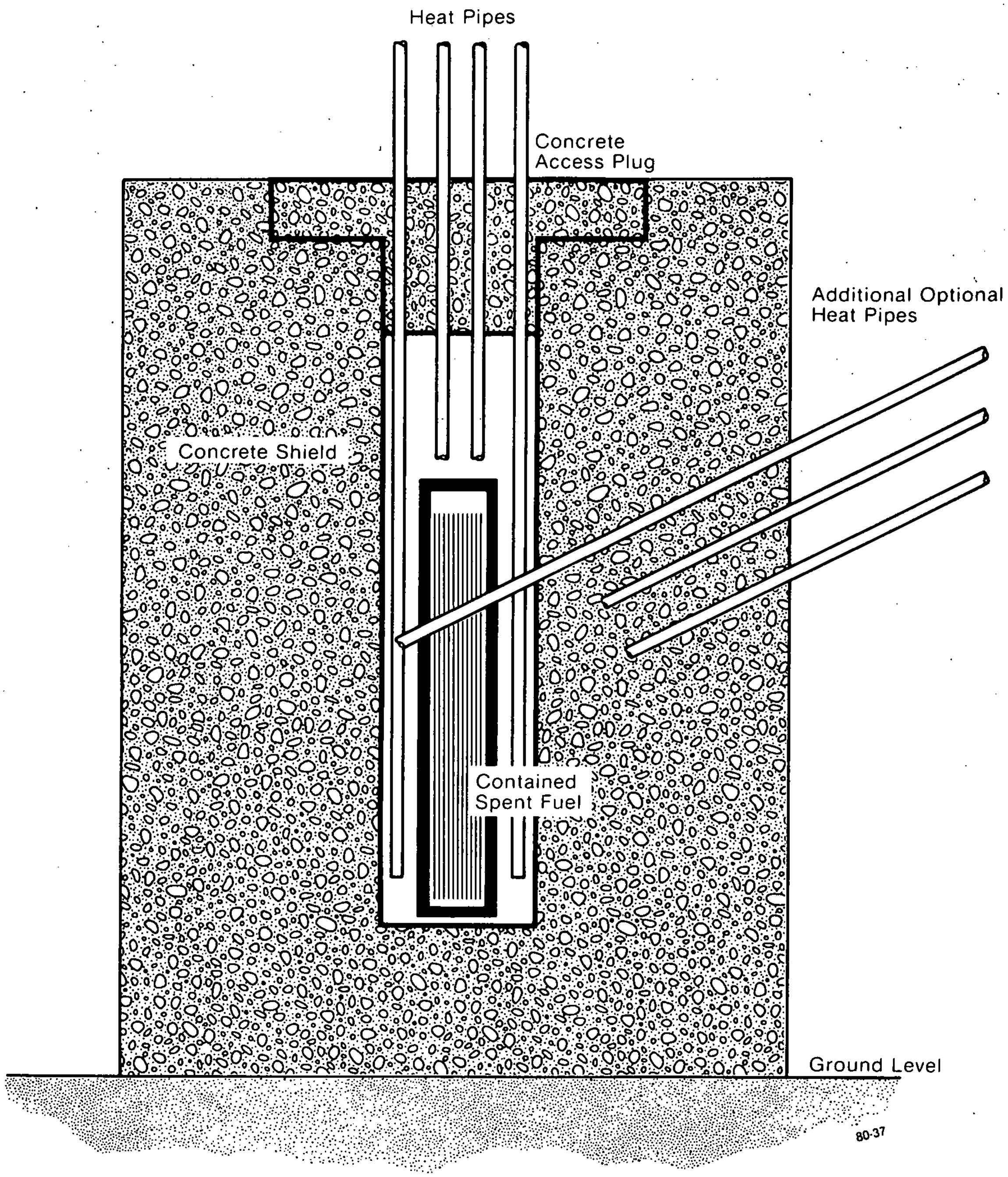
CAISSON - NATURAL CONVECTION - ABOVEGROUND

FIGURE 6-1



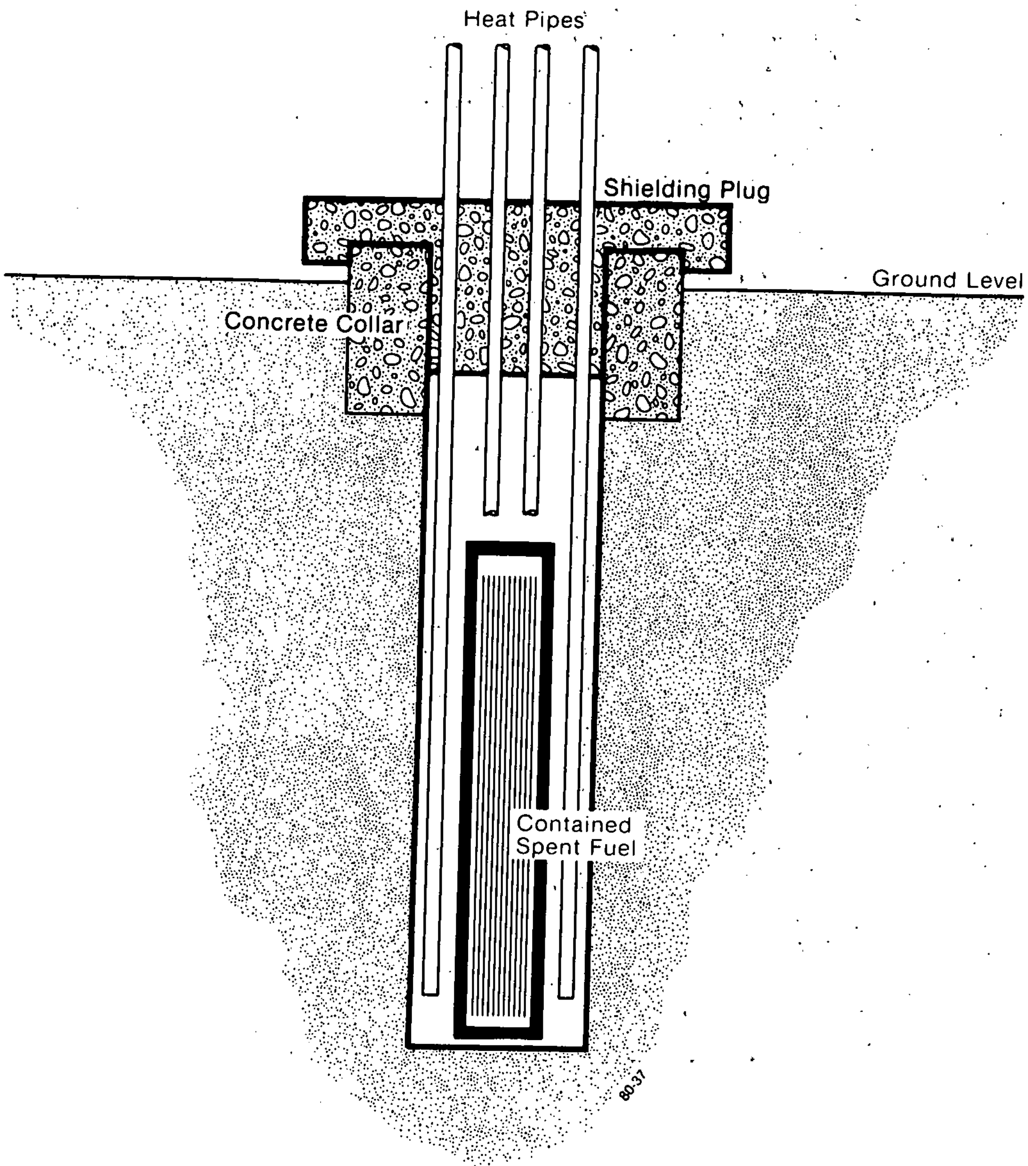
CAISSON - NATURAL CONVECTION - BELOW GROUND

FIGURE 6-2



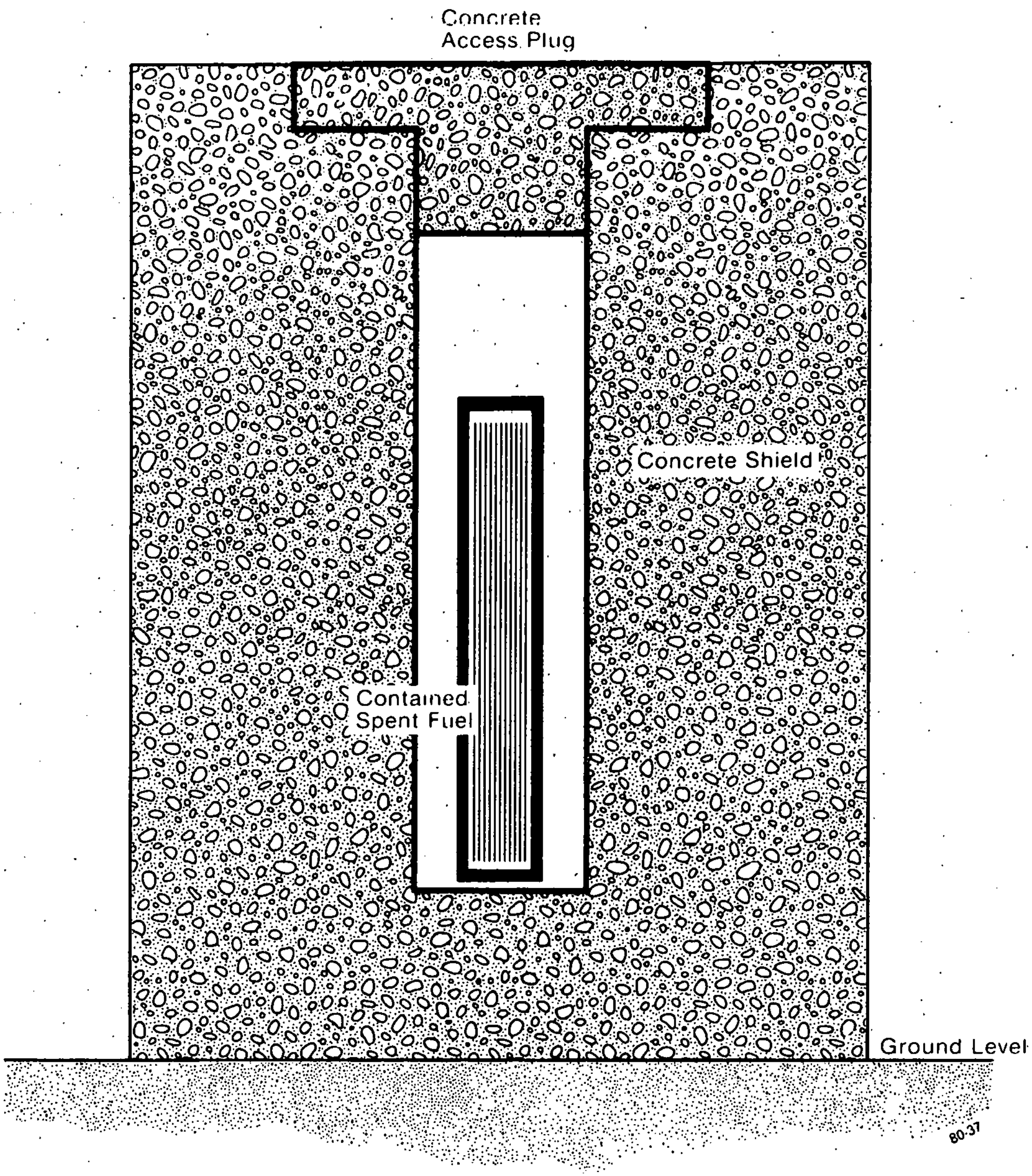
CAISSON ABOVEGROUND WITH HEAT PIPES

FIGURE 6-3



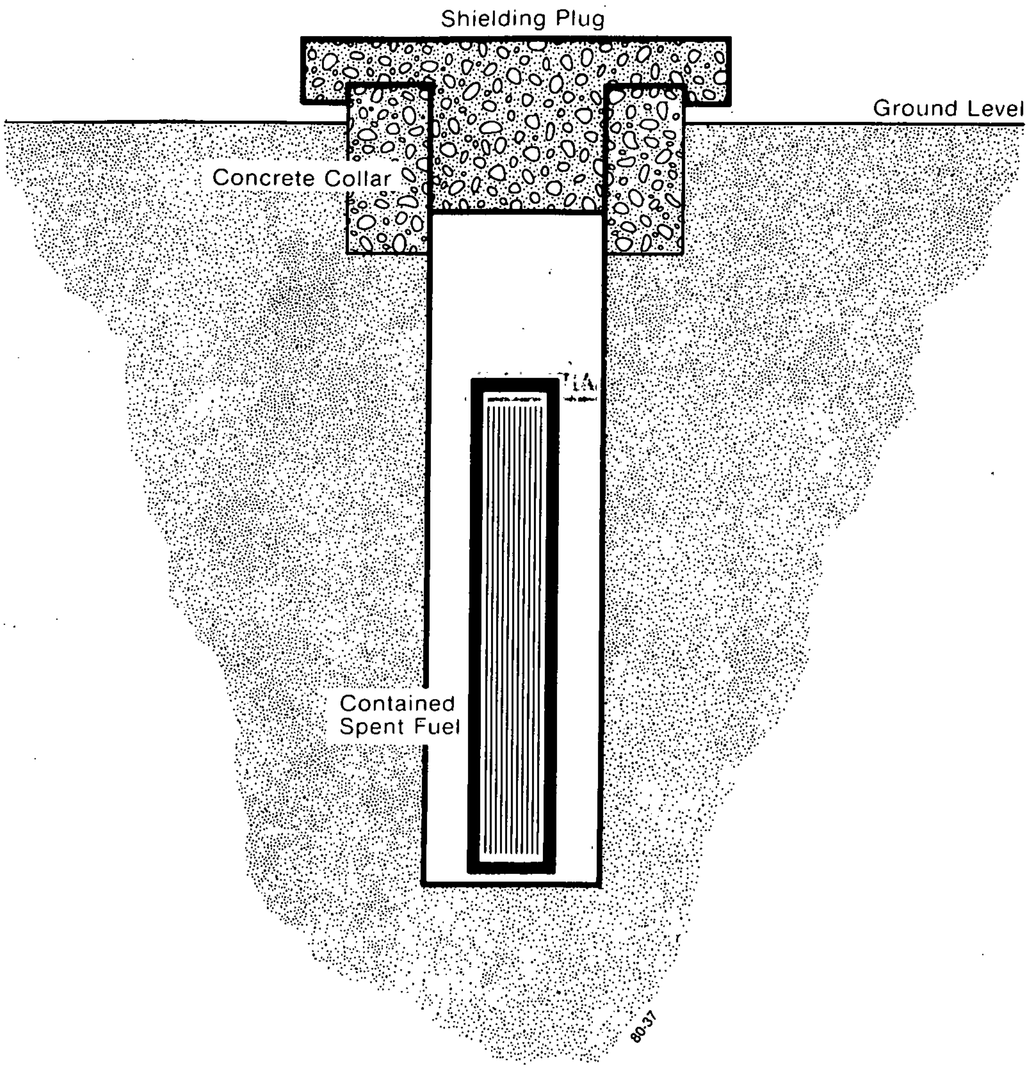
CAISSON BELOW GROUND WITH HEAT PIPES

FIGURE 6-4



CAISSON ABOVEGROUND WITH NO COOLING

FIGURE 6-5



CAISSON BELOW GROUND WITH NO COOLING

FIGURE 6-6

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7.0 ENGINEERED BERM

The caisson storage concepts discussed in this report may, or may not, require an engineered berm. This would be decided by a safety analysis. It was assumed that the below ground concepts would require an engineered berm, while the aboveground concepts would not.

By using an engineered berm*, the entire caisson assembly may be placed in soil above grade level. The berm is erected from materials having known permeability and ion exchange properties. The caissons, which may be metal, are thus isolated from the natural soil, which could be acidic. This approach also allows a three-dimensional dry-well monitoring system to be installed before the berm materials are set in place. Any leakage is monitorable while still within the berm.(4)

The use of a berm also helps in determining that the containment systems will not be breached during a design basis seismic event or a tornado. It is much easier to calculate the effect of design basis accidents if the properties of the soil are well known, as in the case of an engineered berm.

An example of an engineered berm is shown in Figure 7-1. A clay pad is laid at the existing grade level and is covered with a layer of relatively large aggregate. The purpose of the clay and gravel layers is to break the capillary communication between the original soil and the berm. The aggregate is then covered with another clay layer to provide additional capillary contrast. The remainder of the berm is constructed of a homogeneous fill having known ion exchange properties and a pore structure which is more open and free draining than the clay pads.

In the fill, above the clay pads, a horizontal network of monitoring pipes is laid which can be made of any appropriate material. The berm material is added and capped with another relatively impermeable clay layer. The toe of the berm is open, in the manner of an earth fill dam, to provide an escape route for water which may pass through any breach in the clay cap. A monitorable surface drainage system is provided for surface run-off from the berm.

In the case of underground caisson storage concepts, holes are excavated in the berm and corrugated caissons (or concrete "silos") are set in place. Large aggregate is placed around the metallic caisson. The purpose of the aggregate in this case is to: (1) break the capillary communication between the caisson itself and the soil, and (2) insulate the metal from any acidic soil.

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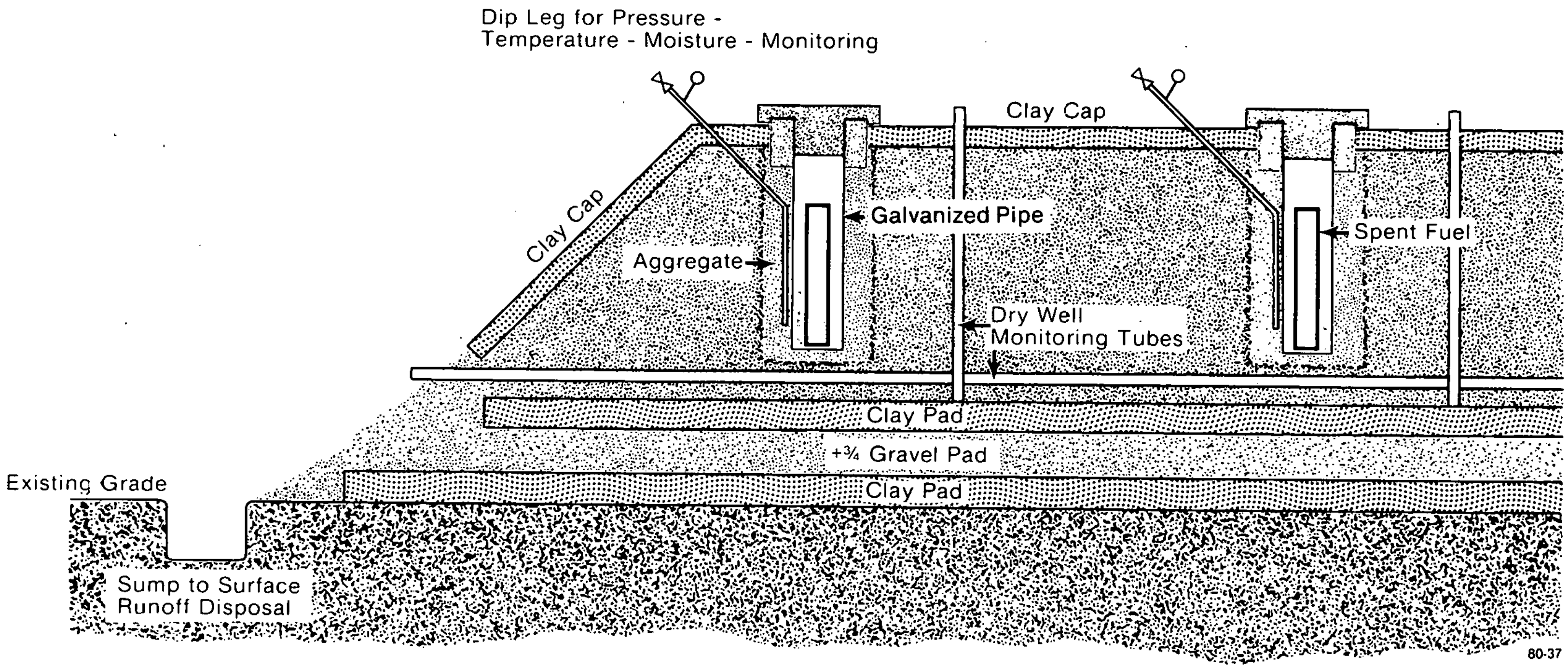
*An engineered berm such as described here becomes a barrier in the confinement system. It could replace one of the fuel containers except in the natural convection case where the berm is bypassed.

The caisson may be equipped with a dip leg for monitoring purposes which is, in turn, equipped with a valve and a pressure gauge. An accumulation of water or change in activity level inside the caisson can be detected via this route. Beside each caisson is a dry well which, coupled with the underlying pipe network, yields a three-dimensional "fix" on any leaked radioactivity. The cover blocks are designed to seal the top of the caisson.

Since caisson breathing will be minor and since tornado criteria (3 psi) is not sufficient to break a properly design cover-block seal, there is no reason to provide for continual airflow. If, however, the need arises, a small HEPA filter could be mounted on the dip tube and the valve left open.



ENGINEERED BERM CONCEPT CAISSON STORAGE

FIGURE 7-1

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8.0 DISCUSSION

Regardless of the spent fuel storage concept employed, certain features will be common to all. The dry storage facility (caisson, vault, etc.) may be divided into the following functional areas[21] including:

(1) A truck and railroad receiving bay providing washdown of vehicles and air lock ventilation control

(2) A cask receiving and decontamination area where casks are removed and decontaminated before being placed onto on-site transport vehicles

(3) Various operating areas for control and operation of the facility

(4) A fuel handling and transfer area where fuel is removed from the shipping casks in a dry environment, inspected, placed within a storage container, and transferred to storage

(5) A fuel storage area for the dry storage of LWR spent nuclear fuel

(6) Miscellaneous support areas providing for emergency power, health physics, emergency monitoring, heating, ventilation, data acquisition, etc.

Each concept discussed, in addition, may or may not utilize fuel disassembly and encapsulation which has the effect of reducing the volume occupied by the fuel and reducing the number of canisters by a factor of two and eliminating nonfuel-bearing components from storage.

Regardless of the vault concept chosen for dry storage, the storage racks must be designed to remain subcritical for all credible degrees of moderation, reflection, and stored fuel interaction. The racks must also be designed to maintain their structural integrity during all credible accident scenarios. The design of critically safe storage racks is similar for each of the vault storage options. It might be possible, however, to fabricate dry storage racks from carbon steel or other materials less costly than the materials of construction (generally stainless steel) used for underwater storage. A dry storage facility would result in a slightly higher exposure to the general public in the event of a criticality incident, but would be so designed as to still remain within existing guidelines. Criticality within a caisson is not a problem, as discussed in this report (there is only one storage container in each caisson).

In all the concepts discussed in this report, the fuel is placed within a fuel storage container. Whether the fuel is left intact (one assembly/container) or compacted via disassembly (two PWR or four BWR assemblies/container), it will be placed within a storage container. This storage container will protect and contain the fuel for a minimum period of 20 years. The most likely material of construction will be stainless steel, although other metallic materials may be acceptable depending upon detailed engineering evaluations. The fuel container is assumed to be a 9-1/4 inch by 9-1/4 inch square with 1/8 inch thick walls. The 9-1/4 inch square design was selected because it accommodates both intact PWR assemblies and disassembled PWR and BWR spent fuel assemblies. The ends will be remotely mechanically capped, although remote welding of the cap is possible. The lid will be tamper-proofed and each container will bear an unremovable, easily read, identification number.

There are several reasons for placing the intact fuel assemblies within fuel storage containers. These reasons include: (1) the fuel could drop off particles of radioactive crud, cladding, or even fuel and they would still remain secure at the bottom of the container and would not contaminate the storage area, (2) from an accountability standpoint, each container can be identified easier from the permanent markings made on each container, (3) from a safeguards standpoint, each container may be individually capped and a tamper-proof seal or lock may be attached, (4) the racks will be less expensive to fabricate since they may now be simply support brackets made from angle iron, pipes, etc., (5) the storage container may meet the qualifications to be classified as a containment barrier and, therefore, the fuel would be one step closer to permanent disposal even as it waited on its interim dry storage site, (6) from an operations standpoint, there would be a maximum of two sizes of storage containers (BWR and PWR) compared with various widths and lengths of fuel assemblies, (7) a fuel assembly encased in the proposed storage container would be able to better survive accident scenarios involving impacts, rough handling, etc., and (8) if desired, the container could be loaded with fuel and then some medium other than air (helium, water, neutron poisons, etc.) could be sealed within the container to provide better heat transfer, less corrosion, or reduce the possibility of criticality. It is not known, at this time, whether the use of individual containers would be beneficial or undesirable in its impact upon seismic criteria.

8.1 Integration of Wet and Dry Storage

If one were designing a dry storage facility "from scratch," it would be more economical to build either wet pool storage or dry storage but not both. A unique advantage of the BNFP is that a fuel storage designer is not starting from scratch. Indeed, there is already an existing pool specifically designed for the storage of LWR spent fuel. To increase the spent fuel storage capacity of the BNFP, one has a choice of expanding pool storage or adding dry storage.

If one were to combine wet and dry storage at the same location (e.g., BNFP), the pool would be used for high burnup fuel recently discharged from a reactor, say one- to five-year-old fuel. The dry storage would handle only fuel that had been stored at least five years after discharge from a reactor. This segregation of fuel results because the wet storage mode, due to water's capability to reject greater quantities of heat than air, is capable of storing fuel which has a much higher heat load. This five-year or greater storage period would normally be accomplished at the utility storage pools but could also be done at the BNFP pool. For example, assume a group of assemblies three years old (from discharge) is transported to the BNFP and placed in the pool. After two more years, this fuel could be removed and placed in dry storage.

Of course, the only reason one would want to remove fuel from wet storage into dry storage is if the dry storage were less costly, safer, or suitable space was already available at the facility. Otherwise, one would just build more pools and accommodate increased storage requirements. Whether dry storage is less costly is difficult to judge without a detailed cost comparison of the two storage modes. Intuitively, the dry storage would be less expensive because it is less complex than pool storage. However, Reference 21 concludes that wet and dry spent fuel storage facilities, based on feasibility studies, would result in approximately the same cost.

If fuel were stored long enough, perhaps 10 years following discharge from LWR's, then it could even be possible to design a dry storage facility that relied on passive means for heat removal. Such passive means might include cooling fins, heat pipes, or natural convection. Forced convection could be eliminated and along with it a large portion of the facility cost. Using passive cooling, a dry storage facility would quite likely cost less than a wet storage pool.

8.2 RPC and RMSC

The use of the RPC for spent fuel storage is shown conceptually in Drawings 533D-A-5002 and 533D-A-5003. It was originally intended to show that the RMSC could also be used for fuel storage, but physical constraints (e.g., limited height) within the RMSC and other operational uses of the cell made this undesirable, if not impossible. The plan view (Drawing 533D-A-5002) shows the proposed disassembly equipment in the RPC, and all of the equipment associated with reprocessing removed except for the existing windows, manipulators, and cranes.

It is assumed that the FRSS pool is also utilized for storage of fuel (particularly fuel that has not had a chance to cool a long time). Therefore, fuel would enter the BNFP in truck or rail casks and be handled and unloaded in the same manner that was originally proposed for reprocessing. Fuel would enter the RPC via the fuel transfer canal (see Drawing 533D-A-5003). Here the fuel would either be disassembled or left intact. In either case, the fuel would be placed in a storage container and placed in the storage rack.

Compared to other alternatives, the use of the RPC for dry fuel storage is impractical. The total storage area, assuming the fuel has been compacted by disassembly, is only 438 MTU. Just as important as the inadequate capacity is the fact that the use of the RPC for storage hinders the disassembly operations planned for the RPC. If disassembly were not conducted in this cell, the capacity would not increase (indeed, it decreases) because the extra room made available by removing the disassembly equipment is more than lost by the fact that fuel is no longer compacted and intact fuel assemblies are stored.

In addition, the storage of fuel is expected to be for an interim period of time, approximately 10 to 30 years. The RPC is essential for reprocessing LWR fuel. If the RPC were committed to storage, the potential use of the BNFP, sometime in the future, for reprocessing would be severely restricted. For these reasons, the RPC is considered impractical for storing spent fuel (except for relatively small quantities used for in-cell operations or tests) and its use for this purpose will not be pursued further.

8.3 Contact Cells

The use of the contact cells (UPC, ILC, HLC, HILC, and PPC) at BNFP for the dry storage of spent fuel is shown in Drawings 533D-A-5004 (plan view) and 533D-A-5005 (elevation view). All of the existing tanks and piping are shown removed and portions of the walls between the individual cells would also be removed. An overhead crane has been added that runs the length of the five cells. Maintenance for the crane would be performed in the crane maintenance area (formerly the PPC). A portion of the wall between the RPC and the HILC has been removed (shown in Drawing 533D-A-5005) to allow fuel transfer between the two cells.

Two of the negative features of utilizing the RPC for storage are eliminated by using the contact cells, i.e., the limited storage capacity and the interference with the potential disassembly operations. The only major disadvantage of using the contact cells is that the potential option of using BNFP at some future date for reprocessing would be lost. The five cells currently contain most of the equipment necessary for the separation of the dissolved LWR fuel into uranium and plutonium streams and the subsequent processing of those streams.

Fuel would be unloaded in the FRSS pool and brought to the RPC via the transfer canal. In the RPC, the fuel is either placed in storage containers directly, or first disassembled (compacted) and then placed into storage containers. The contained fuel is then transferred by the fuel transfer cart to the contact cell storage area. An overhead crane lifts a container (filled with fuel) and places it in a storage rack.

Due to the height of the cells, fuel may be vertically stacked (double-tiered) which yields a storage capacity of 3341 MTU for disassembled fuel and half that for noncompacted fuel. This is a large enough capacity to make the contact cells a viable dry storage option for LWR spent fuel. Any expansion of this capacity would be difficult, however, since these cells are surrounded by existing facilities.

8.4 FRSS Pool

The fuel receiving and storage station pool may also be used for the dry storage of spent fuel and is shown in Drawings 533D-A-5006 (plan view) and 533D-A-5007 (elevation view). Fuel would enter the BNFP in truck or rail casks and be unloaded into the test and decontamination pit. The cask would be cooled down by steam/water and then lifted by the 135-ton crane and lowered into the Cask Unloading Pool (CUP) via the cask access hatch (see Drawing 533D-A-5007). The crane would be unhooked from the cask, leave the CUP, and the access hatch would be replaced.

Spent fuel inside the cask would be remotely removed and sent to the RPC to be either disassembled and placed in a container or to be placed into a container intact. The containerized fuel would be sent back to the FRSS pool and placed into a storage rack. The capacity of the FRSS would be about 976 MTU for disassembled fuel and 488 MTU for intact fuel.

To convert the FRSS pool to accommodate dry spent fuel storage would require extensive modifications. In wet storage, the water acts as a radiation shield, but since the water is removed for dry storage, a structure would need to be added over the pool area to provide shielding. A large movable shielding wall would also need to be added to seal off the CUP area to allow maintenance to be performed on the pool crane.

The use of the FRSS for dry fuel storage is a misallocation of resources. Wet storage of spent fuel is much better for removing thermal loads, particularly from one- to five-year-old fuel, than dry storage is. In addition, dry storage would decrease the storage capacity of the pool and would add additional costs due to the many modifications required to allow the pool to be used for dry storage. The use of the FRSS for dry storage appears undesirable and impractical. This concept will not be pursued further.

8.5 Waste Tank Storage

The use of the existing, but modified, waste tanks at BNFP for the dry storage of spent fuel is shown in Drawings 533D-A-5008 (plan view) and 533D-A-5009 (elevation view). As with the other concepts discussed so far, fuel enters the FRSS and is sent to the RPC for possible disassembly and containerization. At this point, the scenario changes for the waste tank storage concept.

The waste tanks (there are three 400,000-gallon tanks at the BNFP) are located away from the Separations building, which contains the FRSS and RPC. To get the containerized fuel from the Separations area to the waste tanks requires the use of an on-site transport cask. This cask is envisioned to be bottom unloading, similar to an existing cask at the BNFP which was to be used to transport hulls containers. The cask would transport one to four spent fuel containers to the waste tanks for unloading (see Drawing 533D-A-5009).

A polar-type crane would be used to deposit the fuel within a storage rack. A crane maintenance and an operating/viewing area would also be provided. All of the internal piping and equipment now in the waste tanks would be taken out. The modifications required to transform the waste tanks into a dry spent fuel storage facility are extensive and costly.

All three waste tanks together would provide about 3600 MTU capacity for disassembled fuel and about 1800 MTU capacity of intact fuel. Future expansion would be limited by physical constraints and economics.

The use of the waste tanks for dry storage of spent fuel appears to be unrealistic and uneconomical compared with some of the other concepts reviewed in this report. The limited expansion capability, the costly modifications, and the difficult operating conditions combine to eliminate the waste tanks from further consideration in this report as a dry spent fuel storage concept.

8.6 PNC No. 1 and No. 2

The use of the plutonium nitrate cells (PNC) for the dry storage of spent fuel is shown conceptually on Drawings 533D-A-5010 (plan view) and 533D-A-5011 (elevation view). Spent fuel entering the BNFP, in this concept, would first be containerized in the RPC and placed inside an on-site transport cask. The cask would be transported by truck to the cask unloading bay which would be built next to the PNCs.

The cask would be removed from the truck, lifted up, and then lowered through the access hatch into the cask unloading cell. The fuel would be removed from the cask and placed horizontally in the storage area. Horizontally oriented storage was selected, despite operational problems, because the existing cell height precludes vertical placement.

The walls of the existing PNC's are from 18- to 20-inches thick. To be used for spent fuel storage, the walls would need to be increased in thickness by three to four feet. In addition, the wall separating cell No. 1 from cell No. 2 would need to be removed as would all of the existing slab tanks and shielding panels. All of the facilities to unload the cask and handle the fuel would need to be constructed.

The use of the PNC's would restrict the potential use of the BNFP for reprocessing spent fuel. Physical constraints would limit the expansion of the PNC's if additional storage was desired. The present capacity of the PNC storage concept is 366 MTU. Because of the many negative features of using the PNC's for fuel storage (most notably the extensive modifications and new construction required), this concept has been rejected and will not be studied further.

8.7 Emergency Utility Area (EUA)

As with many of the other concepts reviewed, the use of the EUA for fuel storage only makes sense (to even consider) if it is assumed that the use of the BNFP for reprocessing is not a viable option, i.e., the BNFP would not be used for reprocessing. The EUA, modified for spent fuel storage, is shown conceptually in Drawings 533D-A-5012 (plan view) and 533D-A-5013 (elevation view). Spent fuel would first be containerized in the RPC (disassembly is optional) and sent to the EUA inside an on-site truck cask.

The cask would be placed inside a cell and remotely unloaded. The spent fuel would be placed in storage racks via cranes. The capacity as shown in Drawing 533D-A-5012 is 2680 MTU.

Very little of the existing EUA building would be usable in its present form. All of the equipment presently inside would need to be removed. The existing walls would need to be increased in thickness (by three to four feet) and additional hot cells would need to be constructed for handling the spent fuel. The modifications would be very extensive, in fact, it would probably be easier and perhaps less costly to build a new facility rather than trying to modify the EUA. Overall, the negative aspects of utilizing the EUA for spent fuels storage outweigh any positive factors. Therefore, the EUA will be eliminated from further consideration as a dry spent fuel storage facility.

8.8 Caisson Storage Aboveground

Caisson storage aboveground will first require that incoming fuel be containerized in the RPC, where it may also be disassembled (optional). The packaged spent fuel will be transported through the GVOS fuel transfer tunnel (new construction) and into the Caisson Packaging Facility. Once the fuel is placed into a concrete caisson, the caisson will be loaded onto a truck and sent to the aboveground caisson storage area.

8.8.1 Caisson Packaging Facility

The Caisson Packaging Facility (CPF) is shown in Drawings 533D-A-5014 (plan view) and 533D-A-5015 (elevation view). This facility is not used for storage in the aboveground caisson concept but only to load spent fuel containers into concrete caissons.

The concrete caissons themselves are assumed to be fabricated at the BNFP site and transported to the CPF. The transporting vehicle, presumably a large flat-bed truck, would back into the CPF truck loading and unloading bay. The caisson handling crane would unload the empty caisson and set it down in the caisson storage area.

To load a caisson with fuel, an empty caisson would be taken out of storage, via the storage crane, and lowered into the caisson loading cell through the access hatch in the cell's ceiling. The caisson would be detached from the crane, the crane would be lifted out of the cell, and the cover blocks in the ceiling would be replaced. The lid on the caisson would be removed with the in-cell crane.

Meanwhile, spent fuel containers would be loaded into a fuel transfer cart in the RPC and decontaminated in the fuel transfer tunnel. Smear samples would be taken and deposited into a glovebox where radiation readings would be taken. If the samples showed the container was still too "hot" from external smearable contaminants, it would be decontaminated further (a second decontamination for any container would be unusual). When the container was deemed clean, it would be transferred into the caisson loading cell via the fuel transfer cart.

In the caisson loading cell, the overhead crane would lift up a spent fuel container and deposit it within a concrete caisson. The caisson lid would be placed back on top of the caisson and locked. The entire operation inside the caisson loading cell is free from contamination and once the spent fuel is placed inside the caisson, it is also essentially free of radiation.

A filled caisson may be lifted out of the cell and temporarily set down in the caisson storage area. The shielding provided by the caisson's concrete reduces outside surface radiation levels to safe working levels. For this reason, the caisson may be approached by personnel and tasks, such as attaching identification tags, painting, additional locking of the lids, etc., may be performed manually without the use of remote equipment. When the required security and accountability operations have been performed, the caisson is lifted by the handling crane and set upon the bed of the truck. This could be the same truck that brought in an empty caisson. The truck would then transport the caisson to the on-site storage location.

The storage site, known as the Caisson Spent Fuel Storage Area (CSFSA), would consist of approximately 20 acres of land dedicated to dry spent fuel storage. The storage area is shown in Drawing 533D-A-5016. It would require about 12 acres of land to store 2000 MTU of mixed PWR and BWR fuel. This assumes disassembled fuel spaced 15 feet apart, center to center. Two PWR assemblies or four BWR assemblies are stored in each caisson.

8.9 Caisson Storage Below Ground

The below ground caisson storage area is shown in Drawing 533D-A-5017. Fuel that arrives at the Barnwell Nuclear Fuel Plant and is determined to be destined for dry storage, would be first sent to the RPC to be containerized. The fuel would be placed individually, or in small groups, within a metal container. A lid would be placed on top of the container and secured in place.

Fuel containers would be loaded out of the RPC (or perhaps the RMSC) via a bottom loading cask, similar to the existing hulls cask at the BNFP. This cask would be lifted onto a flatbed truck and transported to the below ground caisson storage area. A gantry crane would lift the transport cask and place it above a storage caisson. The lower shielding doors on the cask would be opened and a fuel container would be lowered into a caisson.

The cask would be removed and the crane would place a concrete shielding lid over the loaded caisson. The conceptual design only shows one container (two PWR assemblies or four BWR assemblies) in each caisson, although it would be possible to have more than one fuel container per caisson.

Each caisson would include a concrete pad, at ground level, to accept the size and weight of the transport cask. These concrete pads could be combined to form a solid mat above the storage area or they could be just large enough to support the cask, allowing for drainage between the concrete pads. Which of these variations is used would depend upon cost and drainage requirements. The caissons are assumed to be spaced 15 feet apart and will require about 12 acres of land for 2000 MTU of fuel storage (assuming disassembled fuel). Two PWR assemblies or four BWR assemblies are stored in each caisson.

The below ground storage concept shown on Drawing 533D-A-5017 uses an engineered berm. A detailed description of such a berm is discussed in Section 7.0 of this report. The below ground caissons could also be used in non-engineered soil, if a safety analysis confirmed the validity of this approach. In general, the below-ground storage concept is viewed as being more difficult to expand (particularly if an engineered berm is used) than would be the aboveground storage concept.

8.10 Storage Vault Concept

A dedicated vault storage concept for the dry, interim storage of LWR spent fuel is shown in Drawings 533D-A-5018 (plan view) and 533D-A-5019 (elevation view). The conceptual facility is shown attached to the west side of the existing FRSS and the south side of the existing Separation Plant at the BNFP.

As with the other conceptual storage facilities and scenarios discussed, the spent fuel is first containerized in the RPC. As with all the concepts, the fuel may be left intact or disassembled. Intact BWR and PWR fuel would be individually placed in approximately 6-inch square and 9-inch square metal containers, respectively. Disassembled fuel would be placed in 9-inch square containers; 2 PWR assemblies/container, or 4 BWR assemblies/container.

Full containers of fuel would be sent out of the RPC through an airlocked decontamination area (which would be part of what is now the GVOS). The decontamination step is optional since the containers will remain in a hot-cell type vault remotely stored for perhaps 10 to 30 years. The decontamination step may be used to facilitate general "housekeeping" rather than necessary to preclude the spread of contamination outside the facility.

The spent fuel containers are transferred from the decontamination area into the fuel storage area. An in-cell crane will place the container in a storage rack for interim storage. The fuel storage area shown on Drawing 533D-A-5018 has a capacity of about 2000 MTU, which is comprised of 70% BWR assemblies and 30% PWR assemblies (see Table 2.1). A crane maintenance area is provided at the southern end of the storage area.

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9.0 CONCEPTS ELIMINATED FROM FURTHER CONSIDERATION

The following concepts, discussed in Section 8.0, have been eliminated from further consideration:

- FRSS pool without water
- Waste tank storage
- Emergency Utility Area Building (EUA)
- PNC Nos. 1 and 2
- Remote Processing Cell (RPC)

The use of the FRSS pool for dry storage of spent fuel was eliminated because: (1) extensive modifications would be required to protect personnel from excessive radiation exposure and to remove the fuel's thermal load, (2) use of the pool for dry storage does not allow acceptance of even moderate quantities of short-cooled fuel, and (3) pools appear to be more expensive than hot-cell facilities; and, therefore, the use of the pool for dry storage appears to be a misallocation of scarce resources.

The use of the three existing waste tanks for dry storage of spent fuel at BNFP was eliminated because: (1) extensive modifications would be required, (2) it would be a misallocation of resources, (3) storage capacity would be restricted from expansion, (4) operations would be awkward and difficult, and (5) it would severely limit the use of BNFP at some future date for the reprocessing of spent fuel.

The Emergency Utility Area (EUA) was eliminated from further consideration because: (1) extensive modifications would be required, (2) storage capacity would be limited, and (3) the potential use of BNFP for reprocessing would be restricted.

For similar reasons, the plutonium nitrate cells Nos. 1 and 2 were rejected. The PNC's would (1) require extensive modifications, (2) have a very limited storage area, (3) severely limit the use of BNFP for potential reprocessing, and (4) require building new access facilities.

Lastly, the RPC was rejected because: (1) storage capacity would be very limited, (2) storage would interfere with the disassembly operations, and (3) the use of the RPC for fuel storage would limit the potential use of BNFP for possible reprocessing of spent fuel at some later date.

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10.0 SHIELDING ANALYSIS SUMMARY

It was determined that PWR fuel would, in general, require more shielding than BWR fuel; so, the shielding analysis was based on PWR fuel. The analysis is presented in the Addendum to this report.

The following fuel specifications were used in the shielding analysis:

Fuel	PWR
Maximum enrichment (%U235)	4.1
Maximum burnup (MWd/MTU)	33,000
Maximum specific power (Mw/MTU)	35
Assembly outside square (inches)	8.55
Maximum active fuel length (feet)	12.5
Fuel loading (MTU per assembly)	0.480
Number of assemblies in storage (%)	70
Canister outside square (inches)	9.25
Canister wall thickness (inches)	0.125
Disassembled assemblies per canister	2

An ORIGEN calculation was performed to generate neutron and gamma-ray source terms (see Table 2 of Addendum). The computer program QAD shielding calculations included the neutron-concrete Kernel and gamma-ray point Kernel techniques. Concrete nuclide densities are summarized in Table 4 of the Addendum. The shielding models used in the QAD analysis are illustrated in Figures 7 through 10 of the Addendum.

For shielding analysis purposes an array of about 1800 PWR fuel containers was assumed to be uniformly spaced within a vault (hot cell). The containers (2 PWR assemblies in each container) are assumed to be spaced about 15 inches apart, centerline to centerline.

An example of the shielding analysis results which shows ordinary concrete thickness, to achieve a 0.1 millirem/hour dose rate, for various PWR assembly heat loads, is shown below. More detailed results are described and illustrated in the Addendum.

	Heat Load, Kw/PWR Assembly			
[0.1 millirem/hr @ 1 foot]	4.0	2.0	1.0	0.5
Caisson wall, thickness (inches)	64	63	61	57
Cassion ceiling, thickness (inches)	50	48	46	43
Vault wall, thickness (inches)	70	69	66	63
Vault ceiling, thickness (inches)	64	63	60	57

The dose rate of 0.1 millirem/hour shown above is a conservative limit. A more realistic limit might be about 1 millirem/hour. A chart similar to the one above is shown below for a dose rate of 1.0 millirem/hour at one foot from the concrete on the "cold" side.

[1.0 millirem/hr @ 1 foot]	Heat Load, Kw/PWR Assembly			
	4.0	2.0	1.0	0.5
Caisson wall, thickness (inches)	56	55	52	49
Caisson ceiling, thickness (inches)	42	40	38	35
Vault wall, thickness (inches)	62	60	57	54
Vault ceiling, thickness (inches)	56	54	52	49

One can see from the above that for reasonable dose rates and heat loads (which reflect the time from reactor discharge) the shielding required from the caisson walls, in general, is about 4 to 5 feet of ordinary concrete. The shielding required for vault (hot cell) walls, in general, is about 4-1/2 to 5-1/2 feet of ordinary concrete.

It should be noted that the caissons will normally be much further away than one foot which was used in the shielding analysis. In actual storage the caissons will be placed in an open area with at least one fence surrounding the storage site. Personnel would not get any closer than 100 to 200 feet except to move or handle the caissons for brief periods of time. Therefore, the wall and ceiling thicknesses of the caissons could probably be reduced while still maintaining safe conditions to personnel and the general public.

A summary of the caisson wall shielding requirements at 10 and 100 feet from the caisson's exterior wall is given below.

	Distance (feet)	Dose (mrem/hr)	Heat Load Kw/PWR Assembly			
			4.0	2.0	0.1	0.5
Caisson wall, thickness (inches)	10	0.1	57	55	52	50
↓	10	1.0	48	46	44	40
↓	100	0.1	41	40	38	34
↓	100	1.0	33	31	28	25

Another dose rate calculation was made involving "sky shine" (radiation reflected from a source by the atmosphere) during the loading of an underground caisson. The dose would be received by personnel who would be semi-remotely installing the shielding lid on an underground caisson. The fuel in this analysis was assumed to have the following properties: 4.1% enriched, 29,000 MWd/MTU burnup, 32 MW/MTU specific power, and 2-year cooled (conservative). The dose point location in both cases was assumed to be three feet above ground level. The tops of the fuel rods were located at an elevation of -5.5 feet relative to ground level. It was determined that the dose rates due to gamma sky shine from 1.0 MTU of fuel, located in an open caisson hole in the ground, were 170 mrem/hour at 10 feet from the hole and 6 mrem/hour at 50 feet.

11.0 THERMAL ANALYSIS SUMMARY

The means of storing LWR spent fuel will be based, to a great extent, on thermal considerations. An analysis was performed to determine the feasibility, for various concepts, of storing spent fuel in a dry environment. The complete analysis (includes shielding and thermal considerations) is presented as an Addendum to this report. In general, surface and centerline temperatures were determined for intact fuel, disassembled fuel, and fuel stored in arrays for the various storage concepts. Heat loads of 4 kW, 2 kW, 1 kW, 0.5 kW, and 0.25 kW per fuel assembly (both BWR and PWR) were analyzed. Various concepts for storing the spent fuel in a dry mode were reviewed for feasibility from a thermal standpoint. Various means of cooling such as natural convection, forced convection, use of heat pipes, use of cooling fins, and no cooling devices were also analyzed for their feasibility.

11.1 No Auxiliary Cooling

Part of the thermal analysis was to determine the feasibility of not cooling the spent fuel (no auxiliary cooling devices). It was assumed that the walls of the vault were 5-foot thick concrete. A 2000 MTU array of 30% BWR/70% PWR assemblies (more conservative than design bases) each with a heat load of 1 kW was assumed to be stored within the vault. The temperatures reached by the fuel and the concrete were in excess of safe storage conditions, which makes the "no cooling" concept infeasible. This situation results from the low thermal conductivity of concrete, the relatively low operating temperature limit of concrete, and the relatively small surface area within a vault to dissipate heat. The decay heat from 2000 MTU of stored fuel is shown (for various individual assembly heat loads) in Table 9 of the Addendum.

The aboveground caisson concept with no cooling is feasible for intact and disassembled fuel assemblies, if adequate space surrounds each caisson. Table 10 in the Addendum summarized the caisson wall, canister surface, and fuel pin temperatures utilizing the aboveground caisson concept.

The below ground caisson concept with no cooling is also feasible for intact and disassembled fuel assemblies, if the decay heat is no greater than 1 kW for a PWR and 0.5 kW for a BWR fuel assembly. Calculated temperatures are presented in Table 11 of the Addendum.

11.2 Natural Convection

The thermal analysis (Appendix B of the Addendum) indicates that natural convection cooling is feasible and adequate to cool vaults and caissons to the maximum limit of decay heat studies (4 kW for PWR and 2 kW for BWR fuel assemblies), if the vault and caisson are constructed to freely permit the entrance and exit of air. Thus, the use of natural convection relates not only to thermal feasibility but also to the suitability of convecting air around a caisson and releasing it into the environment without filtering. Perhaps double containment would be required which would increase the maximum fuel pin temperature. The thermal analysis assumed single containment for all concepts, but did not take credit for any containment offered by the fuel cladding (the actual containment system would be decided by a safety analysis). Table 12 of the Addendum presents temperatures in natural convection cooled vaults and caissons either above or below ground.

11.3 Forced Convection

Increasing the airflow velocity by forced convection (blowers) versus natural convection results in a relatively small decrease in temperature difference between the air and the fuel storage canister. Using forced convection to significantly decrease fuel pin temperature appears to be futile. The major advantage of forced convection is to provide a positive, constant supply of air that allows the placement of HEPA filters within the ventilation system (the forced air system can overcome the pressure differential across the filters and the ductwork).

11.4 Heat Pipes

Cooling by using heat pipes is feasible for all of the storage concepts. For example, in the vault storage concept a 2-inch-diameter copper heat pipe may be placed in the center of four canisters which each contain two PWR disassembled fuel assemblies (see Figure 18 in the Addendum). Four fins, each 12 inches long, conduct 8 kW of heat from the fuel assemblies by natural convection and radiation. The operating temperature of the fins is estimated to be 400 to 450°F. The rack supports may pass through holes in the fins, which will not greatly reduce the fin efficiency. The number of heat pipes required, in this example, is one-fourth of the total number of fuel canisters (assuming 2 kW heat load per canister).

11.5 Metal Fins

The concept of using fins through concrete walls is not feasible. Assuming a total conducting length of 6 feet and the use of carbon steel with a thermal conductivity of 30 BTU/hr-ft-°F, the maximum temperature differential across the fins is 400°F. By assuming a maximum concrete temperature of 500°F (very conservative) and a total decay heat of 5089 kW (1.736 E7 BTU/hr), the cross sectional area of the fins calculates to be approximately 26,000 square feet. This represents a prohibitively large mass of steel. To reduce the concrete to a more reasonable temperature, say less than 200°F, would require even more fins.

12.0 CONCLUSIONS

The storage of LWR spent fuel in a dry environment appears to be technically feasible and intuitively more economical than wet storage, if existing wet facilities are not already available. For small quantities of spent fuel (an individual reactor site), it is probably more economical to store utilizing the caisson approach rather than vault storage. For larger quantities of spent fuel, the vault storage concept is probably less costly.

The major difference among the various vault and caisson concepts is the means of eliminating the radiolytic decay heat from the fuel. The thermal analysis demonstrated that the only concepts that are not feasible on a thermal basis are the "no auxiliary cooling" concepts and the use of metal fins.

The most timely and least costly approach appears to be storing the spent fuel at an existing nuclear facility. Previous studies[18] have surveyed existing hot cell facilities in the United States to determine their ability to receive, handle, disassemble, and reconstitute full-length Light Water Reactor (LWR) spent fuel assemblies. Several of the hot cells examined would be adaptable to the storage of spent fuel.

Of the nine methods evaluated (see Table 12-1 for summary of storage concepts) for utilizing the BNFP for dry storage of spent LWR fuel, five have been rejected from further consideration. The five rejected concepts are: (1) FRSS pool without water, (2) waste tanks, (3) Emergency Utility Area building, (4) PNC Nos. 1 and 2, and (5) the RPC. The above concepts were rejected for a variety of reasons, but in general, because they required extensive modifications to the BNFP, the operations would be difficult, the storage capacity would be limited, and their use would severely limit the use of BNFP for other purposes, e.g., reprocessing.

The four remaining concepts are all deemed feasible for dry storage of LWR spent fuel. The four concepts include: (1) contact cells, (2) caisson storage aboveground, (3) caisson storage below ground, and (4) a dedicated storage vault. This study was made assuming that the BNFP would not be used for reprocessing now or in the future. If the BNFP were to be used for reprocessing, the concept of utilizing the contact cells for spent fuel storage would be totally impractical.

The caisson (above and below ground) and dedicated vault storage concepts could be used at BNFP or at hundreds of other possible locations. However, existing facilities at Barnwell make the use of the BNFP very attractive compared with virtually any other potential storage site, including existing national laboratories. The BNFP may utilize the existing RPC for fuel disassembly and containerization. The site also has a relatively large, new, and uncontaminated pool that may be used to store relatively hot fuel (cooled one to five years after discharge from an LWR). In addition, the close location of the RPC, the pool, and available adjacent land (either for vault storage or for the caisson loading facility) will facilitate the handling of the spent fuel.

To meet the shielding constraint of 0.1 millirem/hour dose rate limit at one foot from the concrete wall or ceiling on the "cold" side, 43 to 70 inches of ordinary concrete are required for a range of 0.5 to 4.0 kW/PWR assembly, respectively, in caisson or vault storage of LWR spent fuel. To meet the shielding constraint of 0.1 millirem/hour dose rate limit at ten feet from the caisson concrete wall on the "cold" side, 49 to 57 inches of ordinary concrete are required for a range of 0.5 to 4.0 kW/PWR assembly in caisson storage of LWR spent fuel. To meet the shielding constraint of 0.1 millirem/hour dose rate limit at one hundred feet from the caisson concrete wall on the "cold" side, 33 to 42 inches of ordinary concrete are required for a range of 0.5 to 4.0 kW/PWR assembly in caisson storage of LWR spent fuel.

Vaults, either above or below ground or for intact or disassembled fuel assemblies, can not adequately conduct sufficient decay heat across their walls to dissipate the heat without some type of auxiliary cooling.

A single-canister caisson above ground can dissipate the decay heat adequately, but below ground, auxiliary cooling is required for canister decay heat greater than approximately 2 kW, depending on established design criteria.

Natural convection cooling of a vault and a caisson in which air is circulated into and out of the vault and caisson is feasible if large openings are provided at the bottom and top of the vault and caisson with no filters in the inlet or outlet. No attempt was made to quantify pressure drops across filters and determine their effect on cooling.

Forced convection, although not theoretically needed for thermal performance of a vault or caisson, is desirable to supply specific quantities of coolant air. Forced convection also assures adequate pressure head for filtering the coolant air, which might eliminate double containment depending on safety analyses.

A properly finned heat pipe is a good passive system that can remove sufficient quantities of decay heat in a vault or caisson. Also, sufficient numbers are required that a built-in redundancy is provided when installed in a vault, i.e., if several heat pipes should fail, the total heat dissipation capability would not be significantly reduced. Installing metal fins through the concrete wall of a vault or caisson is not thermally practical due to the amount of fins required and is not recommended.

TABLE 12-1

SUMMARY OF SPENT FUEL DRY STORAGE CONCEPTS AT BNFP

Dry Storage Location	Disassembled (Compacted) Capacity (MTU)	Remarks Concerning Dry Storage of Spent Fuel
RPC and RMSC	438	Impractical - limited capacity - operational problems
Contact Cells	3341	Desirable assuming no reprocessing - Facilities in place - cost effective - vertically stacked (two tier)
FRSS Pool	976	Impractical - extensive modifications
Waste Tanks	3600	Undesirable - extensive modifications
PNC No. 1 and No. 2	366	Impractical - limited capacity - extensive modifications
EUA	2680	Undesirable - extensive modifications
Caisson - Aboveground	2000 + (unlimited)	Acceptable storage concept - some handling problems with heavy caissons
Caisson - Below ground	2000 + (unlimited)	Good storage concept - harder to expand than aboveground - may require engineered berm
Vault	2000 +	Good storage concept - expansion in modules - existing technology

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ADDENDUM

SPENT FUEL DRY STORAGE STUDIES AT BARNWELL NUCLEAR FUEL PLANT

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September 1980

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Final Report

on

THERMAL AND SHIELDING ANAYLSIS

OF THE

ALLIED GENERAL NUCLEAR SERVICES

CAISSON AND VAULT

LWR SPENT FUEL STORAGE

prepared for

Allied General Nuclear Services

August 12, 1980

by

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ABSTRACT

A shielding analysis was performed for light water reactor (LWR) spent fuel storage in caisson and vault environments for parametric decay heat in kilowatts/assembly. The shielding wall and ceiling requirements for ordinary concrete vary from 70 to 43 inches for caisson and vault storage over a range of 4 to 0.5 KW/PWR assembly. These shielding requirements provide dose rate limits of less than 0.1 millirem/hour at one foot away from the concrete on the "cold" side.

To provide dose rate limits of less than 0.1 millirem/hour at ten feet away from the concrete on the "cold" side, the shielding requirements for ordinary concrete vary from 57 to 49 inches for caisson storage over a range of 4 to 0.5 KW/PWR assembly.

To provide dose rate limits of less than 0.1 millirem/hour at one hundred feet away from the concrete on the "cold" side, the shielding requirements for ordinary concrete vary from 42 to 33 inches for caisson storage over a range of 4 to 0.5 KW/PWR assembly.

Thermal analyses were performed for PWR and BWR spent fuel stored in vaults and caissons above and below ground and for an engineered berm for various cooling methods. Ranges of decay heat of 0.25 to 4 kw per PWR fuel assembly and 0.25 to 2 kw per BWR fuel assembly were considered. These analyses provide maximum fuel pin temperature and maximum canister surface temperature. Intact and disassembled fuel assemblies were assumed.

Also, cooling of two PWR disassembled fuel assemblies was studied for a range of decay heat of 0.5 to 4 kw per assembly, a range of divider plate thickness of 0 to 0.25 inch, a range of pin gap size (average distance between pins) of 0 to 0.009 inch, and for one side of the canister insulated. Cooling of a canister in a rack in a water pool also was analyzed.

INTRODUCTION

In compliance with the request of the May 30, 1980, letter (1) DOE/3026-80-105, DOE-3026-0.2 from the Allied General Nuclear Services (AGNS) to Ridihalgh, Eggers and Associates (REA), a thermal and shielding analysis were performed for light water reactor (LWR) spent fuel storage in caisson and vault environments. The QAD (2) point-kernel computer code with three-dimensional geometry and self-shielding capability was used to perform the neutron and gamma shielding calculations. The ORIGEN (3) isotope generation and depletion computer code was used to prepare the neutron and gamma ray source strengths and the energy spectra.

Thermal analyses were performed with mathematical models of the PWR and BWR fuel assemblies in intact and disassembled configurations. The TRUMP (4) heat transfer computer code was used to calculate temperatures for the various parametric studies. Hand calculations were used for feasibility calculations of cooling requirements, total heat load calculations, and theoretical gap sizes. Standard heat transfer correlations were used or placed in a form suitable for use in the TRUMP program.

SUMMARY OF SHIELDING AND THERMAL RESULTS

The shielding requirements of ordinary concrete to reduce the dose rate to a level of 0.1 millirem/hour at one foot from the concrete on the "cold" side are illustrated in Figures 1 and 4 through 6. Figures 2 and 3 illustrate the shielding requirements of ordinary concrete to reduce the dose rate to a level of 0.1 millirem/hour at ten and one hundred feet, respectively, from the caisson concrete wall on the "cold" side. The parameter of 4 to 0.5 kilowatts/PWR assembly is shown on all the figures. The caissons contain two disassembled PWR assemblies in a single canister and the vaults are modeled as 42 x 42 canisters containing two disassembled PWR assemblies in each canister. Figure 1 illustrates the caisson concrete wall shielding requirements at one foot from the exterior wall. Figure 2 illustrates the caisson concrete wall shielding requirements at ten feet from the exterior wall. Figure 3 illustrates the caisson concrete wall shielding requirements at one hundred feet from the exterior wall. Figure 4 illustrates the caisson concrete ceiling shielding requirements. Figure 5 illustrates the vault concrete wall shielding requirements. Figure 6 illustrates the vault concrete ceiling shielding requirements.

The results of the thermal analysis are presented in tables and figures which are presented later, and detailed calculations are presented in Appendices.

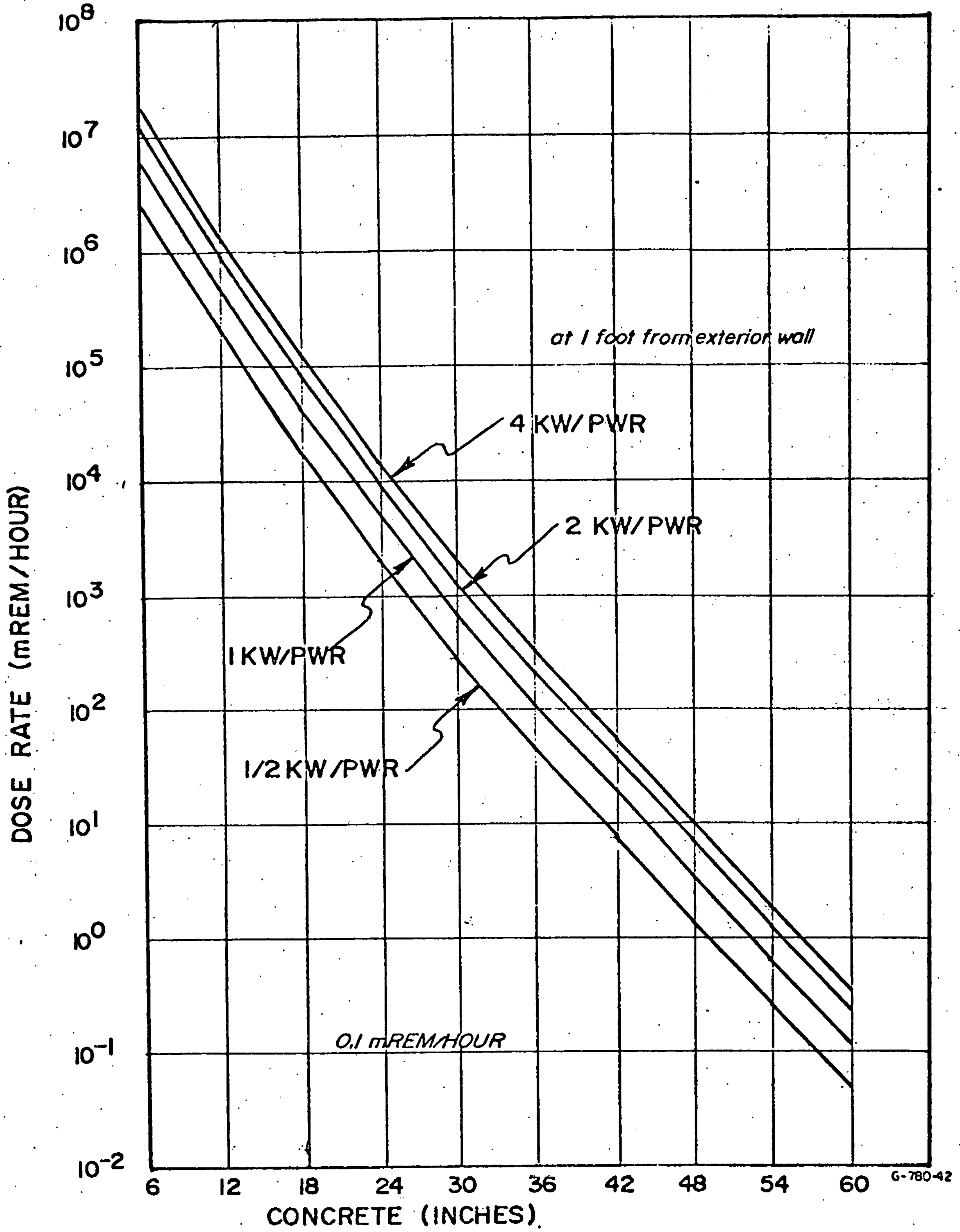


FIGURE 1 — CAISSON WALL SHIELDING REQUIREMENTS

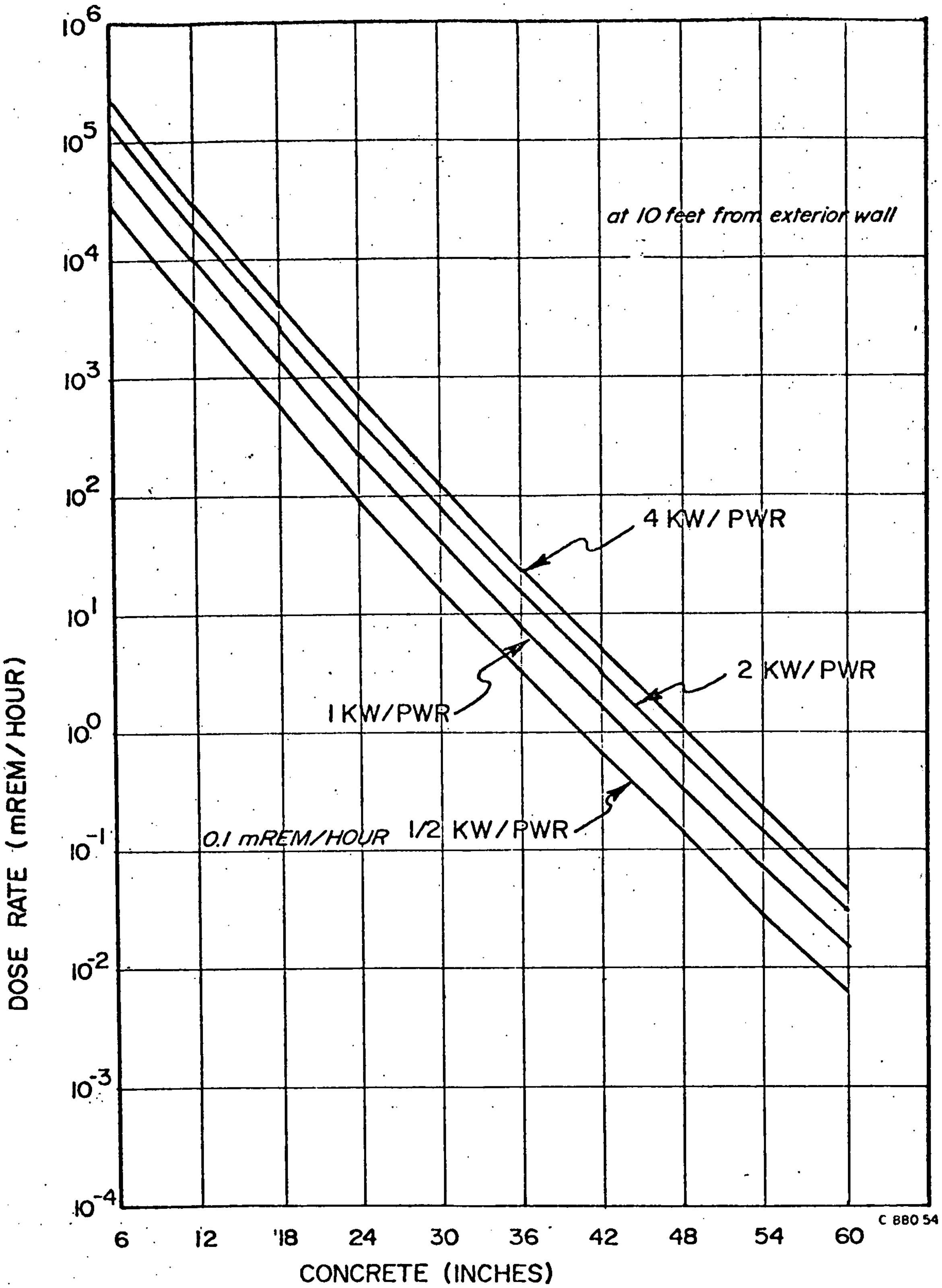


FIGURE 2 — CAISSON WALL SHIELDING REQUIREMENTS

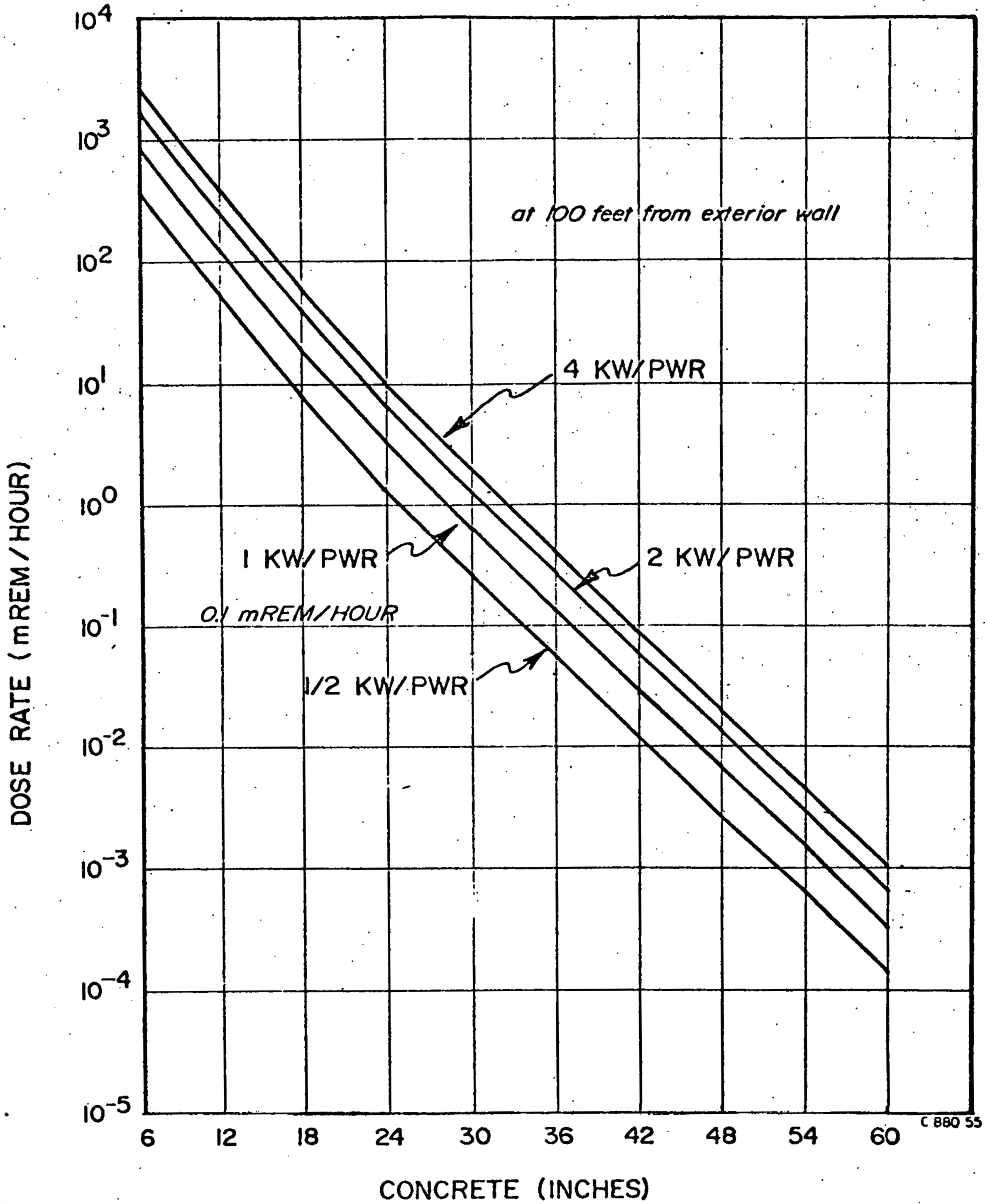


FIGURE 3— CAISSON WALL SHIELDING REQUIREMENTS

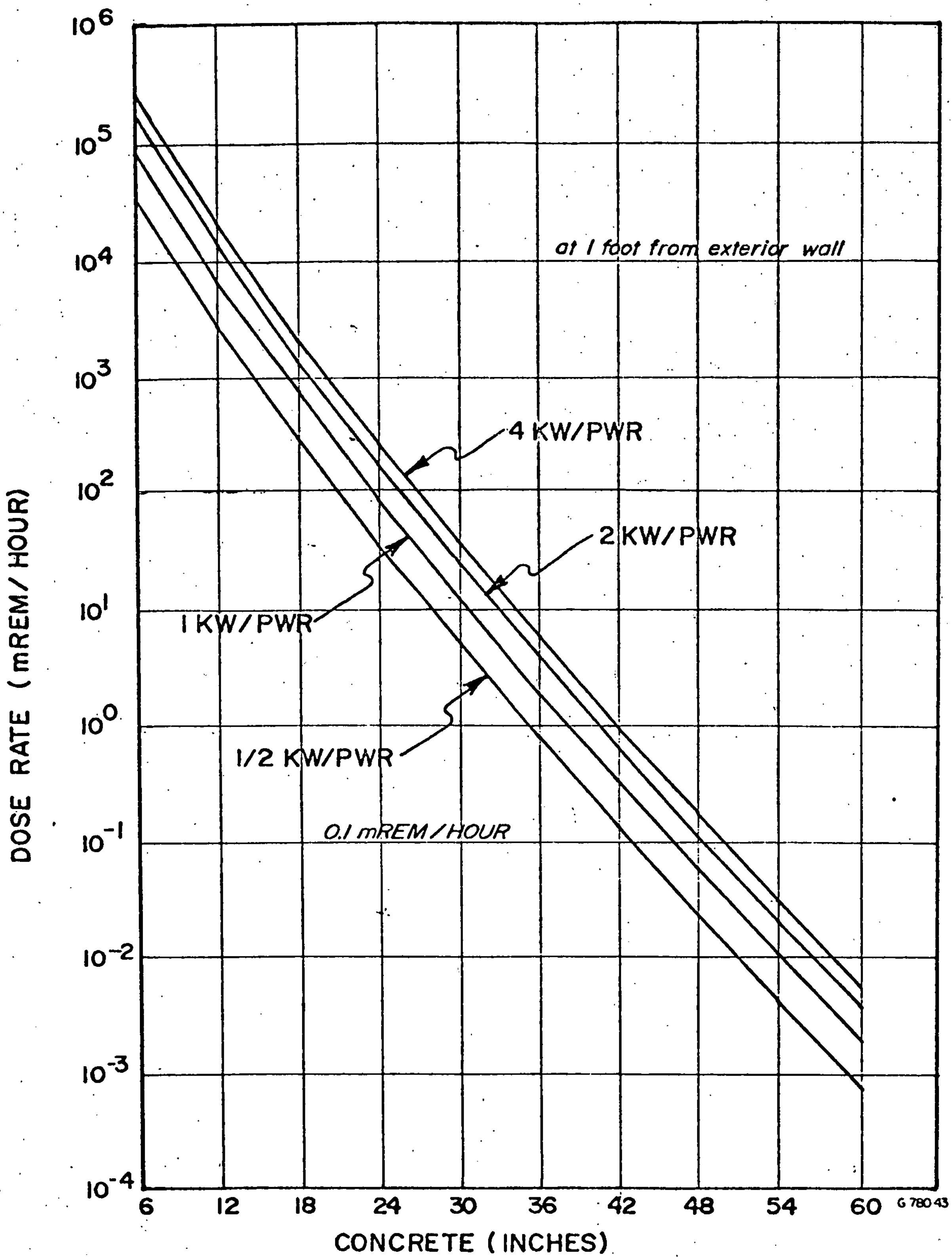


FIGURE 4 — CAISSON CEILING SHIELDING REQUIREMENTS

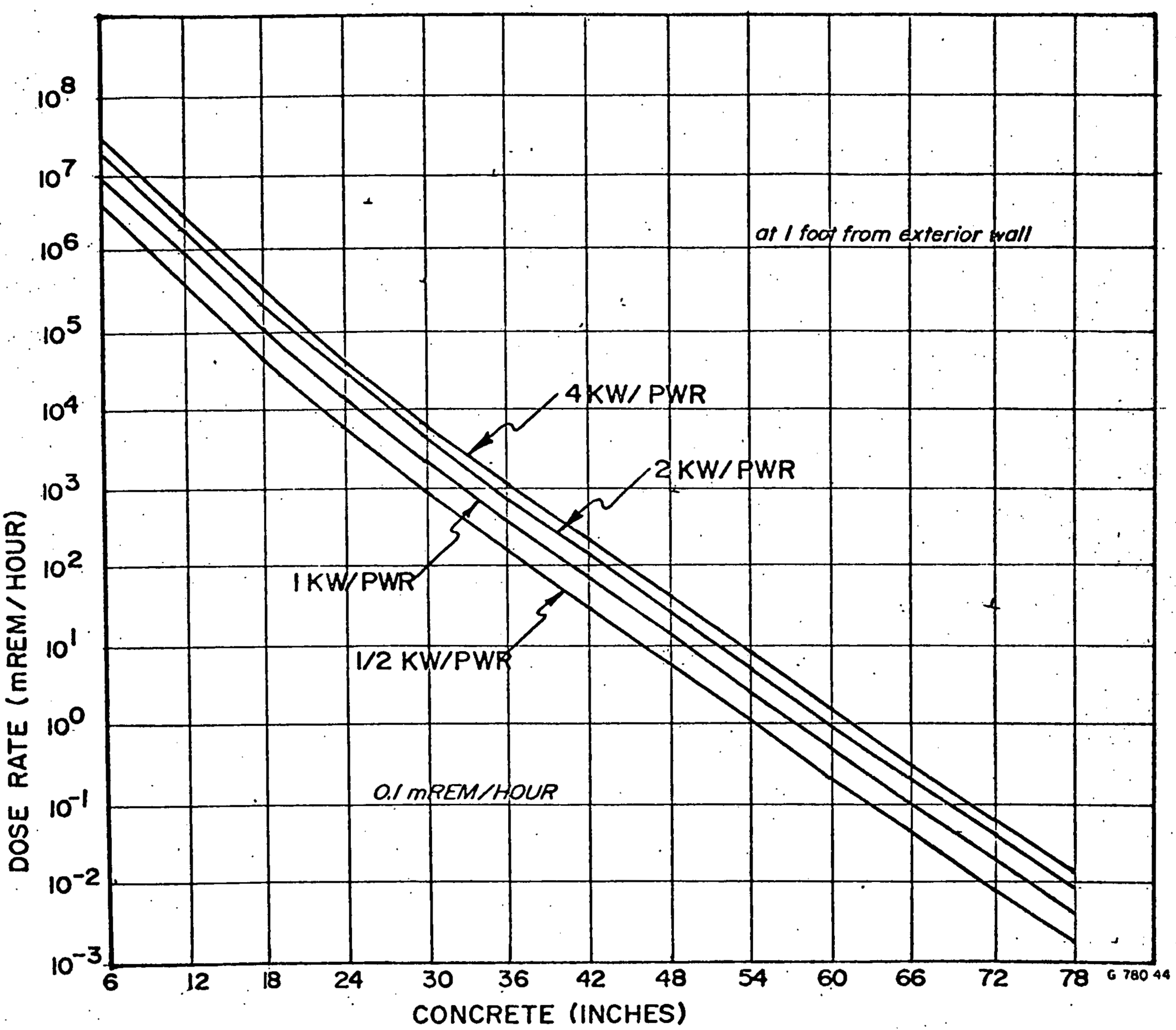


FIGURE 5 —VAULT WALL SHIELDING REQUIREMENTS

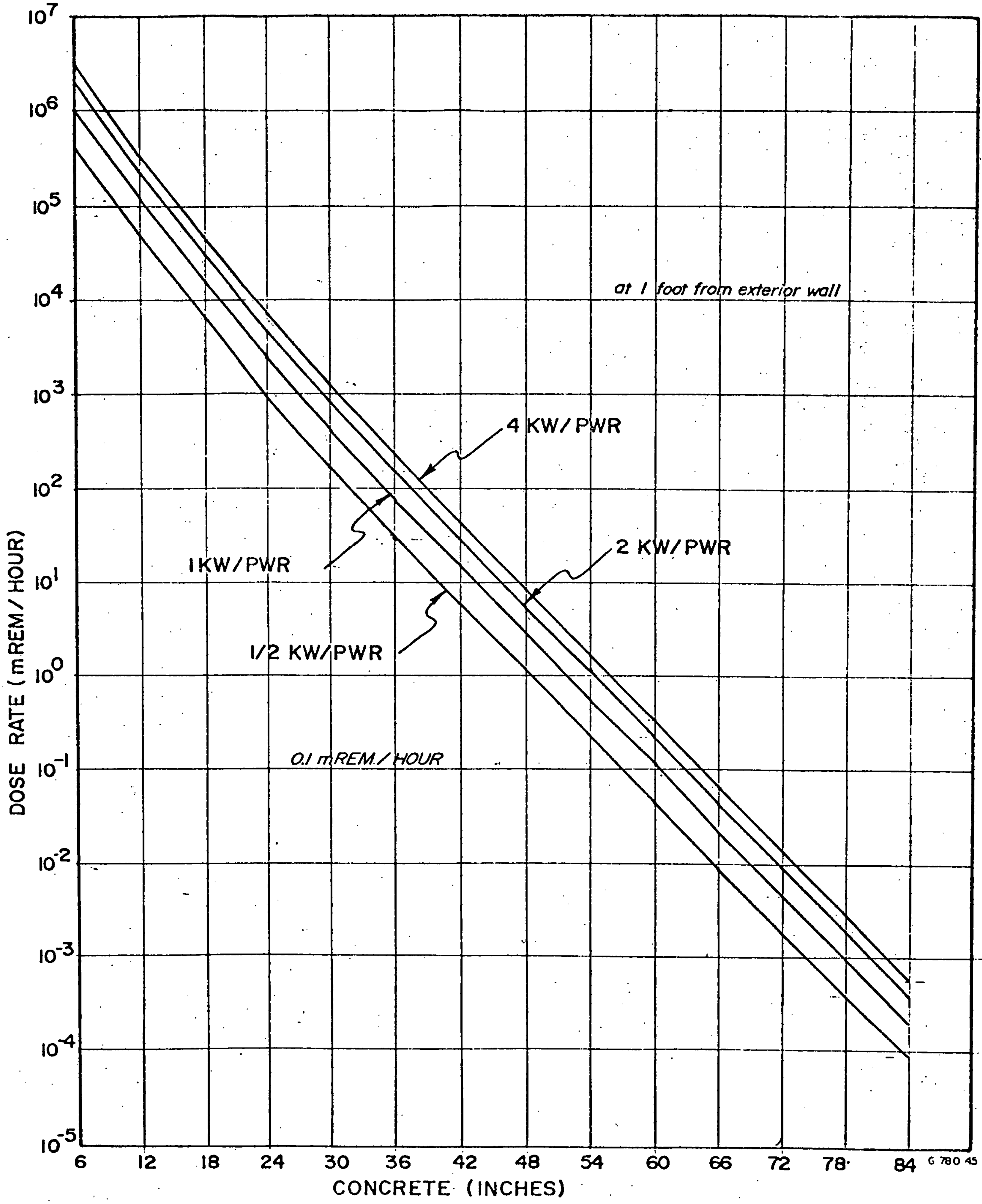


FIGURE 6 —VAULT CEILING SHIELDING REQUIREMENTS

SHIELDING DISCUSSION

The shielding analysis was based upon PWR fuel only. The fuel specifications were taken from AGNS supplied documents (5,6,7) and are reported in Table 1.

An ORIGEN calculation was performed to generate neutron and gamma-ray source terms and are reported in Table 2. The gamma photon spectrum for the 4 KW/PWR assembly fuel is outlined in Table 3.

The QAD shielding calculations included the neutron-concrete kernel and gamma-ray point kernel techniques. The concrete nuclide densities are summarized in Table 4.

The shielding geometry models used in the QAD analysis are illustrated in Figures 7 through 10. Specifically, Figures 7 and 8 are the caisson shielding model; Figures 11 and 12, the vault shielding model.

The vault storage capacity is specified to be 2000 MTU and loaded 70% with PWR assemblies and 30% with BWR assemblies. At 0.190 MTU/BWR assembly and 0.480 MTU/PWR assembly, approximately 3562 PWR assemblies may be stored or 1781 canisters of two disassembled PWR assemblies each. This constitutes an array of canisters of approximately 42 x 42 and was used in this analysis.

The caisson and vault shielding models were based upon designs in AGNS documents (8,9).

TABLE 1. FUEL SPECIFICATIONS

Fuel	PWR
Maximum enrichment (% U235)	4.1
Maximum burnup (MWD/MTU)	33,000
Maximum specific power (MW/MTU)	35
Assembly cross section (inches)	8.55
Maximum active fuel length (feet)	12.5
Fuel loading (MTU)	0.480
PWR assemblies (% of total in storage)	70
Canister outside cross section (inches)	9.25
Canister wall thickness (inches)	0.125
Disassembled assemblies per canister	2

TABLE 2. NEUTRON AND GAMMA SOURCE TERMS

KW / PWR	Cooling Time, Months	Photons / (Sec-PWR)	Neutrons / (Sec-PWR)
4	17.2	1.203(16)	8.693(7) [a]
2	41.4	7.972(15)	8.106(7)
1	62.8	3.986(15)	7.813(7)
0.5	151.7	1.639(15)	5.314(7)

(a) 8.693(7) --> $8.693*10^{7}$

TABLE 3. GAMMA SOURCE SPECTRUM FOR 4 KW/PWR

Energy (Mev)	[photons/(sec-PWR)]
0.03	1.186(11)[a]
0.04	2.127(12)
0.06	1.485(12)
0.10	1.452(10)
0.15	8.313(10)
0.20	4.684(10)
0.30	1.815(15)
0.63	9.664(15)
1.10	3.752(14)
1.55	1.287(14)
1.99	6.372(13)
2.38	5.908(12)
2.75	4.473(11)
3.25	1.409(10)
3.70	1.755(06)
4.22	1.106(06)
4.70	5.233(05)
5.25	3.291(05)
	1.203(16)

(a) 1.186(11) --> $1.186*10^{11}$

TABLE 4. ORDINARY CONCRETE DENSITY

Nuclide	Density, grams/cm^3
hydrogen	0.020
carbon	0.118
oxygen	1.116
magnesium	0.057
aluminum	0.085
silicon	0.342
sulfur	0.007
potassium	0.004
calcium	0.582
iron	0.026
	2.390

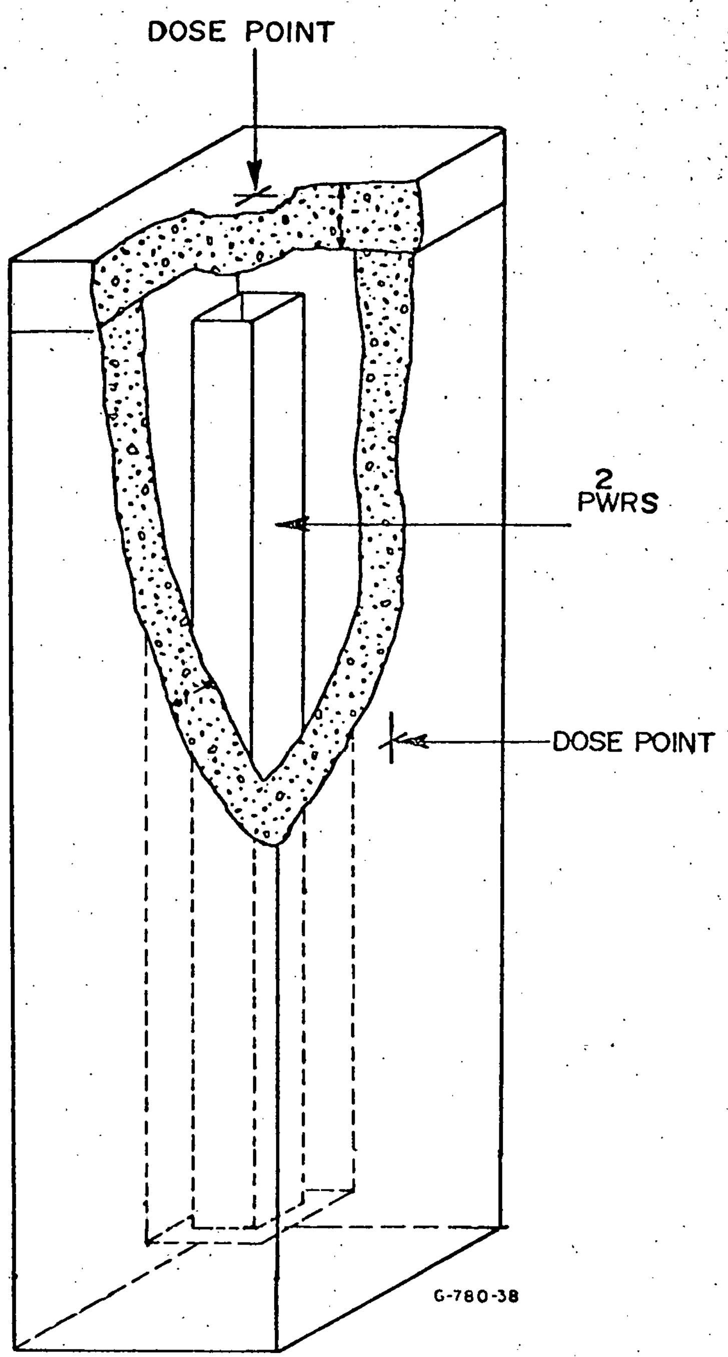


FIGURE 7 — CAISSON SHIELDING MODEL

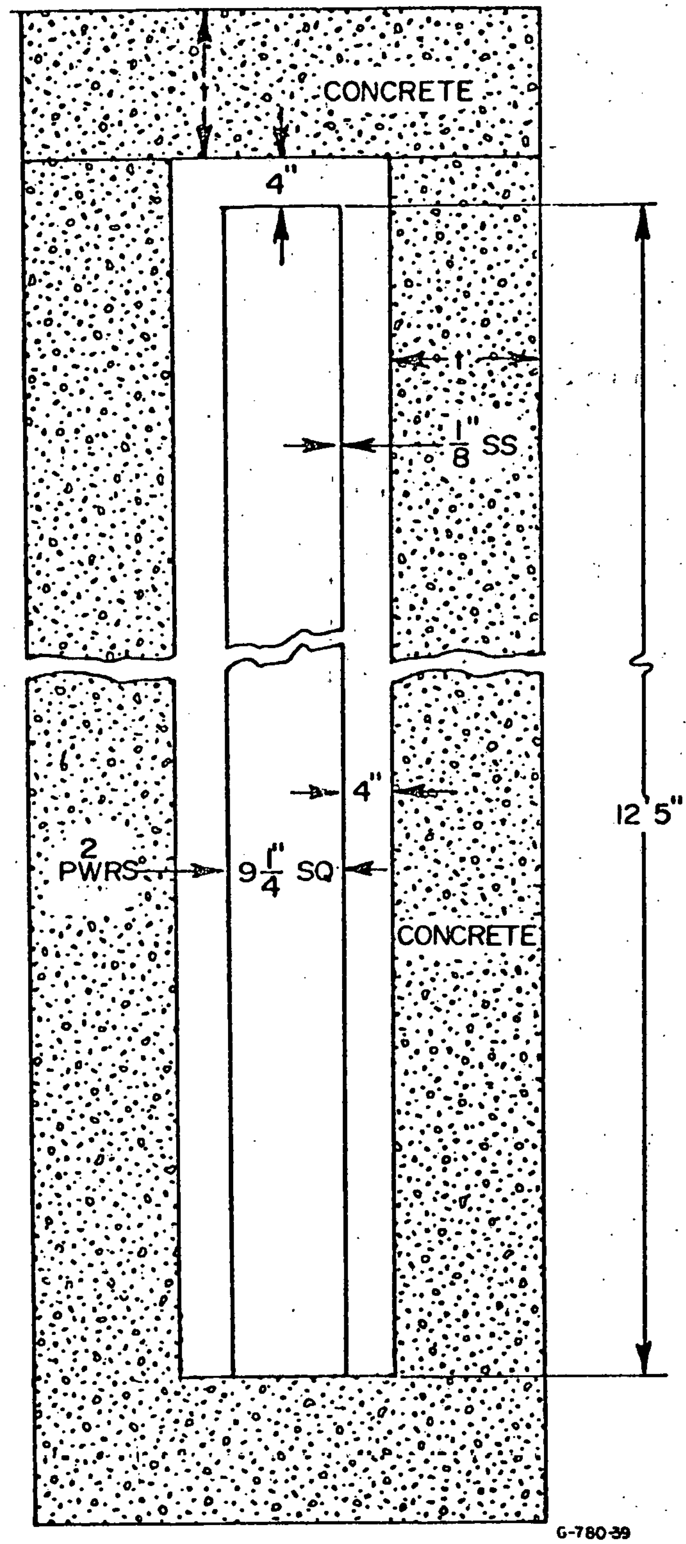


FIGURE 8 — CAISSON SHIELDING MODEL

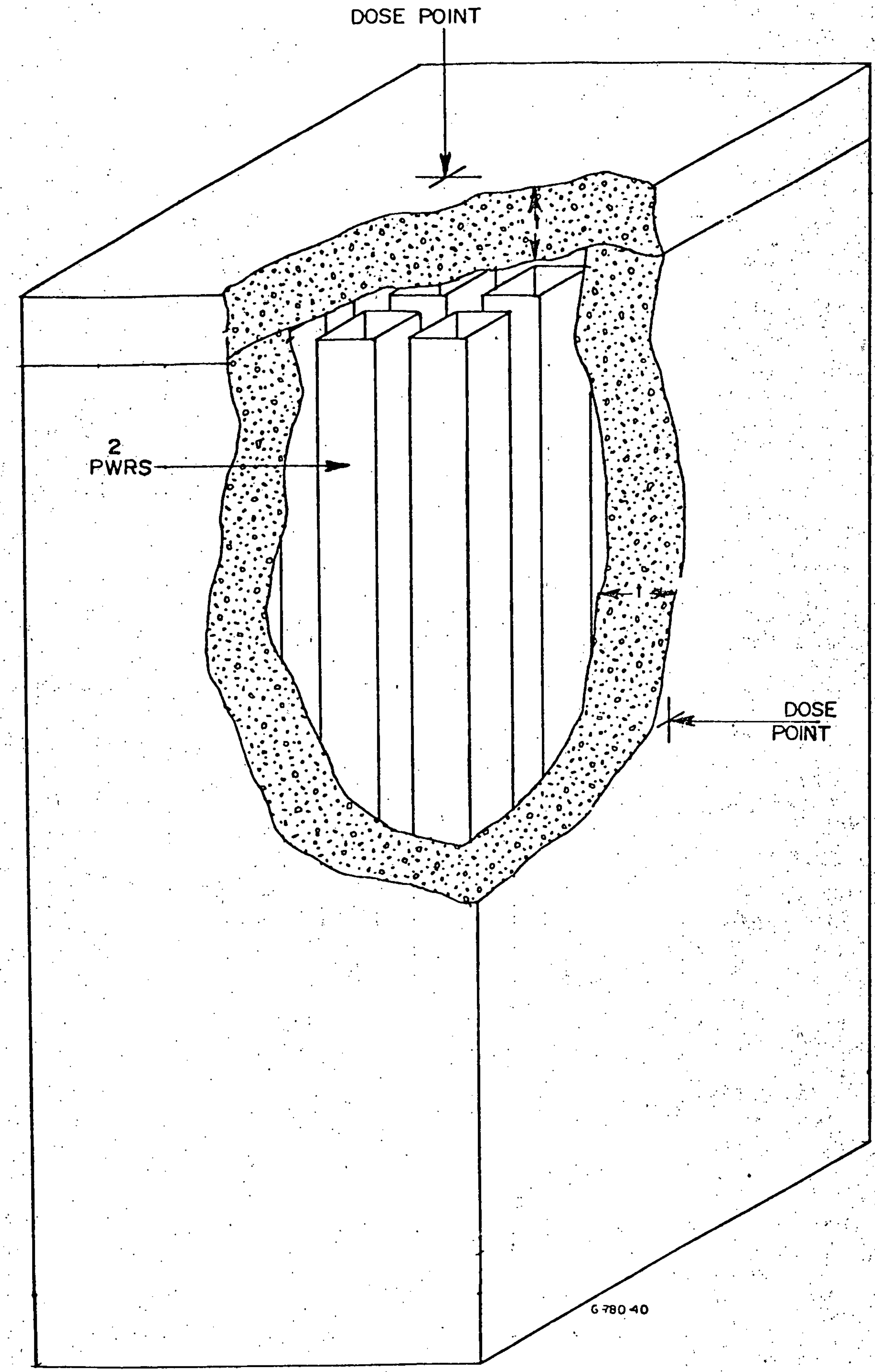


FIGURE 9 — VAULT SHIELDING MODEL

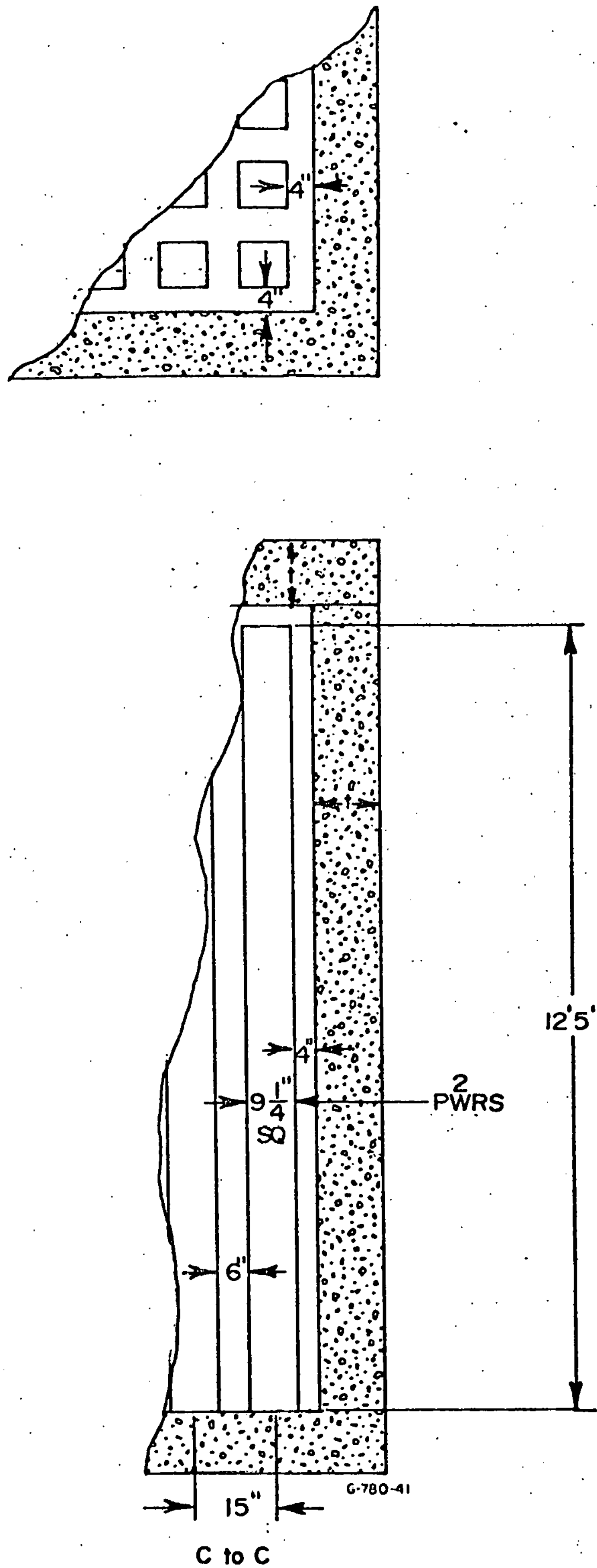


FIGURE 10— VAULT SHIELDING MODEL

THERMAL DISCUSSION

The maximum fuel pin temperature and approximate location were estimated. The surface temperature of the canister also was determined, but this task was performed separate from the maximum fuel pin temperature study so that the data would be more useful. For example, the surface temperature depends on the type cooling and the optimization of a particular type of cooling. Optimization is beyond the scope of this study. As the surface temperature varies depending on the method of cooling, the maximum fuel pin temperature also changes by a nonlinear amount due to radiation. Thus, if it were decided to vary the surface temperature, it would be difficult to estimate the maximum fuel pin temperature from data depending on a particular value of canister surface temperature. Therefore, the maximum fuel pin temperature is displayed over ranges of canister surface temperature and decay heat. As engineering studies effect a specific cooling system design, a new surface temperature would be calculated. With the latest value of surface temperature, the maximum fuel pin curves would be entered to obtain the new value of maximum fuel pin temperature.

To show feasibility of cooling, the most favorable situations were considered first. If a situation was shown to be not feasible, then other situations that can be shown to be worse by deduction were not mathematically analyzed.

The major portion of this study pertains to dry storage, which means with air as the coolant. Other gases were not considered.

In analyses of natural convection on the external surface of the canister and whenever the Rayleigh number was less than 1×10^{8}, the following correlation was used in calculating the heat transfer coefficient.

$$h = 0.52\ Ra^{0.25}$$

where h = heat transfer coefficient, Btu/h-sq.ft-F

Ra = Rayleigh number

For values of Rayleigh number greater than 1×10^{8}, the following correlation was used.

$$h = 0.126\ Ra^{0.333}$$

On the outside of the vaults and caissons in which natural convection occurs at relatively low temperature, the following correlation was used.

$$h = 0.18\ dt^{0.333}$$

where dt = temperature difference between surface and ambient

In all analyses of spent fuel in a hot cell, only PWR disassembled spent fuel was assumed.

SHIELDING RESULTS

In order to achieve the 0.1 millirem/hour dose rate limits at one foot from the exterior concrete, the following amounts of ordinary concrete are needed for the caisson wall corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 64, 63, 61 and 57 inches.

In order to achieve the 0.1 millirem/hour dose rate limits at ten feet from the exterior concrete, the following amounts of ordinary concrete are needed for the caisson wall corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 57, 55, 53 and 49 inches.

In order to achieve the 0.1 millirem/hour dose rate limits at one hundred feet from the exterior concrete, the following amounts of ordinary concrete are needed for the caisson wall corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 42, 40, 37 and 33 inches.

In order to achieve the 0.1 millirem/hour dose rate limits at one foot from the exterior concrete, the following amounts of ordinary concrete are needed for the caisson ceiling corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 50, 48, 46 and 43 inches.

In order to achieve the 0.1 millirem/hour dose rate limits at one foot from the exterior concrete, the following amounts of ordinary concrete are needed for the vault wall corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 70, 69, 66 and 63 inches.

In order to achieve the 0.1 millirem/hour dose rate limits at one foot from the exterior concrete, the following amounts of ordinary concrete are needed for the vault ceiling corresponding to 4, 2, 1 and 0.5 KW/PWR assembly, respectively: 64, 63, 60 and 57 inches.

THERMAL RESULTS

Maximum Fuel Pin Temperature in Dry Storage

Maximum fuel pin temperatures were calculated for ranges of canister surface temperature and are presented in the form of generalized design curves. Canister surface temperatures were calculated for specific cooling situations, and maximum fuel pin temperatures for the specific situations were determined from the design curves.

Tables 5 and 6 present the maximum fuel pin temperature for ranges of decay heat and canister surface temperature for the PWR and BWR intact fuel assemblies, respectively. The locations of the maximum temperatures are indicated in Figures 11 and 12, respectively. Dimensional data used in the analysis are also indicated. Figures 13 and 14 graphically present the temperature data in a form that can be used for various canister cooling conditions.

Tables 7 and 8 present the maximum fuel pin temperature for ranges of decay heat and canister surface temperature for two disassembled PWR and four disassembled BWR fuel assemblies, respectively. A 0.125-inch-thick divider plate was assumed, and gap sizes are indicated in the tables. The locations of maximum temperature are shown on Figure 15 for a number of situations. For the situation with heat transferred from the four sides of the canister, two locations, Locations 1 and 2, were equally hot. These locations also are approximately three pins away from the divider plate, which conducts heat toward the sides of the canister. Moreover, these locations are on the diagonal which is perpendicular to the divider plate. Figures

16 and 17 graphically show trends.

TABLE 5. MAXIMUM FUEL PIN TEMPERATURE (F) FOR ONE INTACT PWR FUEL ASSEMBLY IN DRY CANISTER

Decay Heat, kw	Maximum Fuel Pin Temperature for Indicated Canister Surface Temperature, F				
	100	300	500	700	1000
0.25	132	322	514	709	1005
0.5	160	342	528	718	1010
1.0	210	378	552	735	1020
2.0	296	441	597	766	1038
4.0	431	546	676	824	1074

TABLE 6. MAXIMUM FUEL PIN TEMPERATURE (F) FOR ONE INTACT BWR FUEL ASSEMBLY IN DRY CANISTER

Decay Heat, kw	Maximum Fuel Pin Temperature for Indicated Canister Surface Temperature, F				
	100	300	500	700	1000
0.25	132	321	513	708	1005
0.5	159	339	525	716	1009
1.0	209	374	548	732	1018
2.0	293	435	591	761	1035

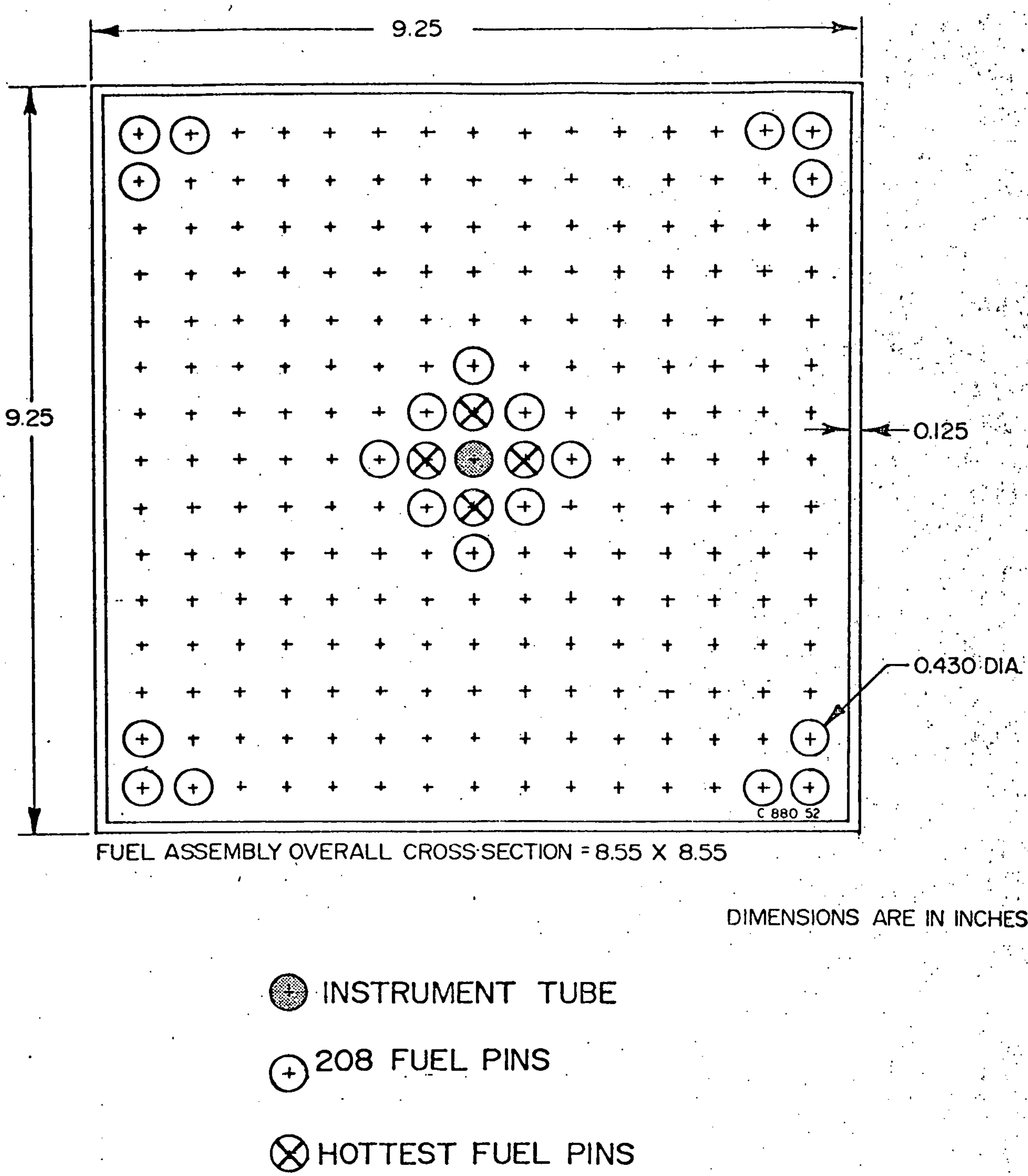


FIGURE 11. LOCATION OF HOTTEST FUEL PINS IN PWR ASSEMBLY

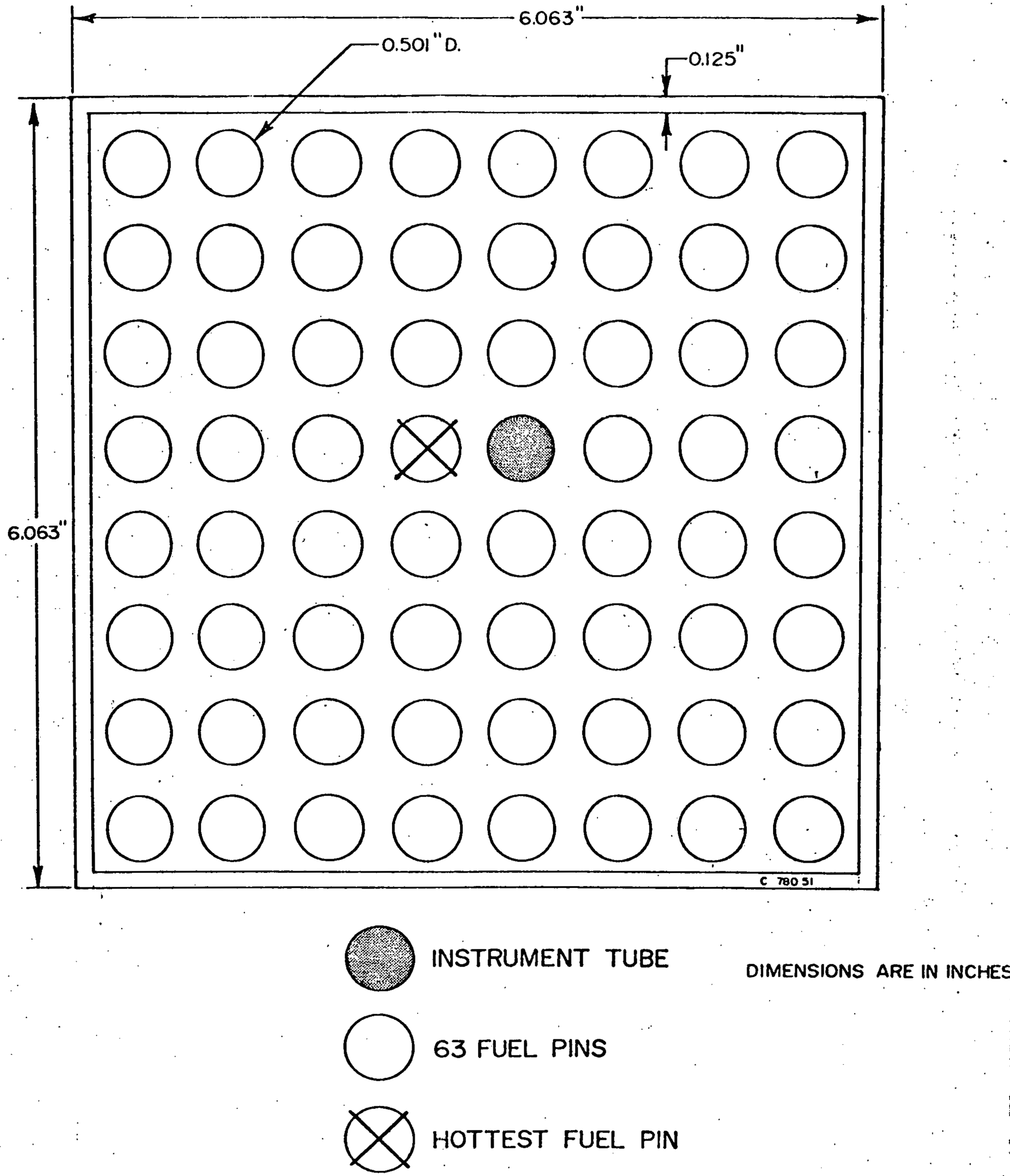


FIGURE 12. LOCATION OF HOTTEST FUEL PIN IN BWR ASSEMBLY

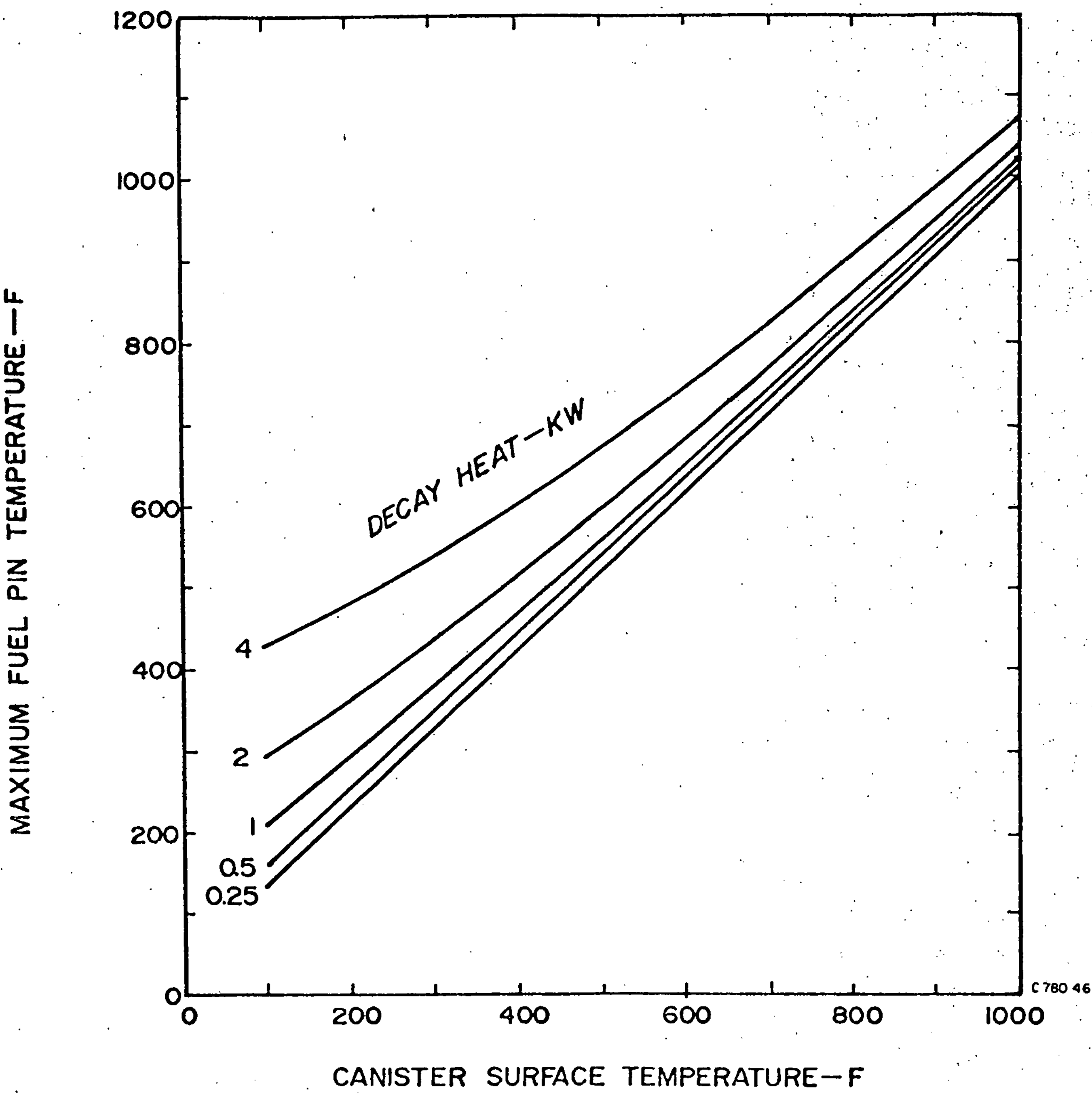


FIGURE 13. MAXIMUM FUEL PIN TEMPERATURE FOR ONE INTACT PWR FUEL ASSEMBLY IN DRY CANISTER

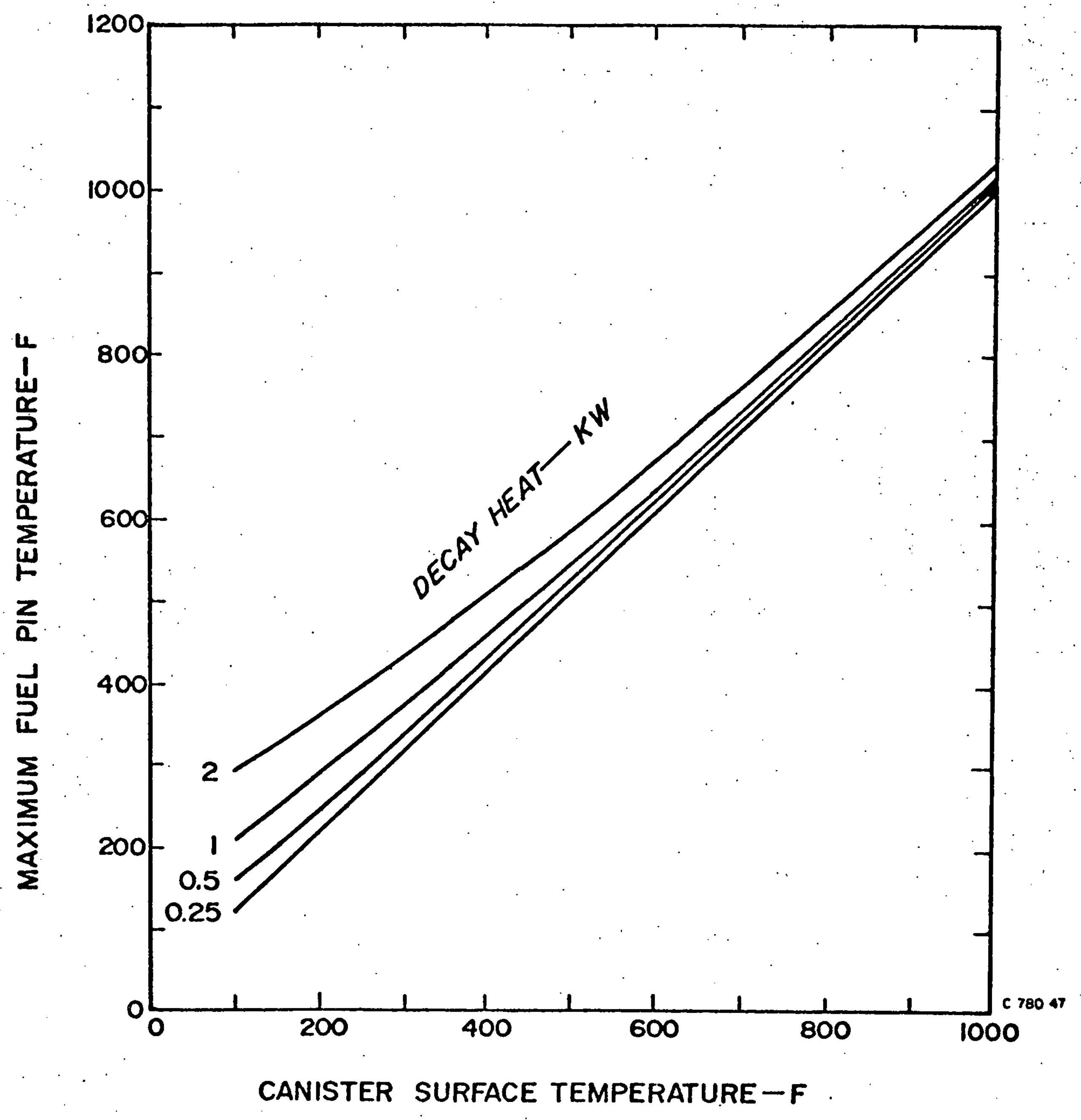


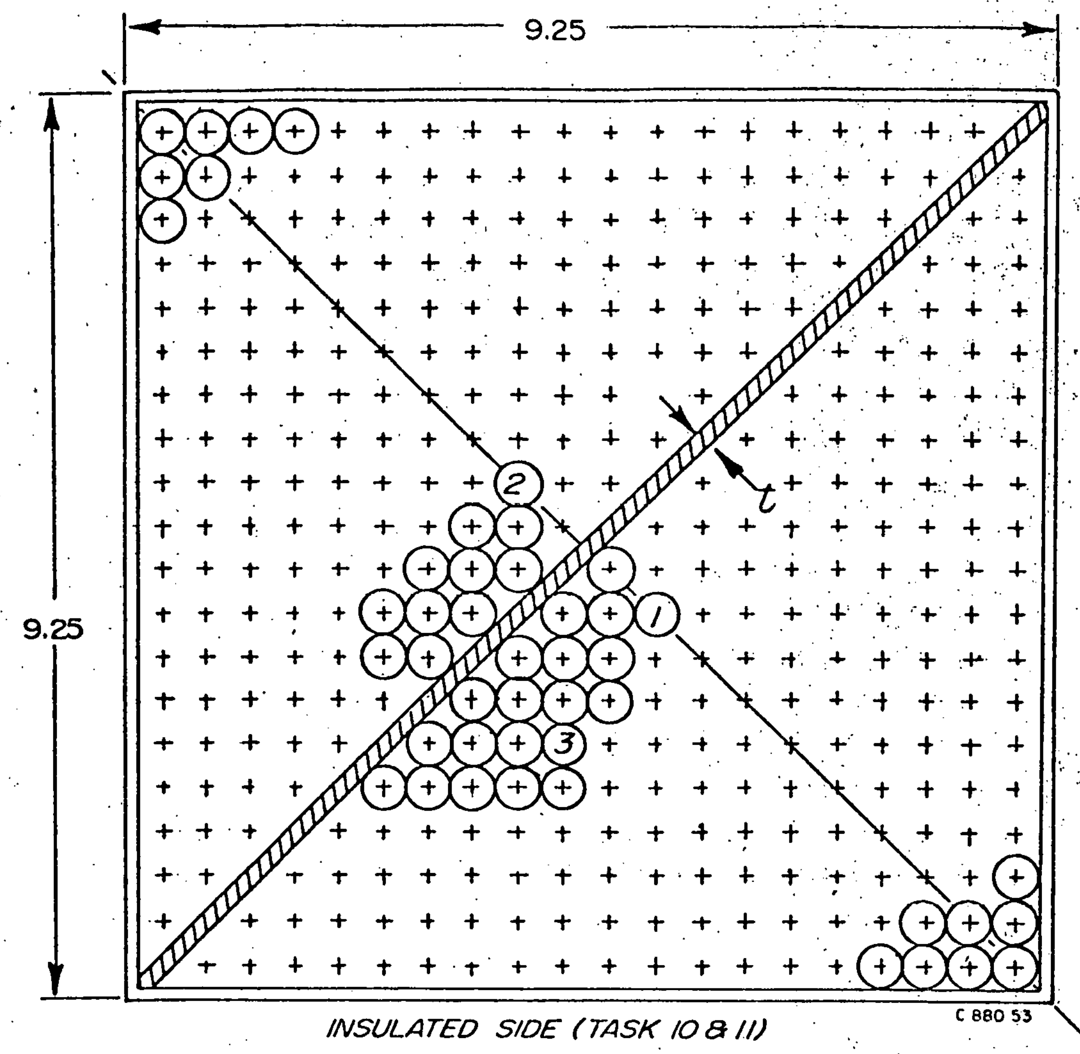
FIGURE 14. MAXIMUM FUEL PIN TEMPERATURE FOR ONE INTACT BWR FUEL ASSEMBLY IN DRY CANISTER

TABLE 7. MAXIMUM FUEL PIN TEMPERATURE (F) FOR TWO DISASSEMBLED PWR FUEL ASSEMBLIES IN DRY CANISTER WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0085 INCH GAP BETWEEN PINS

Decay Heat, kw	Maximum Fuel Pin Temperature for Indicated Canister Surface Temperature, F				
	100	300	500	700	1000
0.25	137	328	521	715	1009
0.5	173	355	541	730	1019
1.0	241	407	579	758	1037
2.0	360	500	649	811	1071
4.0	549	653	771	906	1136

TABLE 8. MAXIMUM FUEL PIN TEMPERATURE (F) FOR FOUR DISASSEMBLED BWR FUEL ASSEMBLIES IN DRY CANISTER WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0099 INCH GAP BETWEEN PINS

Decay Heat, kw	Maximum Fuel Pin Temperature for Indicated Canister Surface Temperature, F				
	100	300	500	700	1000
0.25	179	359	543	731	1019
0.5	251	413	583	760	1037
1.0	376	510	655	815	1073
2.0	569	666	780	912	1139



t = 0.00 (NO WALL) TO 0.25 INCHES

SQUARE-LATTICE PACKING ASSUMED IN ANALYSIS

416 (0.430 D.) PWR FUEL PINS (2 ASSEMBLIES)

196 (0.563 D.) BWR 7X7 PIN — (4 ASSEMBLIES)

252 (0.501 D.) BWR 8X8 PIN — (4 ASSEMBLIES)

FIGURE 15. DISASSEMBLED FUEL PIN CONFIGURATION

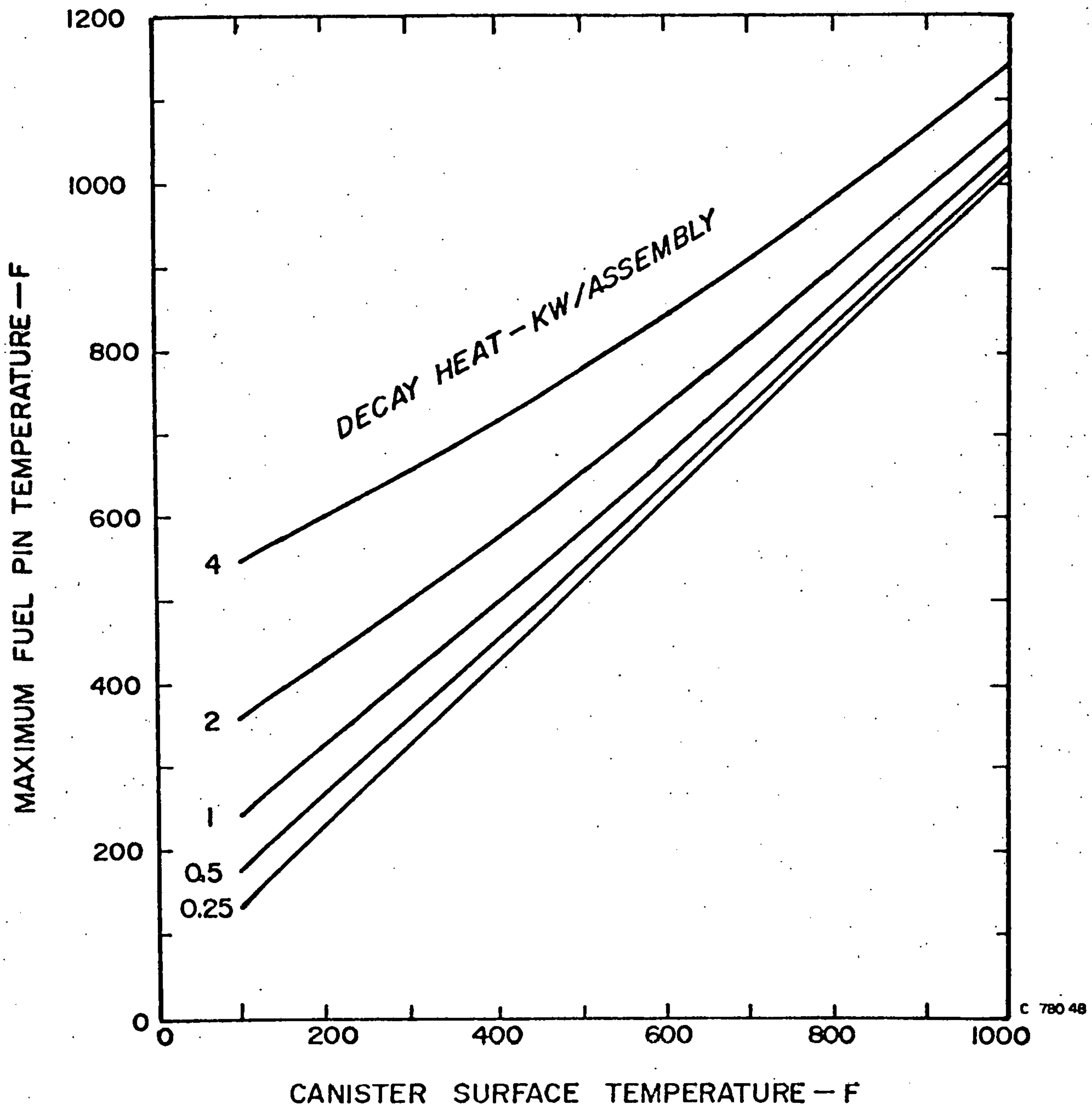


FIGURE 16. MAXIMUM FUEL PIN TEMPERATURE FOR TWO DISASSEMBLED PWR FUEL ASSEMBLIES IN DRY CANISTER WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0085 INCH GAP BETWEEN PINS

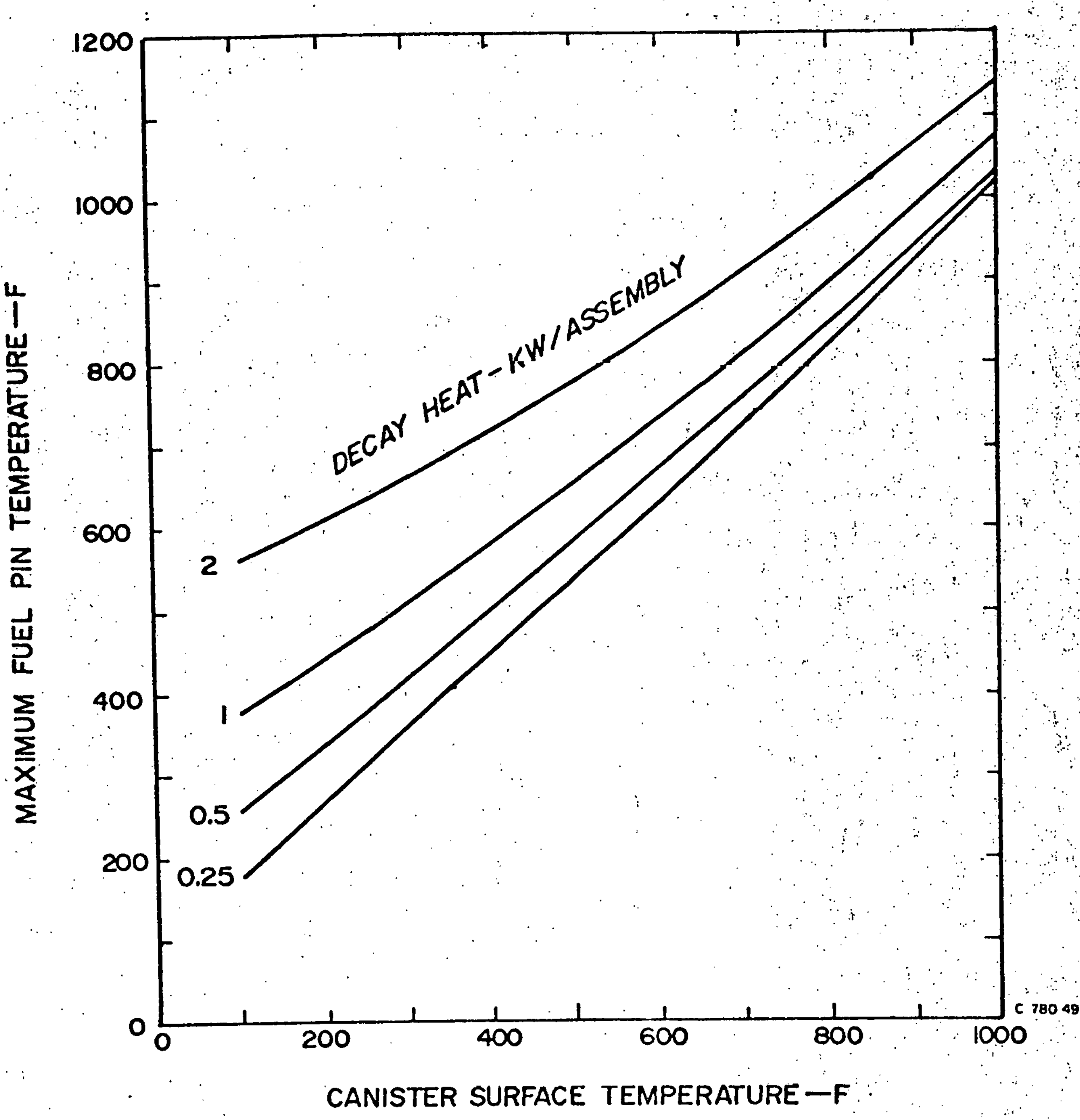


FIGURE 17. MAXIMUM FUEL PIN TEMPERATURE FOR FOUR DISASSEMBLED BWR FUEL ASSEMBLIES IN DRY CANISTER WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0099 INCH GAP BETWEEN PINS

Total Decay Heat

Table 9 presents the total decay heat from 3562 PWR and 1527 BWR fuel assemblies for a range of decay heat rate.

Cooling Concepts

To determine feasibility of a cooling concept, the value of decay heat of 1 kw was used, which is typical of 5 to 6 year cooling time and represents the value for the "average" fuel assembly. If a concept was determined to be feasible, the analysis also was extended over a range of decay heat so that the thermal performance of fuel with cooling times different than 5 to 6 years can be assessed.

No Cooling

Appendix A presents the analysis of vault and caisson no-cooling concepts and shows sample calculations. All of the vault concepts with no cooling are not feasible because of the relatively low thermal conductivity of concrete, the relatively low operating temperature limit of concrete, and the relatively small surface area to dissipate heat.

The above-ground caisson concept with no cooling is feasible for intact and disassembled fuel assemblies, if adequate environmental space surrounds each caisson. Table 10 summarizes the various temperatures for intact and disassembled PWR and BWR fuel assemblies.

The below-ground caisson concept with no cooling is feasible for intact

TABLE 9. DECAY HEAT FROM 30%/70% BWR/PWR FUEL ASSEMBLIES FOR TOTAL STORAGE OF 2000 MTU

Decay Heat kw	Total Decay Heat Rate, kw: 3562 PWR Fuel Assemblies	Total Decay Heat Rate, kw: 1527 BWR Fuel Assemblies
0.25	891	382
0.5	1781	764
1.0	3562	1527
2.0	7124	3054
4.0	14248	--

Notes:

1. Total decay heat rate depends on value assumed for PWR and BWR mixture. Maximum total is with 4 kw per PWR and 2 kw per BWR fuel assembly or a total 14,248 kw plus 3054 kw, which is 17,302 kw.

2. Values apply for intact or disassembled fuel assemblies. For stored PWR disassembled fuel assemblies, the number of canisters is half that for stored intact fuel assemblies, but the decay heat rate per canister for disassembled PWR fuel assemblies is twice that for intact fuel assemblies, thus these effects offset each other. A similar effect occurs with the BWR fuel assemblies, but the factor is four (four assemblies in a canister).

TABLE 10. TEMPERATURES (F) FOR NO-COOLED ABOVE-GROUND CAISSONS WITH INTACT AND DISASSEMBLED PWR AND BWR SPENT-FUEL ASSEMBLIES

Temperature or Temperature Difference, F	Total Canister Decay Heat, kw					
	0.25	0.5	1	2	4	8
Ambient temperature	100	100	100	100	100	100
Ambient-outside wall dt*	1	1	2	4	8	15
Caisson outside temperature	101	101	102	104	108	115
Caisson wall dt	11	22	44	88	175	351
Caisson inside temperature	112	123	146	192	283	466
Canister-caisson dt	23	43	76	119	189	194
Canister surface temperature	135	166	222	311	472	660
Maximum fuel pin temperature:						
PWR intact fuel assembly	165	220	312	450	658	--
PWR disassembled fuel	--	200	284	416	628	879
BWR intact fuel assembly	165	218	310	444	--	--
BWR disassembled fuel	--	--	289	422	635	886

* dt refers to temperature difference

Note:
For individual assembly decay heat load, divide column headings by 2 for PWR disassembled fuel and by 4 for BWR disassembled fuel. Thus, the individual assembly decay heat ranges of 0.25 to 4 kw per PWR assembly and 0.25 to 2 kw per BWR assembly are included.

disassembled fuel assemblies, if the decay heat in each fuel assembly is no greater than 1 kw for a PWR and 0.5 kw for a BWR fuel assembly. Calculated temperatures are presented in Table 11. As the table indicates, with a total of 2 kw in the caisson, the concrete temperature in the vertical side wall is 629 F, which is greater than the somewhat arbitrary value of 500 F discussed in Appendix A. A detailed design study with optimization, redefining of design criteria, and the use of a detailed thermal model instead of the closed form solution used in Appendix A may reveal that the 2 kw decay heat is acceptable. Thus, with these reservations, 2 kw is indicated as feasible in Table 11. Above 2 kw, storage in a below-ground, no-cooled caisson does not appear to be feasible.

The data in Table 11 are valid for a caisson or an array of caissons in level ground or in an engineered berm, if the center-to-center spacing is at least 9.44 feet, which is the overall size of the caisson that was analyzed.

Natural Convection

Table 12 presents temperatures in natural-convection cooled vaults and caissons either above or below ground. Values in the table were calculated assuming no heat is conducted through the walls of the vault or caisson. As discussed in Appendix B, the use of Table 12 includes a small amount of conservatism for the vaults and below-ground caisson, but for the above-ground caisson the amount of conservatism is approximately 20 percent. Thus, a correction can be applied by the use of Table 10 with Table 12, if desired. This procedure is described in Appendix B.

TABLE 11. TEMPERATURES (F) FOR NO-COOLED BELOW-GROUND CAISSONS WITH INTACT AND DISASSEMBLED PWR AND BWR SPENT-FUEL ASSEMBLIES

Temperature or Temperature Difference, F	Total Canister Decay Heat, kw					
	0.25	0.5	1	2	4	8
Ambient temperature	100	100	100	100	Not	
Ambient-outside top dt*	7	12	23	42		Feasible
Caisson outside temperature	107	112	123	142	Not	
Caisson access plug dt	36	73	146	292		Feasible
Caisson inside top temp.	143	185	269	434	Not	
Caisson top-wall dt	24	49	98	195		Feasible
Caisson inside wall temp.	167	234	367	629	Not	
Canister-caisson dt	22	33	42	41		Feasible
Canister surface temperature	189	267	409	670	Not	
Maximum fuel pin temperature:						Feasible
PWR intact fuel assembly	217	312	473	741	Not	
PWR disassembled fuel	--	296	456	731		Feasible
BWR intact fuel assembly	216	309	468	736	Not	
BWR disassembled fuel	--	--	459	733		Feasible

* dt refers to temperature difference

Note:
For individual assembly decay heat load, divide column headings by 2 for PWR disassembled fuel and by 4 for BWR disassembled fuel. Thus, the individual assembly decay heat ranges of 0.25 to 4 kw per PWR assembly and 0.25 to 2 kw per BWR assembly are included.

TABLE 12. TEMPERATURES (F) FOR NATURAL CONVECTION COOLED VAULTS AND CAISSONS WITH INTACT AND DISASSEMBLED PWR AND BWR SPENT-FUEL ASSEMBLIES

Temperature or Temperature Difference, F	Total Canister Decay Heat, kw					
	0.25	0.5	1	2	4	8
Ambient temperature	100	100	100	100	100	100
Inlet-outlet air dt*	6	10	16	26	42	67
Outlet air temperature	106	110	116	126	142	167
Canister-air dt	30	51	87	153	273	488
Canister surface temperature	136	161	203	279	415	655
Maximum fuel pin temperature:						
PWR intact fuel assembly	166	216	297	426	621	--
PWR disassembled fuel	--	195	267	390	586	876
BWR intact fuel assembly	166	214	294	420	--	--
BWR disassembled fuel	--	--	272	396	593	882

* dt refers to temperature difference

Note:
For individual assembly decay heat load, divide column headings by 2 for PWR disassembled fuel and by 4 for BWR disassembled fuel. Thus, the individual assembly decay heat ranges of 0.25 to 4 kw per PWR assembly and 0.25 to 2 kw per BWR assembly are included.

The analysis in Appendix B indicates that natural convection cooling is feasible and adequate to cool vaults and caissons to the maximum expected limit of decay heat (4 kw for PWR and 2 kw for BWR fuel assemblies), if the vault and caisson are constructed to freely permit the entrance and exit of air. Thus, the use of natural convection relates not only to thermal feasibility but to the environmental suitability of convecting air around a caisson and ejecting it into the environment without filtering. Perhaps double containment would be required, and this analysis does not include double containment, which would increase the maximum fuel pin temperature.

Forced Convection

In Appendix B, the velocity of 5.67 ft/s is shown to be attainable for natural convection with a resultant value of heat transfer coefficient of 1.11 Btu/h-sq. ft-F. A forced convection correlation reveals that if the air flow velocity were increased to 10 ft/s, the value of heat transfer coefficient would increase to only 1.52 Btu/h-sq. ft-F. This would result in considerably greater fan power with a relatively small decrease in temperature difference between the air and the canister. Also, this temperature differential is relatively small compared to the overall temperature difference between the air and the hottest fuel pin. Therefore, using forced convection to decrease fuel pin temperature appears to be futile.

The major advantage of forced convection is to provide a positive, constant supply of air in which filters can be installed to ensure a clean environment. For least fan power, the air flow rate would be adjusted to the minimum level consistent with the maximum allowable fuel pin temperature.

Heat Pipes

The heat pipe concept is feasible for all of the storage concepts. For the vault storage, above and below ground, a 2-inch-diameter copper heat pipe may be placed in the center of four canisters which contain PWR disassembled fuel as shown in Figure 18. Therefore, the heat pipe capacity is 8 kw. Four fins, each 12 inches long, conduct heat from the fuel assemblies, which transfer heat to the fins by natural convection and radiation. The operating temperature of the fins is estimated to be 400 F to 450 F, depending on the efficiency desired and the expense. The rack supports may pass through holes in the fins, which will not greatly reduce the fin effectiveness. The number of heat pipes required is one-fourth of the total number of PWR canisters. For BWR disassembled fuel with 4 kw per canister, twice as many heat pipes would be required as that for an equal number of PWR canisters.

The copper fins can be coated to increase their emittance to approximately 0.9, which is equal to that of concrete. Therefore, maximum fuel pin temperatures can be determined from Table 10 for no-cooled caissons. Temperature values are approximately equal whether natural convection occurs by circulation within a closed caisson between canister and concrete or between canister and fins. In this example, a total decay heat of 8 kw is assumed. Entering Table 10 with 8 kw, the temperature differential between the canister and caisson (intrepreted as canister and fins in this example) is 194 F. Thus, assuming a fin temperature of 450 F, the canister surface temperature would be 450 F plus 194 F or 644 F. Using this value and the data of

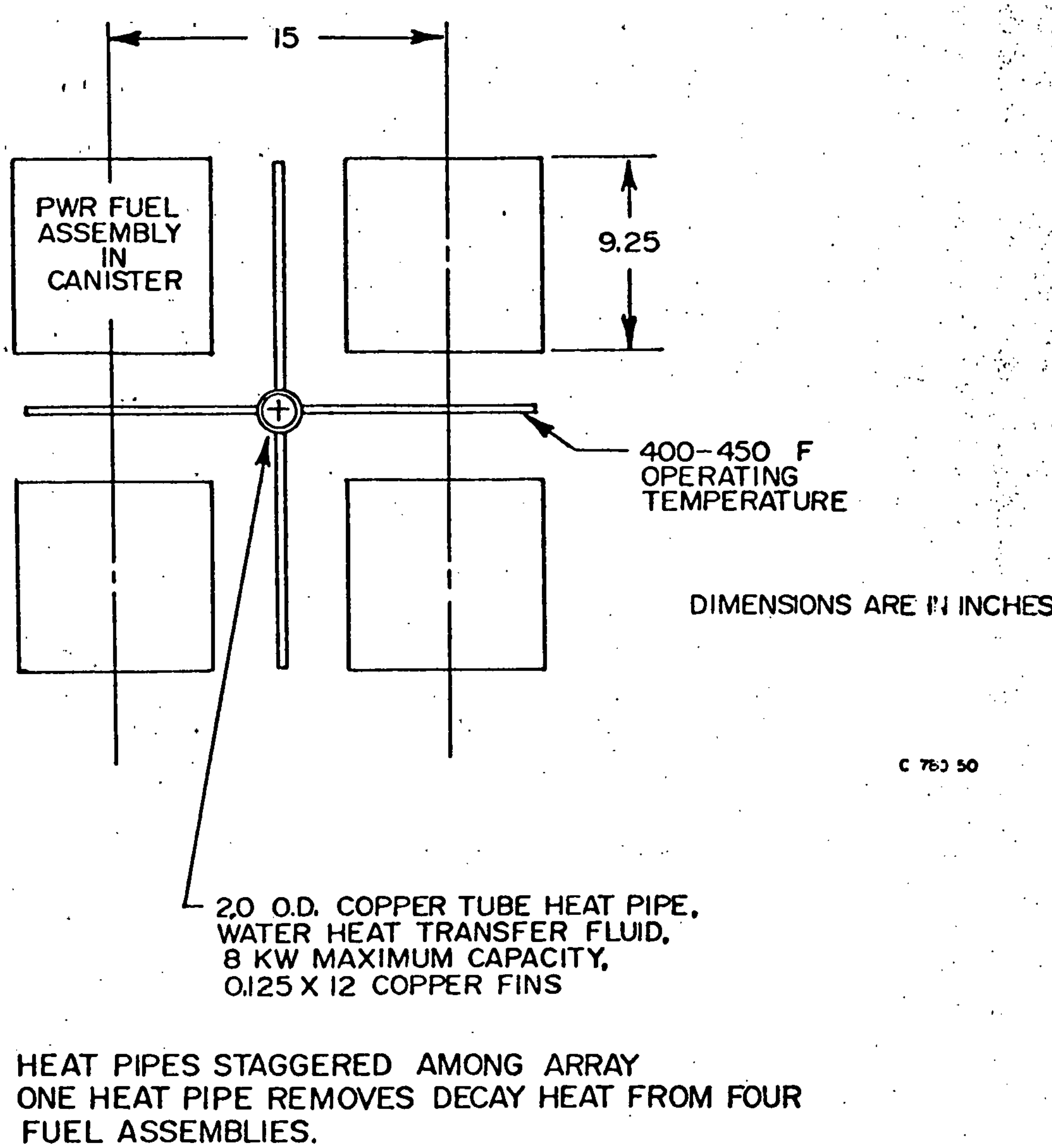


FIGURE 18. TYPICAL HEAT PIPE COOLING FOUR PWR FUEL ASSEMBLIES

maximum fuel pin temperature as a function of canister surface temperature, the maximum fuel pin temperature can be determined.

Fins

The concept of using fins through the concrete walls is not feasible. In this concept, the fins should be installed slanted in relation to the wall cross section to reduce nuclear radiation through the steel. Assuming a total conducting length of 6 feet, the use of carbon steel with thermal conductivity of 30 Btu/h-ft-F, the maximum temperature differential across the fins is 400 F (maximum concrete temperature of 500 F), and total decay heat of 5089 kw (1.736 E7 Btu/h); the cross sectional area of the fins would be approximately 26,000 square feet. This represents a prohibitively large mass of steel.

Fins are feasible, if used with a heat pipe as discussed previously. Inside vault fins were discussed. Carbon steel, stainless steel, or copper fins also would be placed around the heat pipe external to the vault. Assuming a view factor between fins to the environment of 0.2 for 6-inch-high fins spaced 2 inches on center, a temperature difference between the fin surface and the environment of 300 F, and a heat transfer coefficient value for natural convection of 1.2 Btu/h-sq. ft-F; the required total fin surface area would be 28,000 square feet. Since adequate space exists on top of the vault, the fins could be spaced farther apart to increase heat transfer by radiation. Fins in two or three decks would be required on top of the vault for disassembled fuel assemblies. Whether the fins would be installed in decks, which are commercially available, or installed as circular fins directly on the heat pipes and protrude several feet above the top of the vault is a design decision beyond the scope of this report.

Effect of Decay Heat in a Hot Cell

In this analysis, the ambient temperature of 100 F was specified, thus the maximum temperature for each case has been calculated using the specified ambient temperature. Table 13 presents the maximum fuel pin temperature with a 0.125-inch-thick divider plate in the canister and a 0.0085 inch gap between fuel pins in a square array for two disassembled PWR fuel assemblies. Heat was assumed to be transferred from four sides of the canister by natural convection and radiation. An emittance of 0.4 was used on the external surface of the canister. If 10 air changes per hour were assumed in the hot cell, the resulting velocity would not increase the heat transfer coefficient greater than that which could be attained by natural convection. By a heat balance, the minimum supply of air must be 84.3 standard cubic feet per minute (SCFM). This is equivalent to the fuel being in a room 17.2 feet cube. The locations of the maximum fuel pin temperature are Locations 1 and 2 in Figure 15, which is approximately three pins away from the divider plate.

Effect of Divider Plate Thickness

Table 14 presents the maximum fuel pin temperature for a range of divider plate thickness for two disassembled PWR fuel assemblies each with 2 kw decay heat. For no divider plate, the centrally located fuel pins in the 20 by 20 pin array are hottest (416 pins are in the canister, but only 20 pins will fit in a row, assuming a square matrix). With a divider plate, the hottest pins are approximately in Locations 1 and 2 in Figure 15.

TABLE 13. MAXIMUM TEMPERATURES OF TWO DISASSEMBLED PWR FUEL ASSEMBLIES STORED IN DRY 100 F ENVIRONMENT WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0085 INCH GAP BETWEEN PINS SHOWING EFFECT OF DECAY HEAT

Decay Heat Rate Per Assembly, kw	Maximum Fuel Pin Temperature, F	Maximum Storage Canister Temperature, F	Maximum Divider Plate Temperature, F
0.5	227	162	215
1.0	328	210	307
2.0	488	289	454
4.0	713	412	671

TABLE 14. MAXIMUM TEMPERATURES OF TWO DISASSEMBLED PWR FUEL ASSEMBLIES STORED IN DRY 100 F ENVIRONMENT WITH 2 KW PER ASSEMBLY (TOTAL 4 KW) AND 0.0085 INCH GAP BETWEEN PINS SHOWING EFFECT OF DIVIDER PLATE THICKNESS

Divider Plate Thickness, inch	Maximum Fuel Pin Temperature, F	Maximum Storage Canister Temperature, F	Maximum Divider Plate Temperature, F
0	535	293	--
0.0625	506	290	484
0.125	488	289	454
0.1875	475	292	433
0.25	466	291	418

with the thinnest plate, the location may move one or two pins closer to the plate, because little heat is conducted from the center of the canister with a thin plate.

Effect of Pin Gap Size

Table 15 presents the maximum fuel pin temperature for a range of gap size for two disassembled PWR fuel assemblies each with 2 kw decay heat. The gap size corresponding to the specified 1.04 area factor is 0.0085 inch for the 0.430 inch diameter fuel pins. This value was calculated by using the relationship that the gap size is equal to (1.098 - 1)(0.430) or 0.0085 inch, where the factor 1.098 is the square root of the factor 1.04. Although slightly different heat transfer coefficient values were used inside the canister to account for the different spacing, gap size had little difference in maximum temperature, except for zero gap. For zero gap, lowest maximum temperature was predicted because of the additional conduction around the fuel pin cladding.

Effect of Insulating One Side of Canister

Table 16 presents maximum fuel pin temperatures for two disassembled PWR fuel assemblies for a range of decay heat with one side of the canister insulated, i.e., heat is transferred from three sides only. The location of the maximum fuel pin temperature is at Location 3 in Figure 15. Maximum canister temperature occurs on the insulated side, which acts as a fin to conduct heat to the corners of the canister. Thus the divider plate does not transfer heat to the one hot corner, and the location of the hottest pin shifts toward the hot corner

TABLE 15. MAXIMUM TEMPERATURES OF TWO DISASSEMBLED PWR FUEL ASSEMBLIES STORED IN DRY 100 F ENVIRONMENT WITH 0.125 INCH THICK DIVIDER PLATE AND 2 KW PER ASSEMBLY (TOTAL 4 KW) SHOWING EFFECT OF PIN GAP SIZE

Gap Between Pins, inch	Maximum Fuel Pin Temperature, F	Maximum Storage Canister Temperature, F	Maximum Divider Plate Temperature, F
0	469	288	442
0.003	483	288	452
0.006	486	288	453
0.0085	488	289	454
0.009	488	289	454

TABLE 16. MAXIMUM TEMPERATURES OF TWO DISASSEMBLED PWR FUEL ASSEMBLIES STORED IN DRY 100 F ENVIRONMENT WITH 0.125 INCH THICK DIVIDER PLATE AND 0.0085 INCH GAP BETWEEN PINS SHOWING EFFECT OF INSULATING ONE SIDE OF CANISTER FOR A RANGE OF DECAY HEAT

Decay Heat Rate Per Assembly, kw	Maximum Fuel Pin Temperature, F	Maximum Storage Canister Temperature, F	Maximum Divider Plate Temperature, F
0.5	272	245	244
1.0	401	359	354
2.0	597	544	527
4.0	865	812	773

a few pins.

Effect of Environmental Temperature

Table 17 presents the hottest fuel pin temperature for a range of environmental temperature for two disassembled PWR fuel assemblies each with 4 kw decay heat. The value for 100 F ambient was copied from a previous analysis to complete the trend. The maximum value decreases with increasing environmental temperature because heat can be transferred more efficiently by radiation at higher temperatures.

Effect of Pool Water

Table 18 presents the maximum bulk water temperature inside a canister containing two disassembled PWR fuel assemblies with the canister in a rack with 0.125 inch clearance between the canister and rack on all four sides. Natural convection is sufficient to maintain temperatures below boiling assuming an inlet temperature of 120 F. If the inside of the canister were to be dry, the surface temperature, which is a function of how much heat crossed the surface, would be the same because the decay heat would not have changed. However, the maximum pin temperature would be greater and this value can be ascertained from the general curves of maximum decay heat versus canister surface temperature, which were presented previously herein. Thus, boiling would not occur outside of the canister and the temperature would be the same as if the inside of the canister had water.

TABLE 17. MAXIMUM TEMPERATURES OF TWO DISASSEMBLED PWR FUEL ASSEMBLIES STORED IN DRY ENVIRONMENT WITH 4 KW PER ASSEMBLY, 0.125 INCH THICK DIVIDER PLATE, AND 0.0085 INCH GAP BETWEEN PINS SHOWING EFFECT OF INSULATING ONE SIDE OF CANISTER FOR A RANGE OF ENVIRONMENTAL TEMPERATURE

Environmental Temperature, F	Maximum Fuel Pin Temperature, F	Maximum Storage Canister Temperature, F	Maximum Divider Plate Temperature, F
100	865	812	773
150	880	830	791
200	897	849	810

TABLE 18. MAXIMUM CANISTER WATER TEMPERATURE AND CANISTER-RACK ANNULUS WATER TEMPERATURE RISE FOR TWO DISASSEMBLED PWR FUEL ASSEMBLIES IN A RACK FOR A RANGE OF DECAY HEAT

Decay Heat Rate Per Assembly, kw	Maximum Water Temperature in Canister, F	Temperature Rise in Canister-Rack Annulus, F
0.5	112*	5
1.0	118	7
2.0	131	10
4.0	154	15

* Temperatures calculated with a water inlet temperature of 120 F.

CONCLUSIONS

To meet the shielding constraint of 0.1 millirem/hour dose rate limit at one foot from the concrete wall or ceiling on the "cold" side, 70 to 43 inches of ordinary concrete are required for a range of 4 to 0.5 KW/PWR assembly in caisson or vault storage of LWR spent fuel.

To meet the shielding constraint of 0.1 millirem/hour dose rate limit at ten feet from the caisson concrete wall on the "cold" side, 57 to 49 inches of ordinary concrete are required for a range of 4 to 0.5 KW/PWR assembly in caisson storage of LWR spent fuel.

To meet the shielding constraint of 0.1 millirem/hour dose rate limit at one hundred feet from the caisson concrete wall on the "cold" side, 42 to 33 inches of ordinary concrete are required for a range of 4 to 0.5 KW/PWR assembly in caisson storage of LWR spent fuel.

For the same canister surface temperature and total decay heat in a canister with intact fuel assemblies, decay heat can be transferred internally from a 7 by 7 pin or an 8 by 8 pin BWR assembly and a 15 by 15 pin PWR assembly in approximately the same ratio as their respective canister surface areas, therefore, the maximum fuel pin temperatures are approximately equal.

For the same total decay heat in a canister with disassembled fuel pins, the maximum fuel pin temperature for BWR fuel pins is only slightly greater than that for PWR fuel pins because the BWR fuel pins and the spaces among fuel pins are only slightly greater than those for

PWR fuel pins.

Vaults, either above or below ground or for intact or disassembled fuel assemblies, can not adequately conduct sufficient decay heat across its walls to dissipate the heat without some type of auxiliary cooling.

A single-canister caisson above ground can dissipate the decay heat adequately, but below ground, auxiliary cooling is required for canister decay heat greater than aproximately 2 kw, depending on established design criteria.

Natural convection cooling of a vault and a caisson in which air is circulated into and out of the vault and caisson is feasible if large openings are provided at the bottom and top of the vault and caisson with no filters in the inlet or outlet, but no attempt was made to quantify pressure loss of filters and determine their effect on cooling.

Forced convection, although not theoretically needed for thermal performance of a vault or caisson, is desirable to supply specific quantities of coolant air. Forced convection also assures adequate pressure head for filtering the coolant air, which might eliminate double containment depending on design criteria.

A properly finned heat pipe is a good passive system that can remove sufficient quantities of decay heat in a vault or caisson. Also, sufficient numbers are required that a built-in redundancy is provided when installed in a vault, i.e., if several heat pipes should fail, the total heat dissipation capability would not be significantly reduced.

Installing fins through the concrete wall of a vault or caisson is not thermally practical and is not recommended.

A 0.25-inch-thick divider plate in a canister decreases the maximum fuel pin temperature 69 F below that with no divider plate for a total of 4 kw decay heat in the canister.

The major mechanism of heat transfer within a dry canister is radiation. Therefore, if conditions are changed which increase the temperature differential between the canister and location of maximum fuel pin temerature (such as increasing environmental temperature, insulating one side of a canister, or increasing the gap between pins), the rate of change of temperature differential with increasing decay heat decreases because radiation heat transfer at elevated temperature is more efficient owing to the fourth-power dependency of radiative heat flux on temperature of a radiating surface.

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APPENDIX A

ANALYSIS OF NO-COOLING CONCEPTS

APPENDIX A

ANALYSIS OF NO-COOLING CONCEPTS

Calculations are presented which indicate the thermal performance of a vault and a caisson with no cooling.

Above-Ground Vault for Intact Fuel

The following data were used in this analysis:

Ambient temperature (ta), F	100
Thermal conductivity of concrete (k), Btu/h-sq. ft-F	1.05
Maximum temperature of concrete, (ti), F	500
Emittance of concrete, (e)	0.9
Inside vault ceiling area, square feet	7146
Inside dimensions (length and width) of square vault, feet	84.53
Inside height of vault, (H), feet	30
Concrete wall thickness (ceiling and walls), (L), feet	5
Outside dimensions (length and width) of square vault, feet	94.53
Inside surface area (ceiling and walls), (Ai), sq. ft	17,290
Outside surface area (ceiling and walls), (Ao), sq. ft	24,060

The value of thermal conductivity of concrete was obtained from Reference 10. The maximum temperature (500 F) that concrete can continuously withstand with approximately a 10 percent reduction of strength, but with no deleterious temperature effects, was confirmed with the Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois (312) 966-6200.

Decay heat was assumed to be conducted through the ceiling and four vertical walls of the vault, but not through the floor, since the thermal conductivity of dry soil is relatively low compared with that of concrete. Also, the conducting distance through the soil is greater than that of concrete, except around the perimeter of the vault. Therefore, heat removal through the floor was neglected.

Heat conducted through the walls of the vault without considering effects of the thick corners is calculated as follows:

$$Qw = k(Ai)(dtw)/L = 1.05(17{,}290)(dtw)/5 \quad \text{(A-1)}$$

$$= 3630.9\ dtw$$

where Qw = heat conducted through vault walls, excluding corners, Btu/h

dtw = temperature difference between inside and outside walls, F

and other symbols and values were presented previously in the tabulated data.

Rohsenow (11) presents a method of correcting for heat conducted through the thick corners of the vault as follows:

$$Qcorr = 0.559NkH(dtw) = 0.559(4)(1.05)(30)(dtw) \quad \text{(A-2)}$$

$$= 70.4\ dtw$$

where Qcorr = heat conducted through corners, Btu/h

N = 4, number of corners

Adding the correction for the corners to the heat transferred through the walls of dimensions equal to the inside dimensions of the vault, the total heat conducted through the walls and ceiling of the vault, Qt, is

$$Qt = Qw + Qcorr = 3630.9\ dtw + 70.4\ dtw \quad \text{(A-3)}$$
$$= 3701.3\ dtw$$

At this stage in the analysis, the temperature of the outside wall is not known, therefore, dtw can not be determined. The temperature of the inside walls is assumed to be the maximum value of 500 F. The outside wall temperature can be calculated by considering natural convection and radiation to the atmosphere, which was assumed to be at 100 F. The quantity of heat transferred by natural convection is

$$Qc = h(Ao)(dta) = 0.18\ (dta)^{0.333}\ (24{,}060)(dta) \quad \text{(A-4)}$$
$$= 4330.8\ (dta)^{1.333}$$

where Qc = heat transferred by natural convection, Btu/h

h = $0.18\ (dta)^{0.333}$, heat transfer coefficient, Btu/h-sq. ft-F

dta = temperature difference between outside walls and ambient, F

The quantity of heat transferred from the outside walls to the environment by radiation is

$$Qr = 0.172 \times 10^{-8}\ e(Ao)[To^{4} - Ta^{4}] \quad \text{(A-5)}$$
$$= 0.172 \times 10^{-8}\ (0.9)(24{,}060)[To^{4} - (560)^{4}]$$
$$= 3724.5 \times 10^{-8}\ [To^{4} - (560)^{4}]$$

where Qr = heat radiated from outside walls to ambient, Btu/h

e = 0.9, emittance of concrete walls

To = temperature of outside wall surface, R

Ta = 560 R (100 F), temperature of environment

The overall temperature difference from the inside surface of the vault to the environment is

$$dtw + dta = 500 - 100 = 400 \text{ F} \qquad \text{(A-6)}$$

Also, the total quantity of heat conducted through the walls must be transferred from the external surface of the walls, therefore,

$$Qt = Qc + Qr \qquad \text{(A-7)}$$

Equations A-3 through A-7 were solved simultaneously, and the following values were determined, to the nearest integer values of temperature:

dtw = 368 F

dta = 32 F

Qt = 1.36 E6 Btu/h (399 kw)

Qc = 4.39 E5 Btu/h (128.7 kw)

Qr = 9.12 E5 Btu/h (267.3 kw)

Assuming 1 kw in each fuel assembly, the total quantity of decay heat that must be transferred is 5089 kw. Therefore, only 7.8 percent of the required heat can be transferred out of the vault with no cooling and within the assumed 500 F temperature limit for concrete. Hence, the vault concept with no cooling is not feasible for intact spent fuel assemblies each with 1 kw decay heat.

It also can be assumed that the no cooling concept is not feasible for disassembled fuel assemblies, since the vault would be smaller than that for intact fuel. Therefore, with less surface area, less heat would be transferred than that calculated previously.

By similar reasoning, the no cooling concept with a below-ground vault is not feasible, since only the top of the vault would be exposed to the environment.

Above-Ground Caisson for Disassembled Fuel

The thermal analysis for the above-ground caisson is similar to that discussed previously for the vault. It was assumed that an adequate air space exists between adjacent caissons for natural convection and radiation to the environment, otherwise the configuration would be similar to that of the below-ground caisson, which is assessed later herein. The following data were used during the analysis of the above-ground caisson:

Ambient temperature (ta), F	100
Thermal conductivity of concrete (k), Btu/h-sq. ft-F	1.05
Maximum temperature of concrete, F	500
Emittance of concrete, (e')	0.9
Emittance of stainless steel canister, (e")	0.4
Inside caisson ceiling area, square feet	2.07
Inside dimensions (length and width) of square caisson, feet	1.44
Inside height of caisson, (H), feet	20
Concrete wall thickness (ceiling and walls), (L), feet	4
Outside dimensions (length and width) of square caisson, feet	9.44
Inside surface area (ceiling and walls), (Ai), sq. ft	117.3
Outside surface area (ceiling and walls), (Ao), sq. ft	1146
Outside surface area of steel canister, (As), sq. ft	44.9

Decay heat was assumed to be conducted through the ceiling and four vertical walls of the caisson, but not through the floor, since the thermal conductivity of dry soil is relatively low compared with that of concrete. Also, the conducting distance through the soil is greater than that of concrete, except around the perimeter of the caisson.

Therefore, heat removal through the floor was neglected. Moreover, since the above-ground caisson concept with no cooling is feasible as shown later, neglecting heat transfer through the floor is conservative.

Heat conducted through the walls of the caisson without considering effects of the thick corners is calculated as follows:

$$Qw = k(Ai)(dtw)/L = 1.05(117.3)(dtw)/4 \quad \text{(A-8)}$$

$$= 30.79 \text{ dtw}$$

where Qw = heat conducted through walls, excluding corners, Btu/h

dt = temperature difference between inside and outside walls, F

and other symbols and values were presented previously in the tabulated data for the caisson.

Using the method of Rohsenow discussed previously for correcting for heat conducted through the thick corners of the caisson, the correction is

$$Qcorr = 0.559NkH(dtw) = 0.559(4)(1.05)(20)(dtw) \quad \text{(A-9)}$$

$$= 46.96 \text{ dtw}$$

where Qcorr = heat conducted through corners, Btu/h

N = 4, number of corners

Adding the correction for the corners to the heat transferred through the walls of dimensions equal to the inside dimensions of the caisson, the total heat conducted through the walls and ceiling of the caisson, Qt, is

$$Qt = Qw + Qcorr = 30.79 \text{ dtw} + 46.96 \text{ dtw} \quad \text{(A-10)}$$

$= 77.75 \text{ dtw}$

At this stage in the analysis, the temperature of the outside wall is not known, therefore, dtw can not be determined. Also, the temperature of the inside walls might be less than the maximum value of 500 F. The outside wall temperature can be calculated by considering natural convection and radiation to the atmosphere, which was assumed to be at 100 F. The quantity of heat transferred by natural convection is

$$Qc = h(Ao)(dta) = 0.18\ (dta)^{0.333}(1146)(dta) \quad \text{(A-11)}$$

$$= 206.3\ (dta)^{1.333}$$

where Qc = heat transferred by natural convection, Btu/h

$h = 0.18\ (dta)^{0.333}$, heat transfer coefficient, Btu/h-sq. ft-F

dta = temperature difference between outside walls and ambient, F

The quantity of heat transferred from the outside walls to the environment by radiation is

$$Qr = 0.172 \times 10^{-8}\ e'(Ao)[To^4 - Ta^4] \quad \text{(A-12)}$$

$$= 0.172 \times 10^{-8}\ (0.9)(1146)[To^4 - (560)^4]$$

$$= 177.4 \times 10^{-8}\ [To^4 - (560)^4]$$

where Qr = heat radiated from outside walls to ambient, Btu/h

e' = 0.9, emittance of concrete walls

To = temperature of outside wall surface, R

Ta = 560 R (100 F), temperature of environment

The total quantity of heat conducted through the walls must be transferred from the external surface of the walls, therefore, for two disassembled PWR fuel assemblies each with 0.5 kw decay heat (total 1 kw or 3412 Btu/h), or one intact fuel assembly with 1 kw decay heat, the total quantity of heat transferred is

$$Qt = Qc + Qr \qquad \text{(A-13)}$$

Equations A-10 through A-13 were solved simultaneously, and the following values were determined, to the nearest integer values of temperature:

dtw = 44 F

dta = 2 F

Qt = 3421 Btu/h (1 kw)

Qc = 520 Btu/h (0.15 kw)

Qr = 2510 Btu/h (0.74 kw)

Since the interior temperature of the concrete is well below the maximum limit for concrete, the above-ground caisson concept with no cooling is feasible. Thus, this analysis is continued to calculate the temperature difference between the interior surfaces of the caisson and the exterior surfaces of the canister. From this temperature difference, the external surface of the canister was estimated. Using the previously calculated data of maximum fuel pin temperature as a function of canister surface temperature, the maximum fuel pin temperature was determined.

The correlation of Jakob (12) was used to calculate the heat transfer coefficient due to natural convection in the 4-inch-wide space between the canister and caisson. The Grashof number was calculated first to determine whether a laminar or turbulent correlation should be used. The access plug over the caisson was assumed to not be sealed tightly, thus the Grashof number was calculated using air properties at elevated temperature but at atmospheric pressure. The Grashof number is

$$Gr = g(b)(L)^{3}(dt)/(v)^{2} \tag{A-14}$$

$$= 32.2(0.001552)(0.333)^{3}(76)/(0.000233)^{2}$$

$$= 2.583\ E6$$

where Gr = Grashof number, based on 4-inch-wide air space

g = 32.2 ft/s/s, gravitational acceleration

b = 0.001552 (1/F), coefficient of cubical expansion of air

L = 0.333 ft (4 inches), air gap between caisson and canister

dt = 76 F, temperature difference between caisson and canister

v = 0.000233 sq. ft/s, kinematic viscosity of air

The temperature difference of 76 F was determined by iteration after the equations which follow were solved. The Grashof number is between the limits of 200,000 and 11,000,000 and Jakob recommends the following correlation to calculate the effective thermal conductivity of air in the 4-inch-wide space between the canister and caisson.

$$ke = 0.065\ (k)\ (Gr)^{0.333}\ (L/H)^{0.1111} \tag{A-15}$$

$$= 0.065\ (0.0176)\ (2.583\ E6)^{0.333}\ (0.01665)^{0.1111}$$

$$= 0.0991\ Btu/h\text{-}ft\text{-}F$$

where ke = effective conductivity of air, Btu/h-ft-F

k = 0.0176 Btu/h-ft-F, thermal conductivity of air

L/H = 0.333/20 = 0.01665, ratio of air space width to height

The quantity of heat transferred from the canister to the caisson by natural convection (calculated as conduction, using the effective thermal conductivity) is

$$Qc = ke(As)(dt)/L \qquad \text{(A-16)}$$

$$= 0.0991(44.9)(76)/(0.333)$$

$$= 1016 \text{ Btu/h } (0.30 \text{ kw})$$

where Qc = heat transferred across the 4-inch-wide air gap by conduction

ke = 0.0991 Btu/h-ft-F, effective thermal conductivity of air

As = 44.9 sq. ft, surface area of canister sides and ends

dt = 76 F, temperature difference between caisson and canister

L = 0.333 ft (4 inches), air gap between caisson and canister

The quantity of heat radiated from the canister to the caisson is

$$Qr = 0.172 \times 10^{-8} F (As)[Ts^4 - Ti^4] \qquad \text{(A-17)}$$

$$= 0.172 \times 10^{-8} (0.38)(44.9)[(682)^4 - (606)^4]$$

$$= 2390 \text{ Btu/h } (0.70 \text{ kw})$$

where Qr = heat radiated from canister to caisson, Btu/h

F = 1/[(1/e' + 1/e") - 1]

= 1/[(1/0.9 + 1/0.4) - 1]

= 0.38, radiation factor between canister and caisson

e' = 0.9, emittance of concrete walls

e" = 0.4, emittance of stainless steel canister

As = 44.9 sq. ft, surface area of steel canister

Ts = 682 R (222 F) temperature of canister surface

Ti = 606 R (146 F), temperature of inside caisson surface

This analysis indicates that the above-ground caisson with no cooling is feasible for 1 kw decay heat, which represents the design decay heat for one intact fuel assembly or 0.5 kw for each of two disassembled fuel assemblies. Since the inside temperature of the caisson is well below the maximum value of 500 F for concrete, this analysis was repeated for the range of decay heat, which results are summarized in Table 9 in the report.

Since the concept of above-ground caisson with no cooling is feasible for disassembled fuel assemblies, it also is feasible for intact fuel assemblies which have less total decay heat than that of disassembled fuel. Temperature values for the canister and caisson walls can be obtained from Table 9 using the appropriate value of total decay heat in the canister. After the canister surface temperature was determined, the maximum fuel pin temperature was estimated using the appropriate data of maximum fuel pin temperature presented as a function of canister surface temperature.

Below-Ground Caisson for Disassembled Fuel

The following data were used during the analysis of the below-ground caisson:

Ambient temperature (ta), F	100
Thermal conductivity of concrete (k), Btu/h-sq. ft-F	1.05
Maximum temperature of concrete, F	500
Emittance of concrete, (e')	0.9
Emittance of stainless steel canister, (e")	0.4
Inside caisson ceiling area, square feet	2.07
Inside dimensions (length and width) of square caisson, feet	1.44
Inside height of caisson, (H), feet	20
Concrete wall thickness (ceiling and walls), (L), feet	4
Outside dimensions (length and width) of square caisson, feet	9.44
Inside surface area (ceiling and walls), (Ai), sq. ft	117.3

Outside top surface area , (Ao), sq. ft 89.1

Outside surface area of steel canister, (As), sq. ft 44.9

The canister was assumed to contain two PWR disassembled fuel assemblies each with 1 kw decay heat or a total of 2 kw in the caisson. Heat was assumed to be transferred from the 9.44 foot square top to the environment by natural convection and radiation. The quantity of heat transferred by natural convection is

$$Qc = h(Ao)(dta) = 0.18\,(dta)^{0.333}\,(89.1)(dta) \qquad \text{(A-18)}$$

$$= 16.038\,(42)^{1.333}$$

$$= 2340 \text{ Btu/h } (0.69 \text{ kw})$$

where Qc = heat transferred by natural convection, Btu/h

$h = 0.18\,(dta)^{0.333}$, heat transfer coefficient, Btu/h-sq. ft-F

dta = temperature difference between outside top and ambient, F

The temperature difference of 42 F was determined by iteration after solving the natural convection and radiation equations. The quantity of heat transferred from the outside top surface of the caisson to the environment by radiation is

$$Qr = 0.172 \times 10^{-8}\, e'(Ao)[To^{4} - Ta^{4}] \qquad \text{(A-19)}$$

$$= 0.172 \times 10^{-8}\,(0.9)(89.1)[(602)^{4} - (560)^{4}]$$

$$= 4550 \text{ Btu/h } (1.33 \text{ kw})$$

where Qr = heat radiated from outside top to ambient, Btu/h

e' = 0.9, emittance of concrete walls

To = 602 R (142 F), temperature of outside top surface

Ta = 560 R (100 F), temperature of environment

The total quantity of heat transferred from the top surface of the caisson to the environment must be equal to the quantity conducted across the 4-foot-thick top; therefore,

$$dtw = Qw(L)/[k(Ao)] \qquad (A\text{-}20)$$

$$= 6824(4)/[1.05(89.1)]$$

$$= 292\ F$$

where dtw = temperature differential across caisson top, F

Qw = 6824 Btu/h (2 kw), decay heat of two PWR assemblies

and other symbols are defined in the aforementioned table of data.

The temperature of the inside top surface of the caisson is 434 F (100 F plus 42 F plus 292 F). The average temperature of the inside vertical walls of the caisson was estimated by the method of Rohsenow (11). This method assumes that the 434 F inside temperature extends uniformly across the plane of the inside top and that heat from the inside vertical walls is conducted outward and upward through the side walls. The thermal conductivity value of 1.05 Btu/h-ft-F was used for the vertical side walls, hence the side walls were assumed to be constructed either of concrete, wet soil encased by a steel liner, or some finning arrangement attached to the steel liner and extending into dry soil to produce the equivalent thermal conductivity as that of concrete. Also, since the method is for a cylinder, an equivalent diameter was calculated by assuming the circumference of the equivalent cylinder is equal to the perimeter of the four square walls of dimension 1.44 feet. Thus, the equivalent diameter (D) is 1.834 feet. The inside height (H) of 20 feet also was used in the calculation for the temperature difference between the vertical inside wall and the inside top of the caisson as follows:

$$dtc = (Qw)\ln[4H/D]/[6.28kH] \quad (A\text{-}21)$$

$$= (6824)\ln[4(20)/1.834]/[6.28(1.05)(20)]$$

$$= 195\ F$$

where dtc = temperature difference between caisson top and sides, F and other symbols have been defined previously.

The temperature of the inside walls is 629 (434 F plus 195 F). The temperature differential between the inside caisson walls and the canister was calculated by the same method shown previously (Equations A-14 through A-17). After determining the canister surface temperature, the maximum fuel pin temperature was estimated from the appropriate data of maximum fuel pin temperature as a function of canister surface temperature.

The various temperature and temperature differentials in the fuel and caisson for ranges of decay heat for intact and disassembled PWR and BWR fuel assemblies are summarized in Table 10 in the report.

APPENDIX B

ANALYSIS OF NATURAL CONVECTION CONCEPTS

APPENDIX B

ANALYSIS OF NATURAL CONVECTION CONCEPTS

Calculations are presented which indicate the thermal performance of a vault and a caisson with natural convection cooling, i.e., with air circulating from outside at 100 F and exiting the vault or caisson without restriction. Since filters were not assumed at the exit, filter pressure loss was not included in this analysis.

Vault with Disassembled Fuel

Since only 7.8 percent of the decay heat can be conducted across the above-ground vault walls (Appendix A), this heat loss was neglected in this analysis. Thus, this analysis applies to above-ground and below-ground vaults. The following data were used in the natural convection analysis:

Ambient temperature (ta), F	100
Maximum temperature of concrete, F	500
Canister height, (L), feet	14.17
Canister pitch (center-to-center distance), inches	15
Canister outside dimension, inches	9.25
Outside surface area of steel canister, (As), sq. ft	44.9
Flow area between canisters, (Af), sq. ft	0.968

An open-type rack was assumed, thus effects of the rack were neglected and the outside surface area of the canister was used for heat transfer. Also, in an infinite array of canisters, the heat transfer characteristics in the space between a group of four canisters were assumed to be like those everywhere in the array. Thus, only one-fourth of four canisters (i.e., one canister) need be considered. The flow area between four canisters was calculated by subtracting the cross sectional area of a canister (or one-fourth of four, which is 85.6 square inches) from the area in a 15- by 15-inch array (225 square inches). Hence, the flow area is 139.4 square inches or 0.968 square feet. The perimeter of a canister is 9.25(4) or 37 inches (3.083 feet), thus the hydraulic diameter (D) of the flow area is 4(0.968)/3.083 or 1.256 feet. The decay heat of four disassembled BWR fuel assemblies, which is 4 kw or 13,650 Btu/h, was assumed for the sample calculations which follow.

The quantity of air needed to cool a canister is

$$W = Q/[C(dt)] = 3.791/[0.24(dt)] = 15.8/dt \qquad \text{(B-1)}$$

where W = air flow rate to cool canister, lb/s

Q = 3.791 Btu/s (13,650 Btu/h), decay heat

C = 0.24 Btu/lb-F, heat capacity of air

dt = temperature differential between inlet and outlet air

The quantity of air that is convected in the space among canisters depends on the pressure loss in flowing into and out of the space among canisters and on the frictional pressure loss in flowing along the canisters. This pressure loss must also be balanced by the available potential energy (buoyancy) which depends on the density difference of the inlet and outlet air.

For the calculations which follow, a value of 42 F was assumed for dt. Thus, the outlet air was assumed to be 142 F and the average temperature of 121 F was used to calculate the average air density between the inlet and outlet of the vault. A value of 0.0684 pounds per cubic feet was calculated.

The velocity of the air is

$$V = W/[(DENa)Af] = 0.376/[(0.0684)0.968] = 5.67 \text{ ft/s} \quad (B\text{-}2)$$

where V = air velocity, ft/s

W = 15.8/42 = 0.376 lb/s, air flow rate from Equation B-1

DENa= 0.0684 lb/cu. ft, average air density

Af = 0.968 sq. ft, flow area among four canisters

The Reynold's number, which was used to estimate the friction factor, is

$$Re = VD/v = 5.67(1.256)/0.0001941 = 36{,}690 \quad (B\text{-}3)$$

where Re = Reynold's number

D = 1.256 ft, hydraulic diameter of flow area

v = 0.0001941 sq. ft/s, kinematic viscosity

A friction factor (f) of 0.022 was determined from standard friction factor curves using the smooth-surface curve. Expressed as a pressure loss coefficient (Kf), the value of Kf is

$$Kf = fL/D = 0.022(14.17)/1.256 = 0.25 \quad (B\text{-}4)$$

where Kf = number of velocity heads due to friction

f = 0.022, friction factor

L = 14.17 feet (170 inches), height of a canister

The standard values for entrance and exit pressure loss coefficients are 0.5 and 1.0, respectively. Thus, the total pressure loss coefficient (K) is K = 0.25 + 0.5 + 1.0 = 1.75, which is the sum of the frictional pressure loss coefficient and the inlet and outlet values. Since calculations were performed over a range of flow rates and the friction factor was as great as 0.04 for low velocities, a value of K equal to 2 was used subsequently.

The velocity head is

Vh = DENa(V)(V)/[2gc] (B-5)

= 0.0684(5.67)(5.67)/[2(32.2)]

= 0.0342 lb/sq. ft

where Vh = velocity head, lb/sq. ft

gc = 32.2 lbm-ft/lbf-s/s, gravitational constant

The total pressure loss is

dP = K(Vh) = 2(0.0342) = 0.0684 lb/sq. ft (B-6)

This value of pressure loss must be balanced by potential energy, which overcomes the flow resistance (pressure loss calculated in Equation B-6). The potential energy from buoyancy force is

PE = [DENin-DENout]L = [0.071-0.0659]14.17 = 0.0721 lb/sq. ft (B-7)

where PE = potential energy, lb/sq. ft

DENin = 0.071 lb/cu. ft, density of inlet air at 100 F

DENout= 0.0659 lb/cu. ft, density of outlet air at 142 F

Since the potential energy is approximately equal to the pressure loss, the assumed value of 42 F for the temperature differential between the outlet and inlet air is valid.

Instead of substituting values into Equations B-2 through B-7, the required flow rate to balance the resistive pressure loss and potential energy can be derived as follows:

$$dP = K(DENa)(V)(V)/[2gc] = [DENin-DENout]L \qquad \text{(B-8)}$$

By substituting previously defined symbols into Equation B-8, the following equation for flow rate can be determined.

$$Wp = 14.62[(0.071)^2 - (DENout)^2]^{0.5} \qquad \text{(B-9)}$$

where Wp = flow rate calculated from pressure loss considerations

The flow rate, Wp, must be at least equal to that calculated from Equation B-1, which can be verified by substituting previous values into Equations B-1 and B-9.

The temperature differential between a canister surface and the maximum (outlet) air temperature was calculated from a standard correlation for natural convection on a vertical wall. Air properties were evaluated at the average of the temperature differential between the canister surface and the average air temperature at atmospheric pressure. The Rayleigh number is

$$Ra = g(b)(L)^3(dt)Pr/(v)^2 \qquad \text{(B-10)}$$

$$= 32.2(0.001316)(14.17)^3(273)(0.69)/(0.000307)^2$$

$$= 2.41\ E11$$

where Ra = Rayleigh number, based on 14.17-foot-high canister

g = 32.2 ft/s/s, gravitational acceleration

b = 0.001316 (1/F), coefficient of cubical expansion of air

L = 14.17 ft (170 inches), canister height

dt = 273 F, temperature difference between the air and canister

v = 0.000307 sq. ft/s, kinematic viscosity of air

The heat transfer coefficient due to natural convection is

$$h = 0.126(k)(Ra)^{0.333}/L \quad \text{(B-11)}$$

$$= 0.126(0.0203)(2.21\ E11)^{0.333}/14.17$$

$$= 1.11\ \text{Btu/h-sq. ft-F}$$

The quantity of heat convected from the surface of the canister to the air is calculated next, and the value of temperature differential of 273 F was selected so that the quantity of heat would equal 4 kw, which was assumed at the start of Appendix B.

$$Qc = h(As)(dt) = 1.11(44.9)(273) = 13{,}600\ \text{Btu/h (4 kw)} \quad \text{(B-12)}$$

where Qc = quantity of heat convected from canister surface, Btu/h

As = 44.9 sq. ft, canister surface area

dt = 273 F, temperature differential between canister and air

The quantity of heat radiated to the top of the vault has been estimated to be approximately 4 percent of the total; therefore, it was neglected. The reason for the small value is due to the small view factor of a vertical canister to the top of the vault when other canisters are in close proximity.

Using the maximum air temperature of 142 F calculated previously, the maximum surface temperature of a canister is 142 F plus 273 F or 415 F as indicated in Table 12 under the column headed 4 kw.

Temperature differentials for a range of flow rate was calculated and summarized in Table 12 in the report. Maximum fuel pin temperatures were determined from data of maximum fuel pin temperature as a function of canister surface temperature.

The concept of natural convection cooling is feasible for a vault, if no filters or other significant pressure losses are in the exit from the vault and if the maximum BWR disassembled fuel temperature of 593 F is acceptable for an assembly with 1 kw for long-term storage.

Below-Ground Caisson with Disassembled Fuel

The flow area around a canister in a caisson is 1.472 square feet, which is greater than than around a canister in a vault. Therefore, the pressure loss is less in a caisson than that in the vault analyzed previously. The temperature differential to dissipate 4 kw was determined to be 32 F instead of 42 F, using the same procedure as shown previously in this appendix. This difference (10 F) is small compared to the overall temperature difference from the hottest fuel pin to the outlet air. Therefore, temperature values in Table 12 can also be applied to below-ground caissons with a small amount of conservatism.

For the above-ground caisson, considerable heat is conducted across the walls of the caisson to the environment. Therefore, Tables 10 and 12 are used to estimate the decay heat that can be dissipated, assuming a maximum fuel pin temperature. Entering Table 12 with 390 F for the maximum fuel pin temperature of a disassembled PWR fuel assembly, the decay heat dissipated to the air is a total of 2 kw (1 kw per assembly) and the outlet air temperature is 126 F. Assuming that the inside caisson walls will also be at the maximum air temperature, entering Table 10 with 126 F for the inside caisson wall temperature, a total of approximately 0.5 kw can be dissipated. Thus, the total decay heat that can be dissipated is 2.5 kw (1.25 kw per assembly). By similar use of these tables of data, if a specified total decay heat is wanted, the temperatures can be interpolated. Alternatively, if some conservatism can be tolerated in the estimate, only Table 12 need be used, since the quantity of heat conducted through the above-ground caisson is approximately 0.5 kw divided by 2.5 kw or 20 percent of the total.

REPORT NO. AGNS 35900-1.3-96

CONCEPTUAL DRAWINGS

SPENT FUEL DRY STORAGE STUDIES AT BARNWELL NUCLEAR FUEL PLANT

Kenneth J. Anderson

September 1980

Allied-General Nuclear Services
Post Office Box 847
Barnwell, South Carolina 29812

CONCEPTUAL DRAWINGS

DRAWINGS:

533D-A-5001 - Dry Storage Concepts for Spent LWR Fuel -- Site Plan

533D-A-5002 - RPC Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5003 - RPC Concept -- Dry Storage of Spent LWR Fuel -- Elev. View

533D-A-5004 - Contact Cells Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5005 - Contact Cells Concept -- Dry Storage of Spent LWR Fuel -- Elevation

533D-A-5006 - FRSS Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5007 - FRSS Concept -- Dry Storage of Spent LWR Fuel -- Elevation View

533D-A-5008 - Waste Tank Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5009 - Waste Tank Concept -- Dry Storage of Spent LWR Fuel -- Elevation View

533D-A-5010 - PNC No. 1 & 2 Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5011 - PNC No. 1 & 2 Concept -- Dry Storage of Spent LWR Fuel -- Elevation View

533D-A-5012 - EUA Concept -- Dry Storage of Spent LWR Fuel -- Plan View

533D-A-5013 - EUA Concept -- Dry Storage of Spent LWR Fuel -- Elevation View

533D-A-5014 - Caisson Loading Facility Plan View

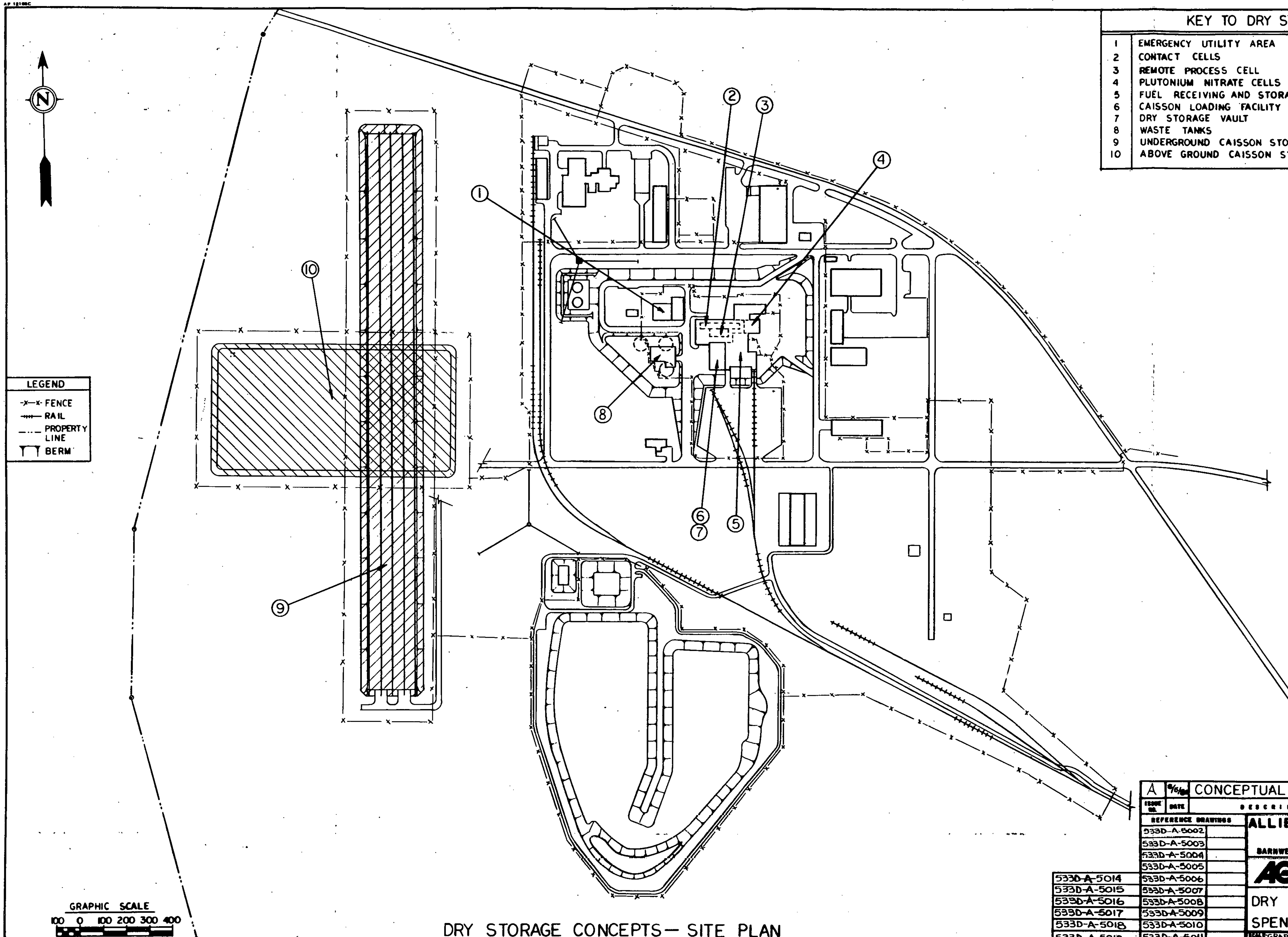
533D-A-5015 - Caisson Loading Facility Elevation View

533D-A-5016 - Above Ground Caisson Storage Concept for Spent LWR Fuel

533D-A-5017 - Below Ground Caisson Storage Concept for Spent LWR Fuel

533D-A-5018 - Vault for Storage of Spent LWR Fuel -- Plan View

533D-A-5019 - Vault for Dry Storage of Spent LWR Fuel Elevation View



DRY STORAGE CONCEPTS— SITE PLAN

KEY TO DRY STORAGE CONCEPTS

1	EMERGENCY UTILITY AREA
2	CONTACT CELLS
3	REMOTE PROCESS CELL
4	PLUTONIUM NITRATE CELLS
5	FUEL RECEIVING AND STORAGE STATION
6	CAISSON LOADING FACILITY
7	DRY STORAGE VAULT
8	WASTE TANKS
9	UNDERGROUND CAISSON STORAGE
10	ABOVE GROUND CAISSON STORAGE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	DESIGN ENG.	DESIGN MGR.	APP'L	APP'L	APP'L
A	9/5/80	CONCEPTUAL DRAWING	APK	PO	KJA		KJA		

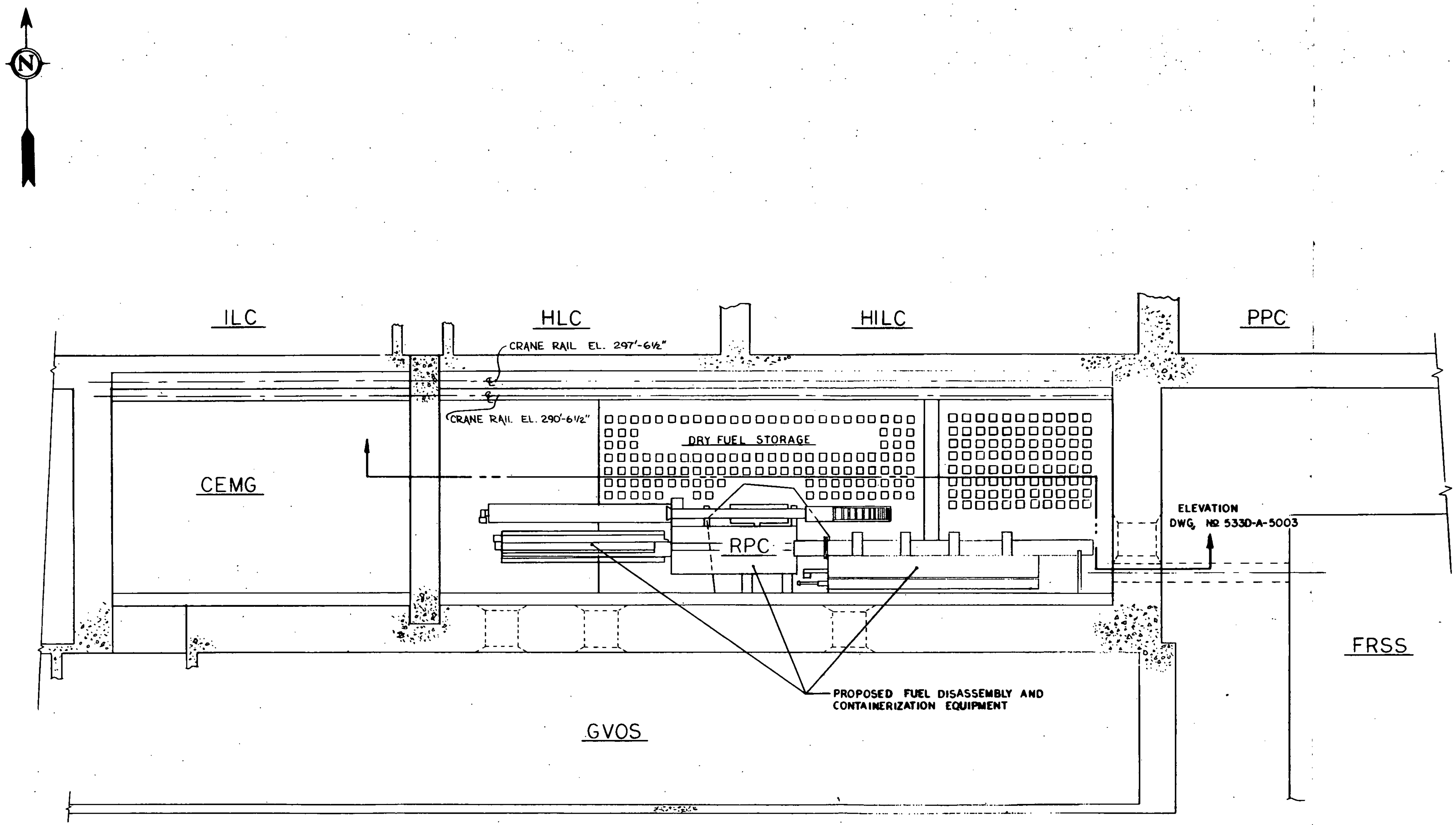
REFERENCE DRAWINGS	
533D-A-5014	533D-A-5002
533D-A-5015	533D-A-5003
533D-A-5016	533D-A-5004
533D-A-5017	533D-A-5005
533D-A-5018	533D-A-5006
533D-A-5019	533D-A-5007
	533D-A-5008
	533D-A-5009
	533D-A-5010
	533D-A-5011
	533D-A-5012
	533D-A-5013

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
BARNWELL SOUTH CAROLINA

AGNS DESIGN ENGINEERING DEPARTMENT
P. O. BOX 847
BARNWELL, S. C. 29812

DRY STORAGE CONCEPTS FOR SPENT LWR FUEL—SITE PLAN

SCALE	FACILITY	DRAWING NO.	ISSUE
GRAPHIC SCALE ONLY	3051005	533D-A-5001	A



LEGEND

ILC	INTERMEDIATE LEVEL CELL
HLC	HIGH LEVEL CELL
HILC	HIGH INTERMEDIATE LEVEL CELL
PPC	PLUTONIUM PRODUCT CELL
CEMG	CRANE EQUIP. MAINT. GALLERY
RPC	REMOTE PROCESS CELL
GVOS	GRADE VIEWING & OPERATING STATION
FRSS	FUEL RECEIVING STORAGE & SHIPPING

NOTES:

1. CAPACITY: 438 MTU AS SHOWN (COMBINED PWR AND BWR STORAGE).

RPC—PLAN VIEW

NO SCALE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK			APPR.	APPR.	APPR.
A	8/6/80	CONCEPTUAL DRAWING	HPB	PO	KJA		KJN		

REFERENCE DRAWINGS

533D-A-5001

533D-A-5003

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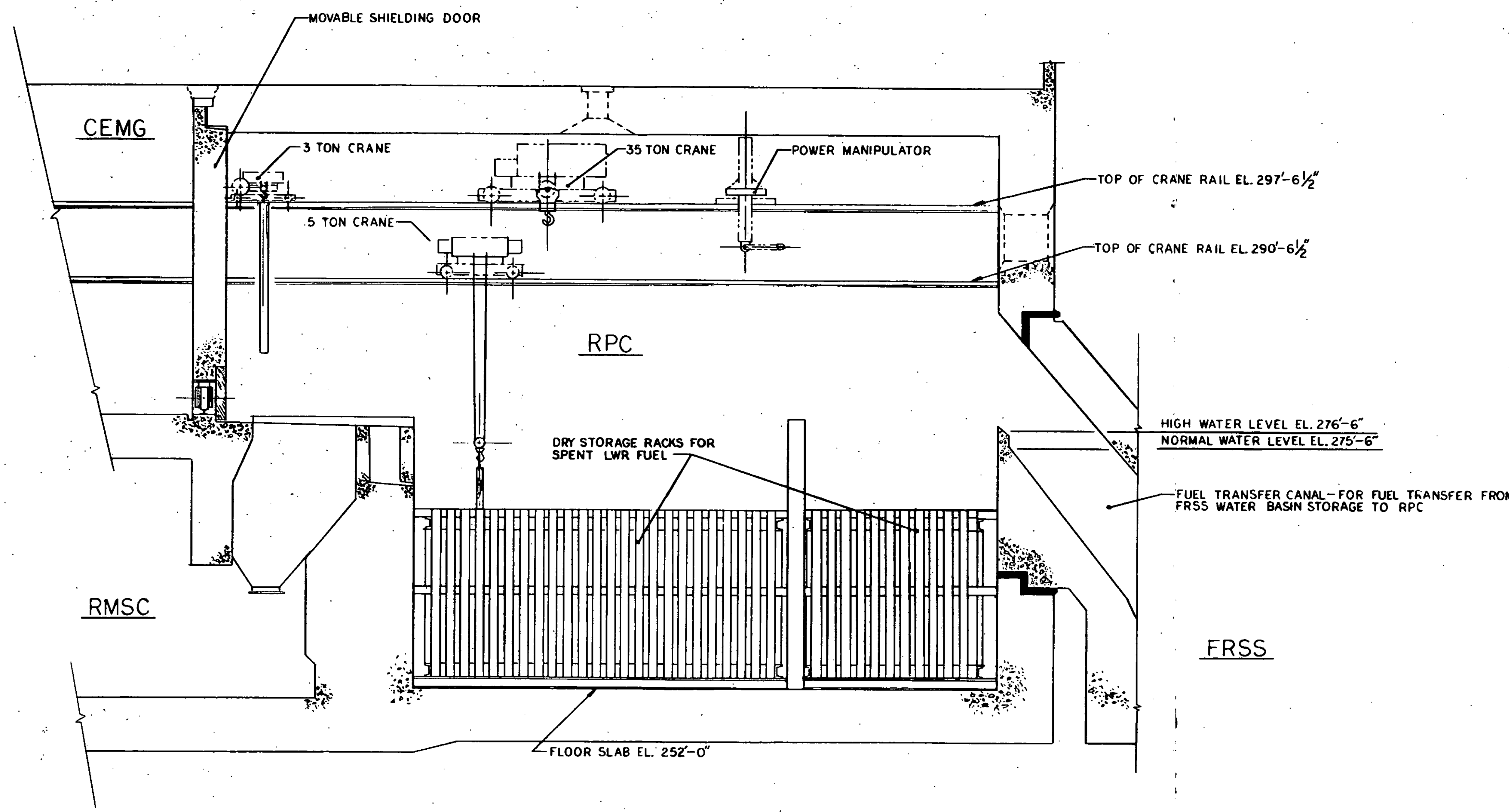
RPC CONCEPT—DRY STORAGE OF SPENT LWR FUEL—PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5002	A



RPC-ELEVATION VIEW
NO SCALE

A	9/5/80	CONCEPTUAL DRAWING	HPE	Fo.	KJA		KJA	
ISSUE NO.	DATE	DESCRIPTION	BY	CHK			APP'L	APP'L

REFERENCE DRAWINGS: 533D-A-5001, 533D-A-5002

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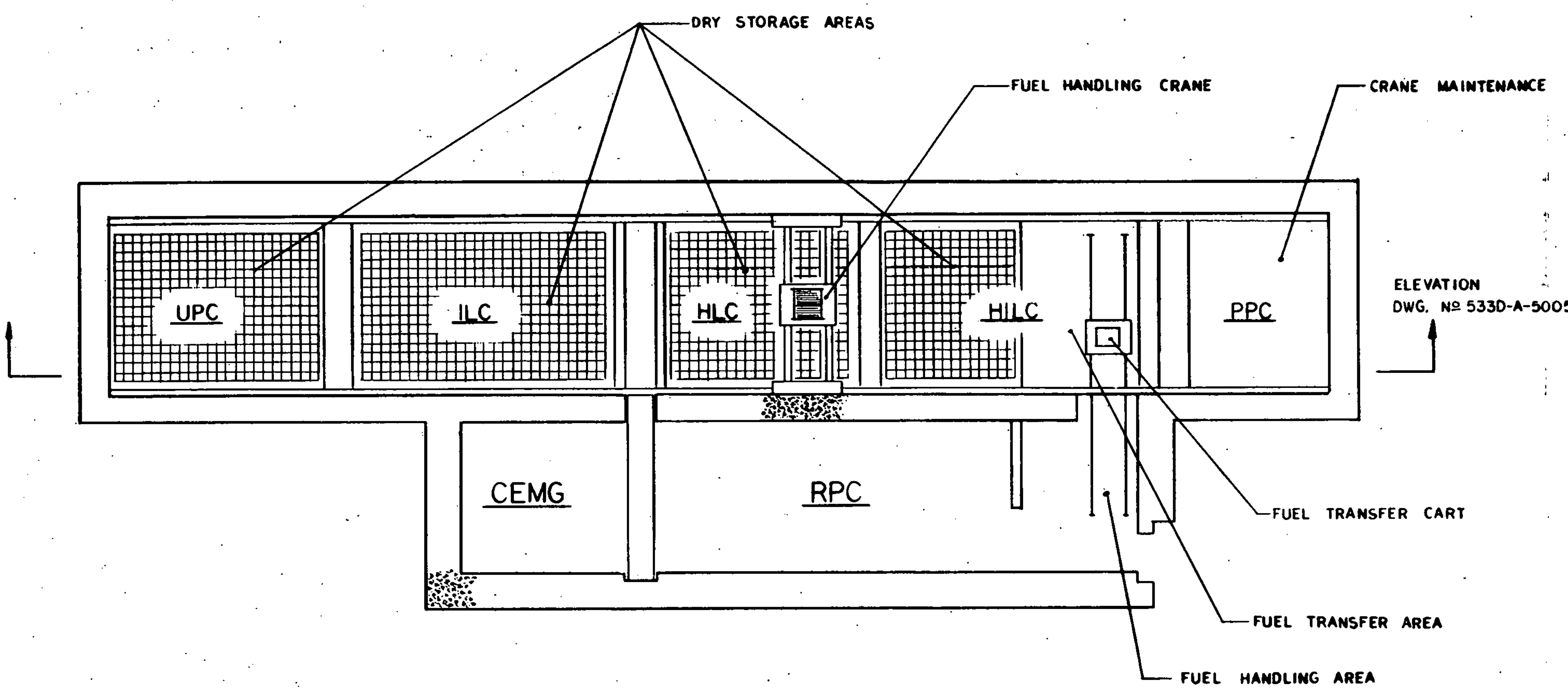
RPC CONCEPT-DRY STORAGE OF SPENT LWR FUEL-ELEV. VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5003	A



CONTACT CELLS — PLAN VIEW

NO SCALE

NOTES:

1. CAPACITY: 3341 MTU AS SHOWN (COMBINED BWR AND PWR STORAGE).

A | CONCEPTUAL DRAWING

REFERENCE DRAWINGS: 533D-A-5001, 533D-A-5005

ALLIED GENERAL NUCLEAR SERVICES
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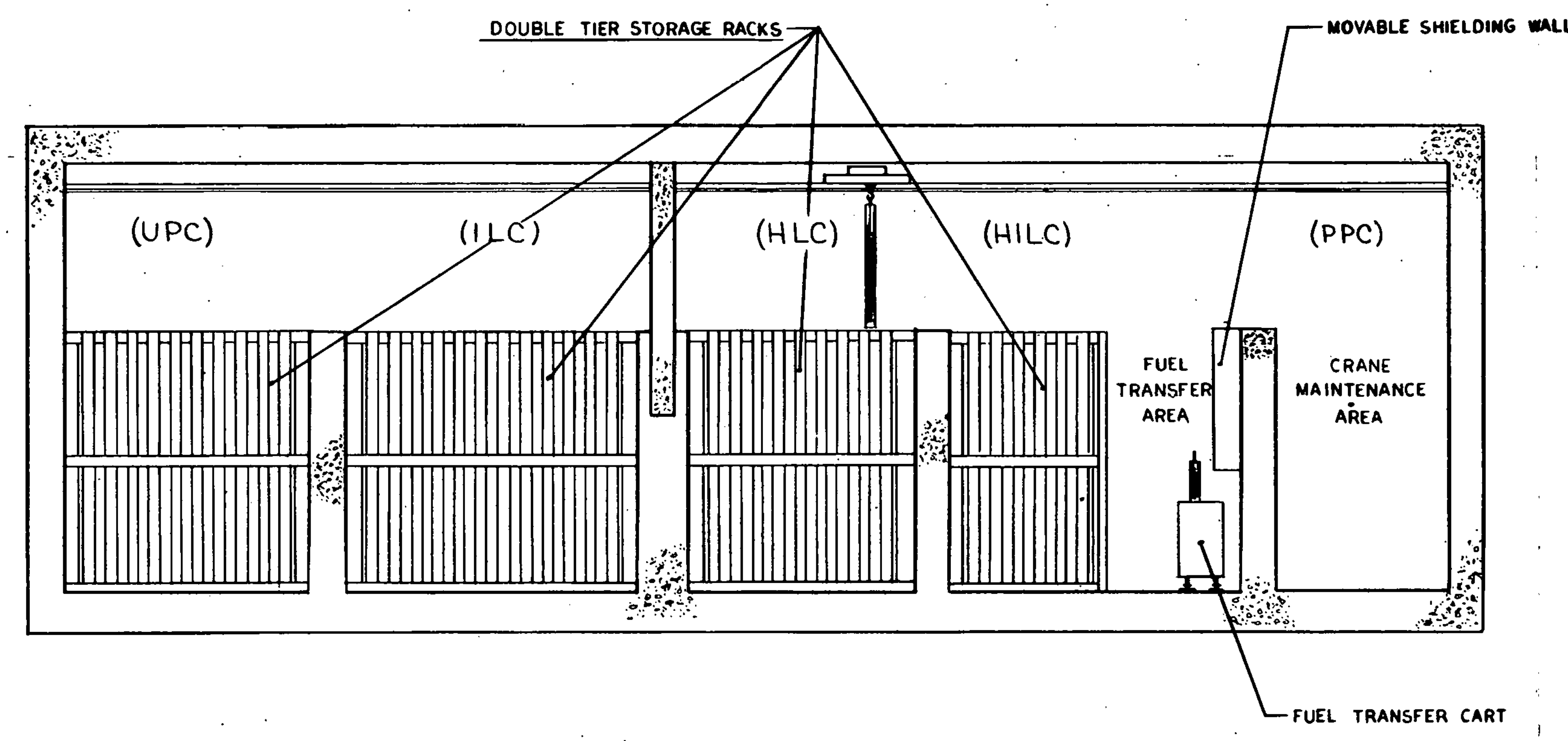
CONTACT CELLS CONCEPT—DRY STORAGE OF SPENT LWR FUEL—PLAN VIEW

SCALE: NONE | FACILITY: 3051003 | DRAWING NO.: 533D-A-5004 | ISSUE: A



CONTACT CELLS — ELEVATION VIEW
NO SCALE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	ENG.	MGR.	APP'L	APP'L	APP'L
A	9/80	CONCEPTUAL DRAWING	HTB	PO	KJA		KJA		

REFERENCE DRAWINGS:
533D-A-5001
533D-A-5004

ALLIED GENERAL NUCLEAR SERVICES
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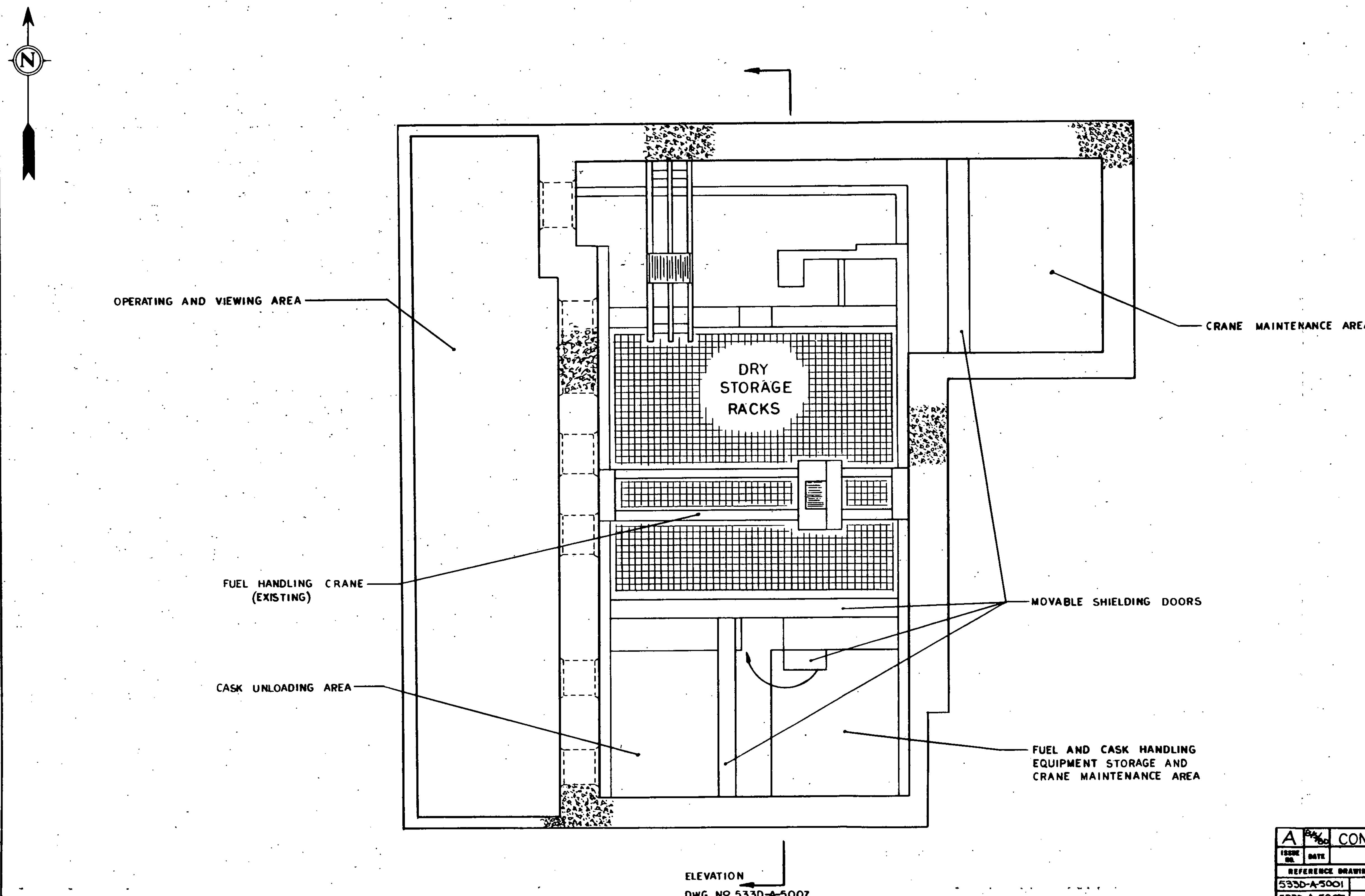
CONTACT CELLS CONCEPT—DRY STORAGE OF SPENT LWR FUEL—ELEV.

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5005	A



FRSS—PLAN VIEW
NO SCALE

NOTES:

1. CAPACITY: 976 MTU AS SHOWN (COMBINED BWR AND PWR STORAGE).

ISSUE NO.	DATE	DESCRIPTION	BY	CHK			APP'L	APP'L	APP'L
A	8/4/80	CONCEPTUAL DRAWING	HPG	P.S.	KJA		KJA		

REFERENCE DRAWINGS
533D-A-5001
533D-A-5007

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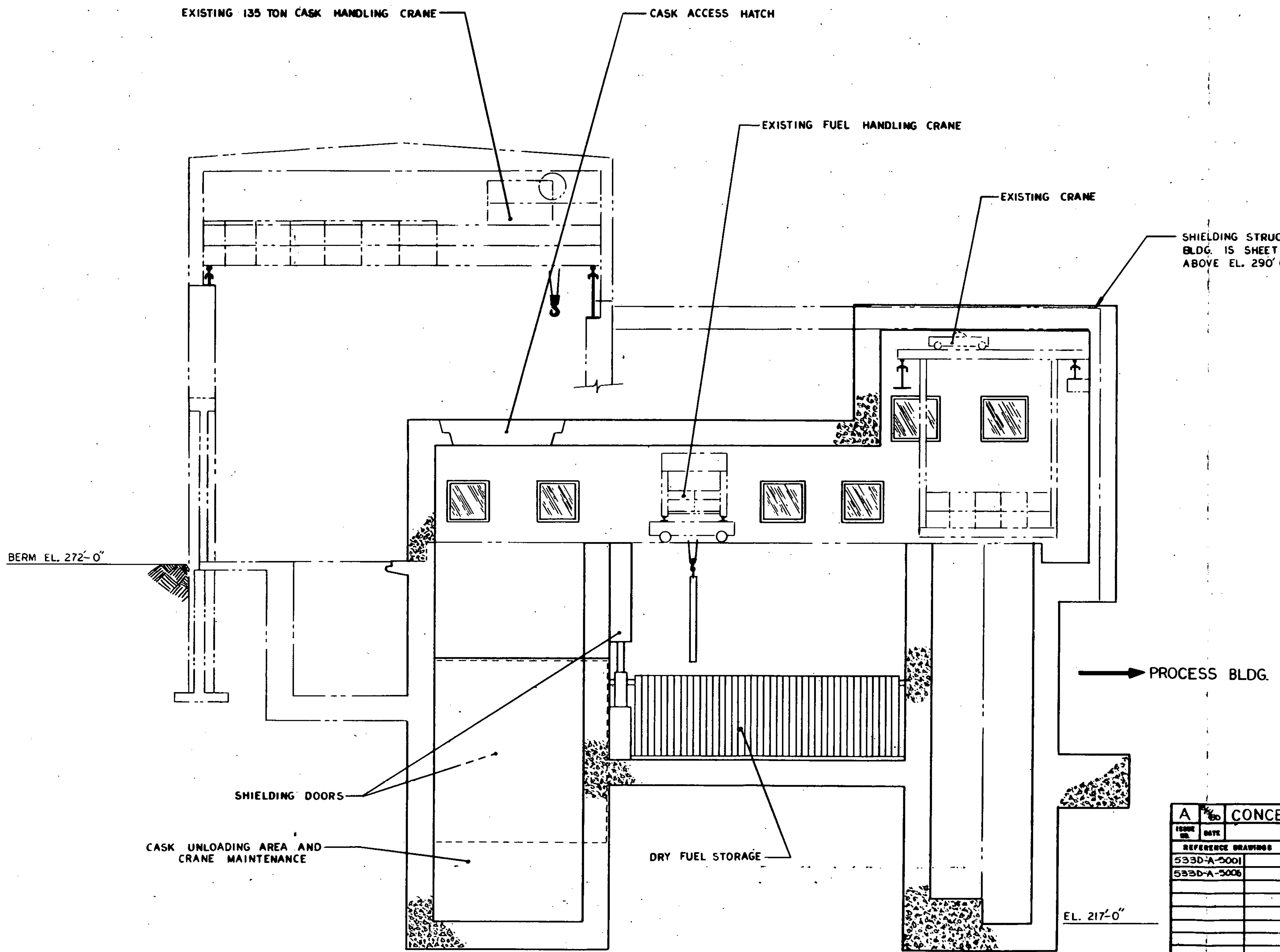
FRSS CONCEPT—DRY STORAGE OF SPENT LWR FUEL—PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051005	533D-A-5006	A



FRSS – ELEVATION VIEW
NO SCALE

A — CONCEPTUAL DRAWING

REFERENCE DRAWINGS: 533D-A-5001; 533D-A-5006

ALLIED GENERAL NUCLEAR SERVICES
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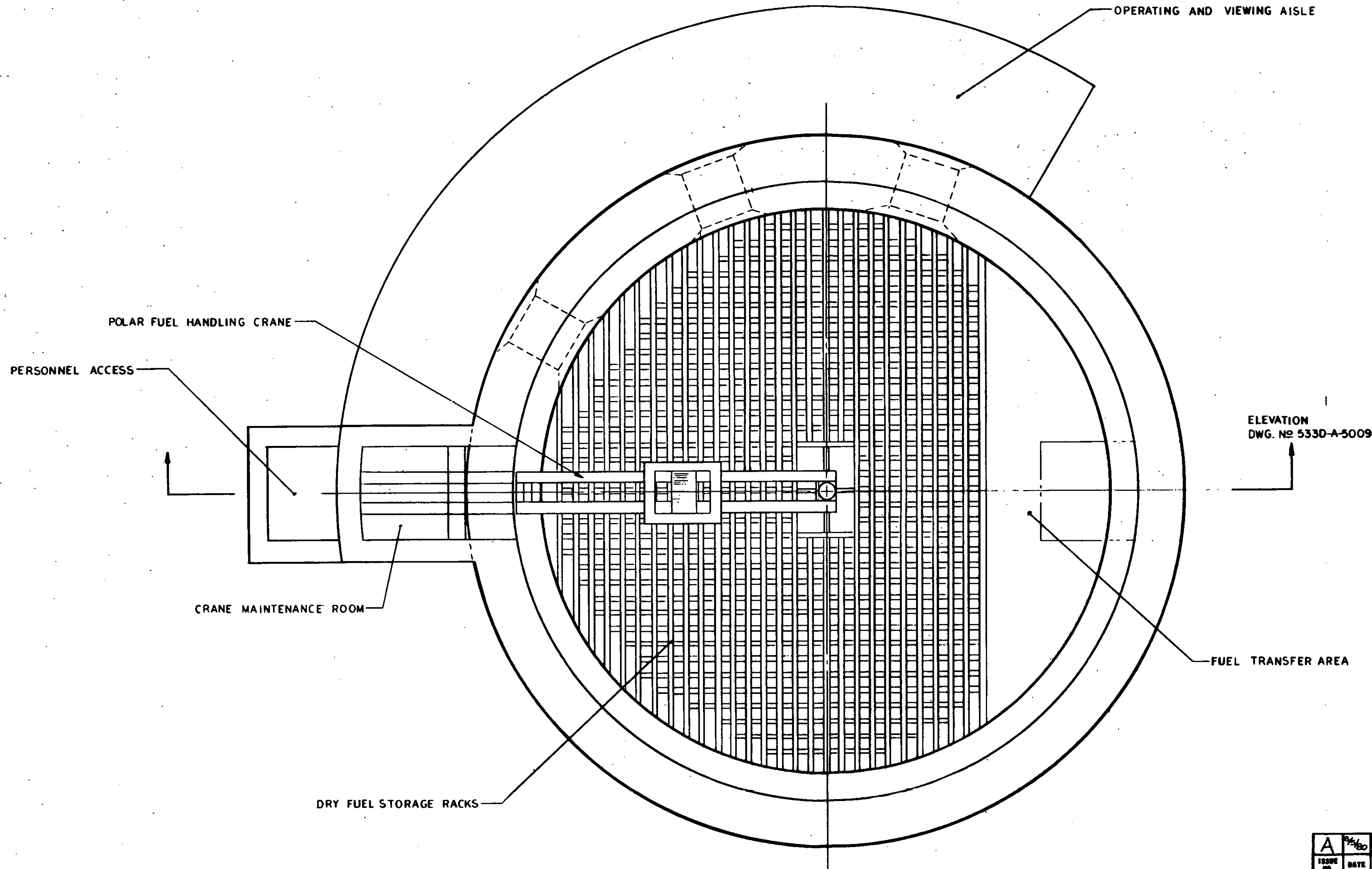
FRSS CONCEPT—DRY STORAGE OF SPENT LWR FUEL—ELEVATION VIEW

SCALE: NONE | FACILITY: 3051005 | DRAWING NO.: 533D-A-5007 | ISSUE: A



WASTE TANK- PLAN VIEW
NO SCALE — TYP. 3 PLACES

NOTES:

1. CAPACITY: 1200 MTU PER TANK, WITH 3 EXISTING TANKS TOTAL CAPACITY IS 3600 MTU AS SHOWN (COMBINED BWR AND PWR STORAGE).

ISSUE NO.	DATE	DESCRIPTION	BY	CKD	DESIGN ENG.	DESIGN MGR.	APP'L	APP'L	APP'L
A	8/5/80	CONCEPTUAL DRAWING	HPS	PO	KJA	HA	KJA		

REFERENCE DRAWINGS	
533D-A-5001	
533D-A-5009	

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
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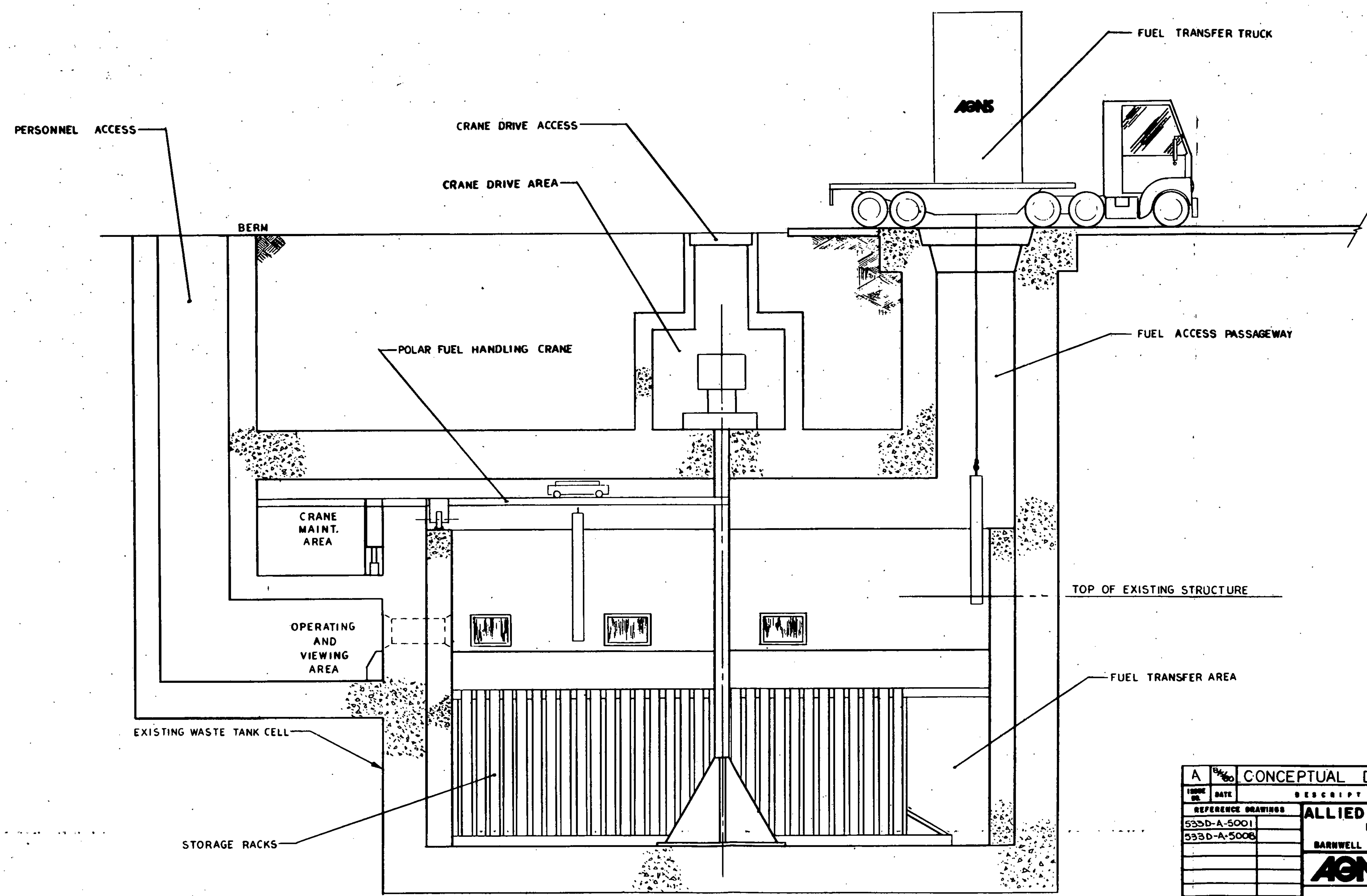
WASTE TANK CONCEPT– DRY STORAGE OF SPENT LWR FUEL– PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5008	A



WASTE TANK—ELEVATION VIEW

NO SCALE

ISSUE NO.	DATE	DESCRIPTION
A		CONCEPTUAL DRAWING

REFERENCE DRAWINGS
533D-A-5001
533D-A-5008

ALLIED GENERAL NUCLEAR SERVICES
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WASTE TANK CONCEPT–DRY STORAGE OF SPENT LWR FUEL–ELEV. VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
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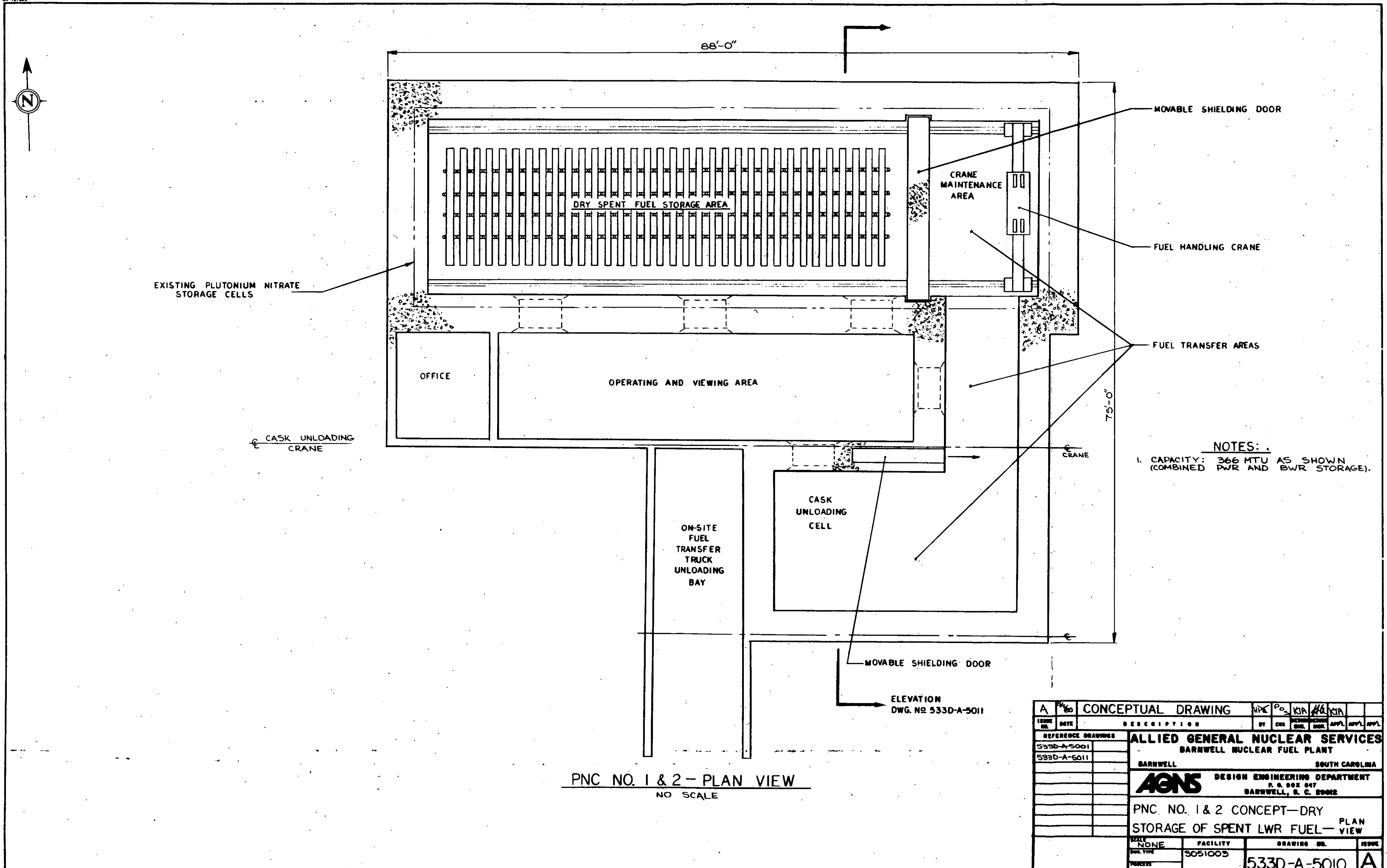
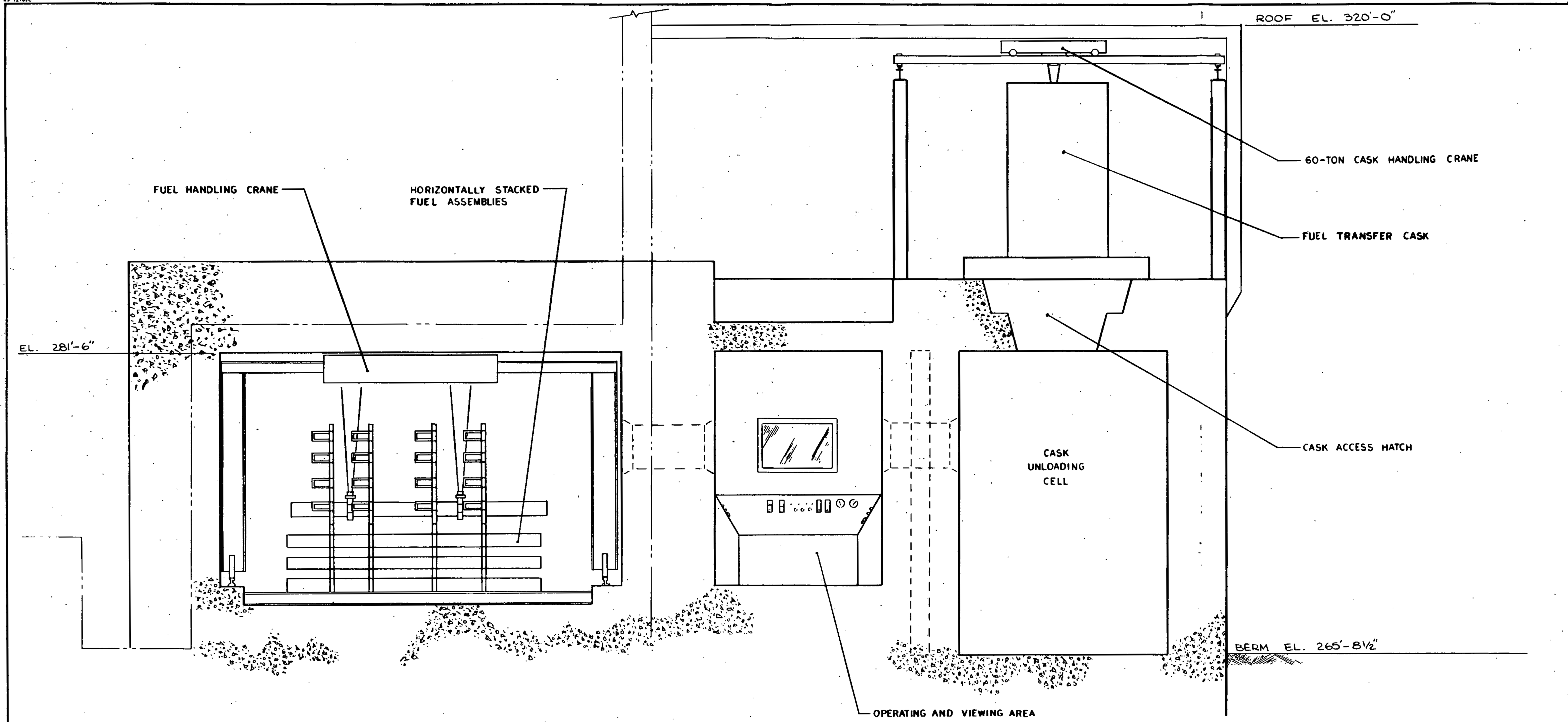


88'-0"
75'-0"
N
MOVABLE SHIELDING DOOR
CRANE MAINTENANCE AREA
DRY SPENT FUEL STORAGE AREA
FUEL HANDLING CRANE
EXISTING PLUTONIUM NITRATE STORAGE CELLS
FUEL TRANSFER AREAS
OFFICE
OPERATING AND VIEWING AREA
℄ CASK UNLOADING CRANE
℄ CRANE
NOTES:
1. CAPACITY: 366 MTU AS SHOWN (COMBINED PWR AND BWR STORAGE).
CASK UNLOADING CELL
ON-SITE FUEL TRANSFER TRUCK UNLOADING BAY
℄
MOVABLE SHIELDING DOOR
ELEVATION DWG. NO 533D-A-5011
PNC NO. 1 & 2 – PLAN VIEW
NO SCALE
A CONCEPTUAL DRAWING
ISSUE NO. DATE DESCRIPTION BY CHK. APP'L. APP'L. APP'L.
REFERENCE DRAWINGS
533D-A-5001
533D-A-5011
ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
BARNWELL SOUTH CAROLINA
AGNS
DESIGN ENGINEERING DEPARTMENT
P. O. BOX 847
BARNWELL, S. C. 29812
PNC. NO. 1 & 2 CONCEPT—DRY STORAGE OF SPENT LWR FUEL— PLAN VIEW
SCALE NONE
FACILITY 3051003
DRAWING NO. 533D-A-5010
ISSUE A



PNC NO. 1 & 2 — ELEVATION VIEW

NO SCALE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	ENG.	MGR.	APP'L	APP'L	APP'L
A	9/5/80	CONCEPTUAL DRAWING	HPS	PO	KJA		KJA		

REFERENCE DRAWINGS	
533D-A-5001	
533D-A-5010	

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
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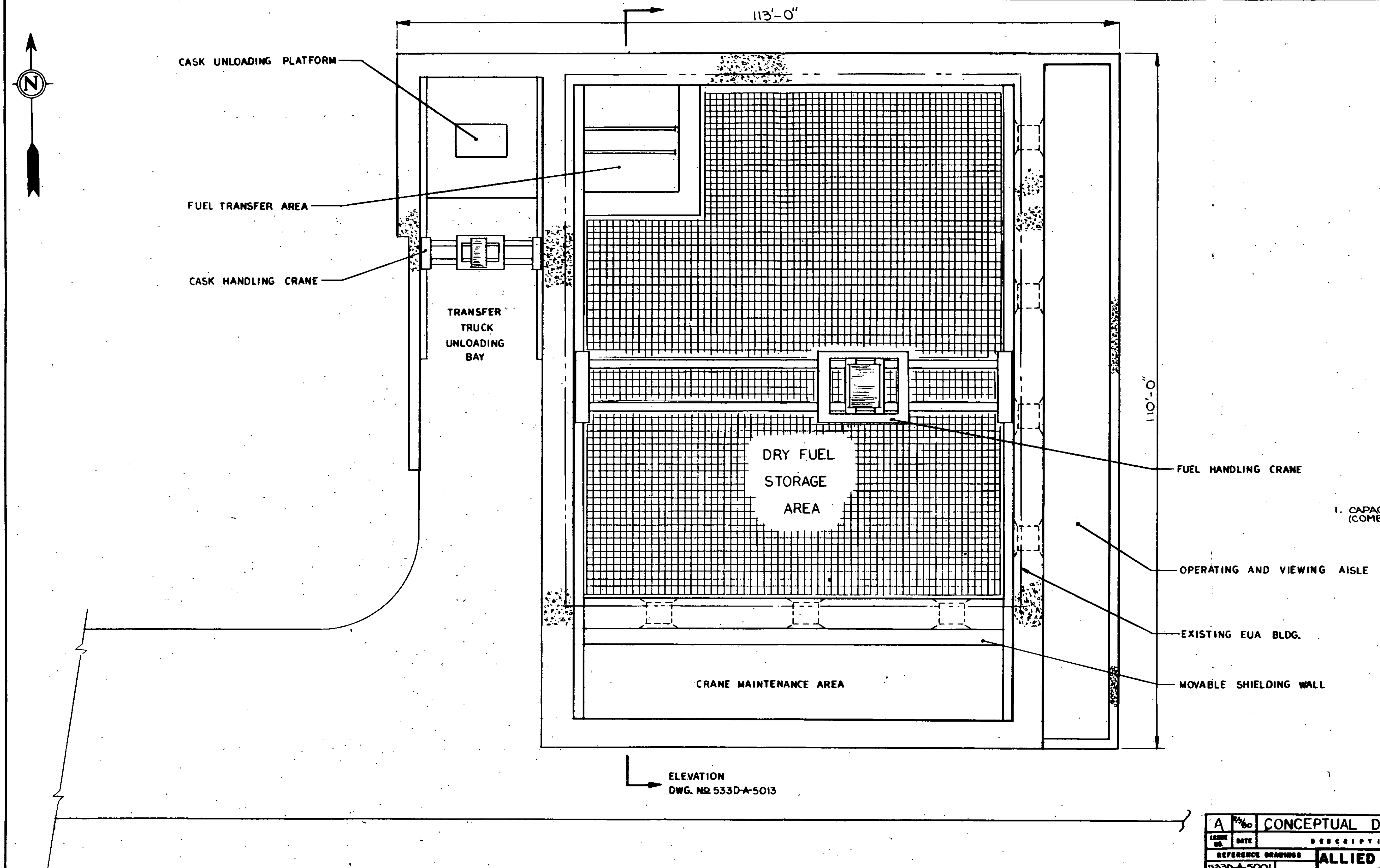
BARNWELL, S. C. 29812

PNC NO. 1 & 2 CONCEPT—DRY STORAGE OF SPENT LWR FUEL—ELEVATION VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5011	A

DWG. TYPE

PROCESS



EUA—PLAN VIEW
NO SCALE

NOTES:

1. CAPACITY: 2680 MTU AS SHOWN (COMBINED BWR AND PWR STORAGE).

ISSUE NO.	DATE	DESCRIPTION	BY	CHK			APP'L	APP'L	APP'L
A	7/80	CONCEPTUAL DRAWING	HPB	PO	KJA		KJA		

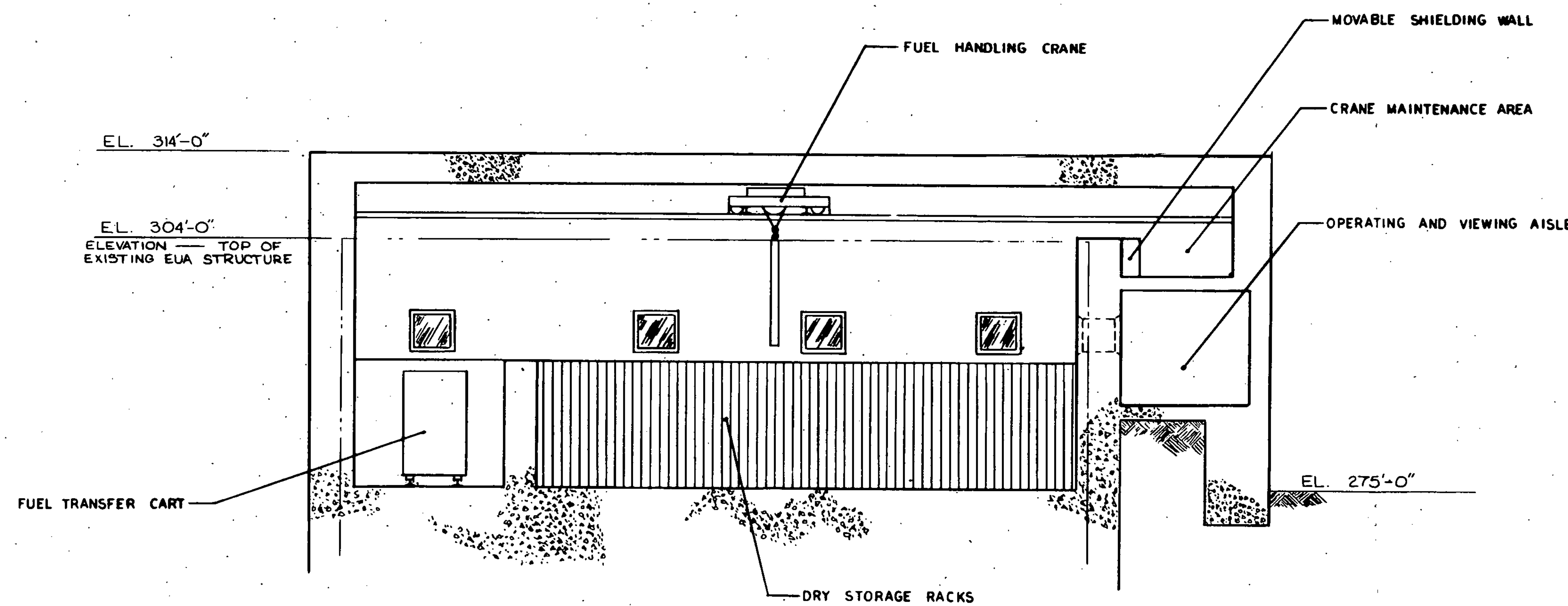
REFERENCE DRAWINGS
533D-A-5001
533D-A-5013

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
BARNWELL SOUTH CAROLINA

AGNS DESIGN ENGINEERING DEPARTMENT
P. O. BOX 847
BARNWELL, S. C. 29812

EUA CONCEPT—DRY STORAGE OF SPENT LWR FUEL—PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5012	A



EUA–ELEVATION VIEW
NO SCALE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	DESIGN ENG.	DESIGN MGR.	APP'L	APP'L	APP'L
A	6/4/80	CONCEPTUAL DRAWING	HPG	PO	KIA		KIA		

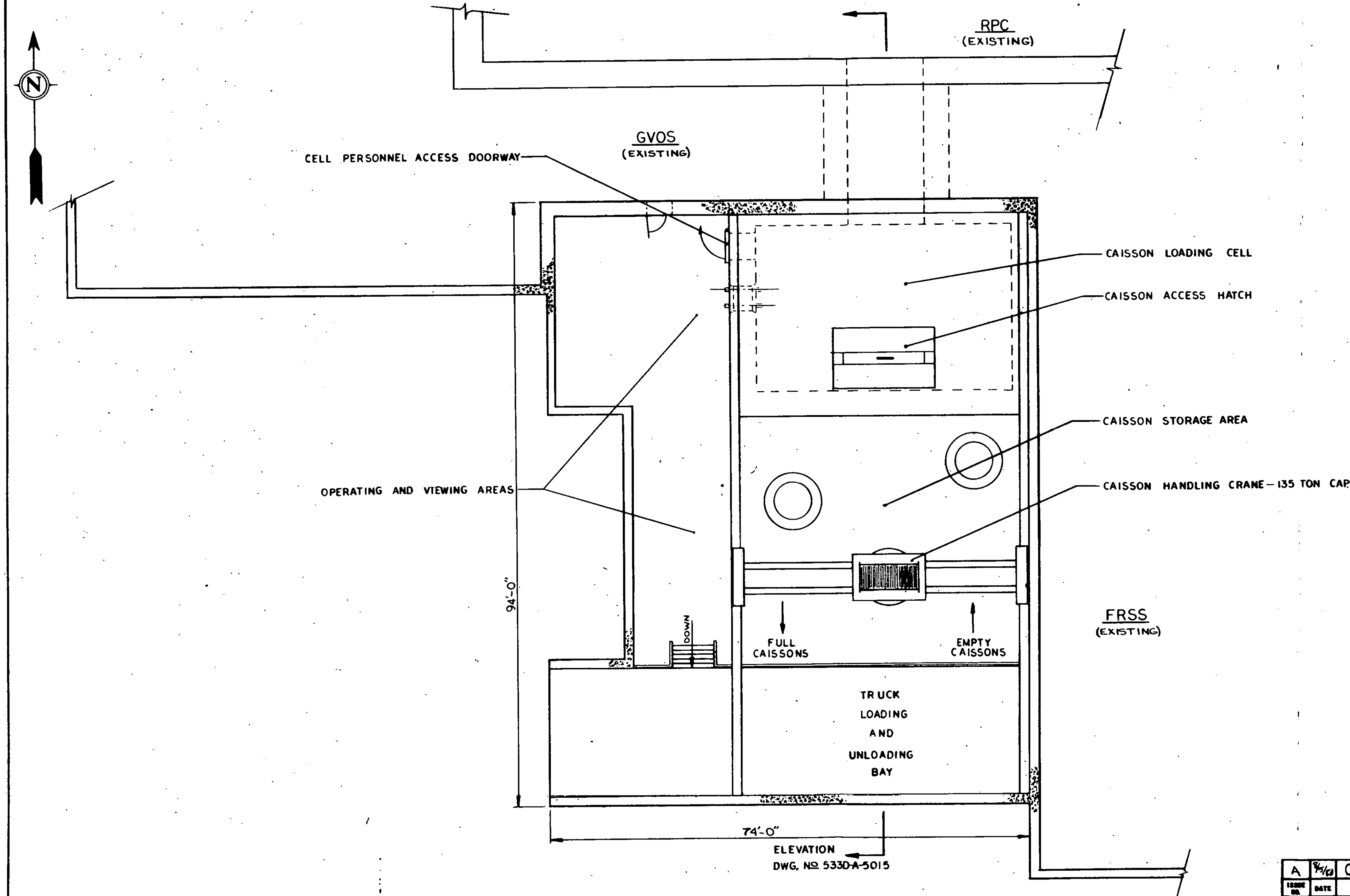
REFERENCE DRAWINGS
533D-A-3001
533D-A-5012

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
BARNWELL SOUTH CAROLINA

AGNS DESIGN ENGINEERING DEPARTMENT
P. O. BOX 847
BARNWELL, S. C. 29812

EUA CONCEPT—DRY STORAGE OF SPENT LWR FUEL—ELEVATION VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5013	A



CAISSON LOADING FACILITY – PLAN VIEW

NO SCALE

ISSUE NO.	DATE	DESCRIPTION
A		CONCEPTUAL DRAWING

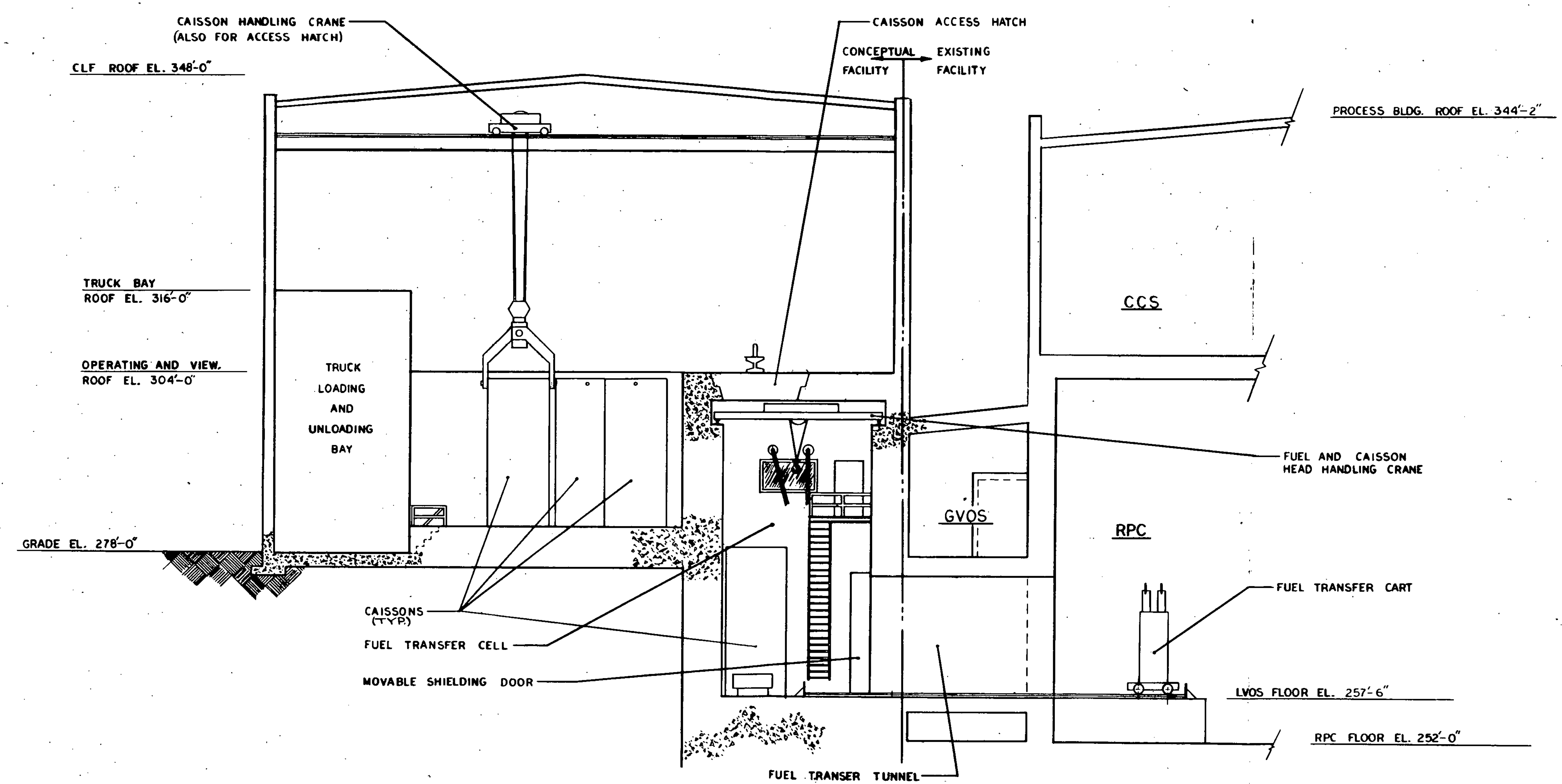
REFERENCE DRAWINGS: 533D-A-5001, 533D-A-5015

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
BARNWELL SOUTH CAROLINA

AGNS DESIGN ENGINEERING DEPARTMENT
P. O. BOX 847
BARNWELL, S. C. 29812

CAISSON LOADING FACILITY PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5014	A



CAISSON LOADING FACILITY—ELEVATION VIEW

NO SCALE

A — CONCEPTUAL DRAWING

ISSUE NO. | DATE | DESCRIPTION | BY | CHK | DESIGN ENG. | DESIGN MGR. | APP'L | APP'L | APP'L

REFERENCE DRAWINGS: 533D-A-5001, 533D-A-5014

ALLIED GENERAL NUCLEAR SERVICES
BARNWELL NUCLEAR FUEL PLANT
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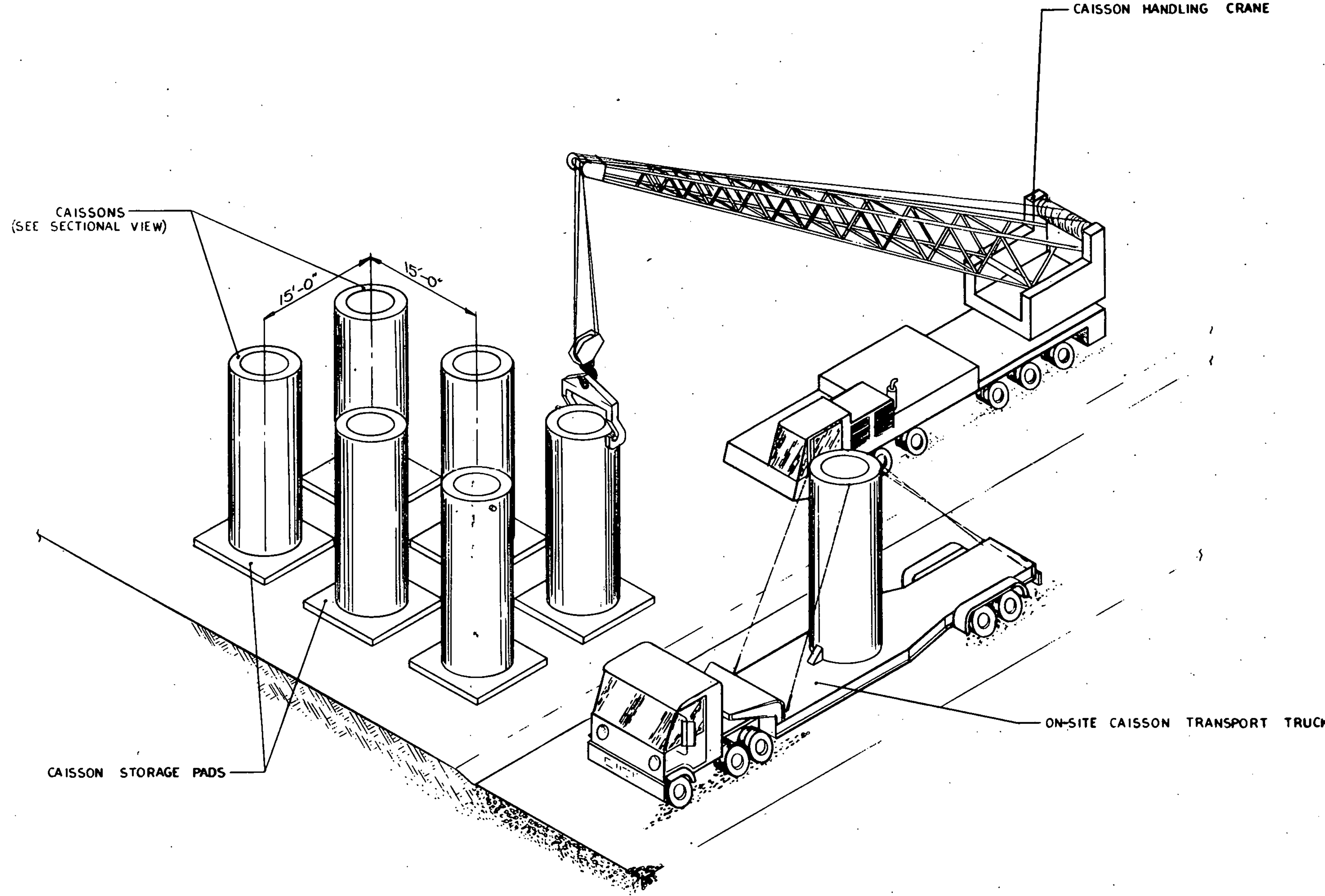
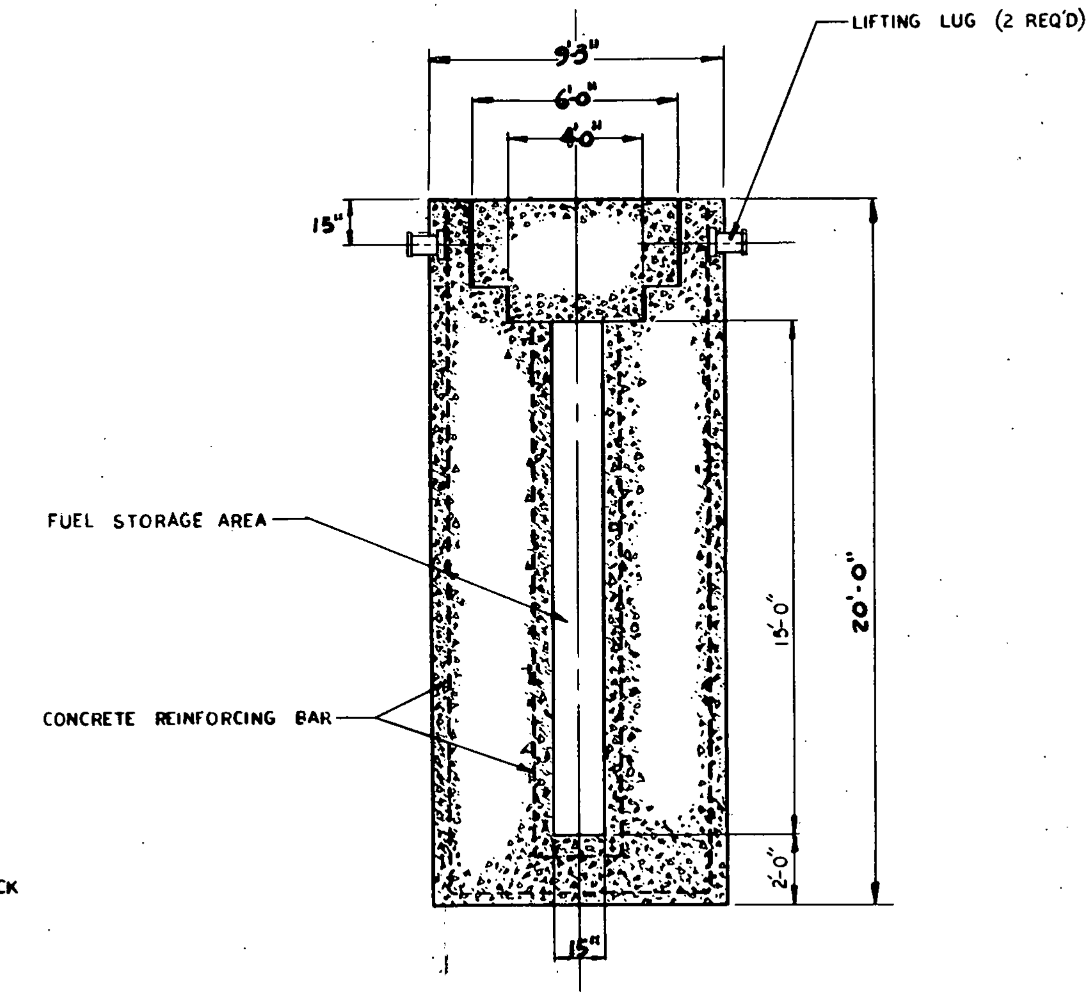
CAISSON LOADING FACILITY
ELEVATION VIEW

SCALE: NONE | FACILITY: 3051005 | DRAWING NO.: 533D-A-5015 | ISSUE: A



ABOVEGROUND CAISSON STORAGE — OPERATIONAL VIEW

NO SCALE



CAISSON SECTIONAL VIEW

SCALE: NONE

NOTES:

1. 497,025 SQ. FT. OF LAND (11.4 ACRES) WILL BE REQUIRED FOR THE STORAGE OF 2000 MTU. THIS IS BASED ON 15'-0" SPACING OF CAISSONS CONTAINING ENCAPSULATED FUEL ASSEMBLIES. THIS DOES NOT INCLUDE ANY AREA FOR SUPPORT ACTIVITIES, I.E., ACCESS ROADS, DRAINAGE, OR SECURITY.

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	ENG.	MGR.	APP'L	APP'L	APP'L
A	9/6/80	CONCEPTUAL DRAWING		PDS	KJA		KJA		

REFERENCE DRAWINGS: 533D-A-5001

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ABOVE GROUND CAISSON STORAGE CONCEPT FOR SPENT LWR FUEL

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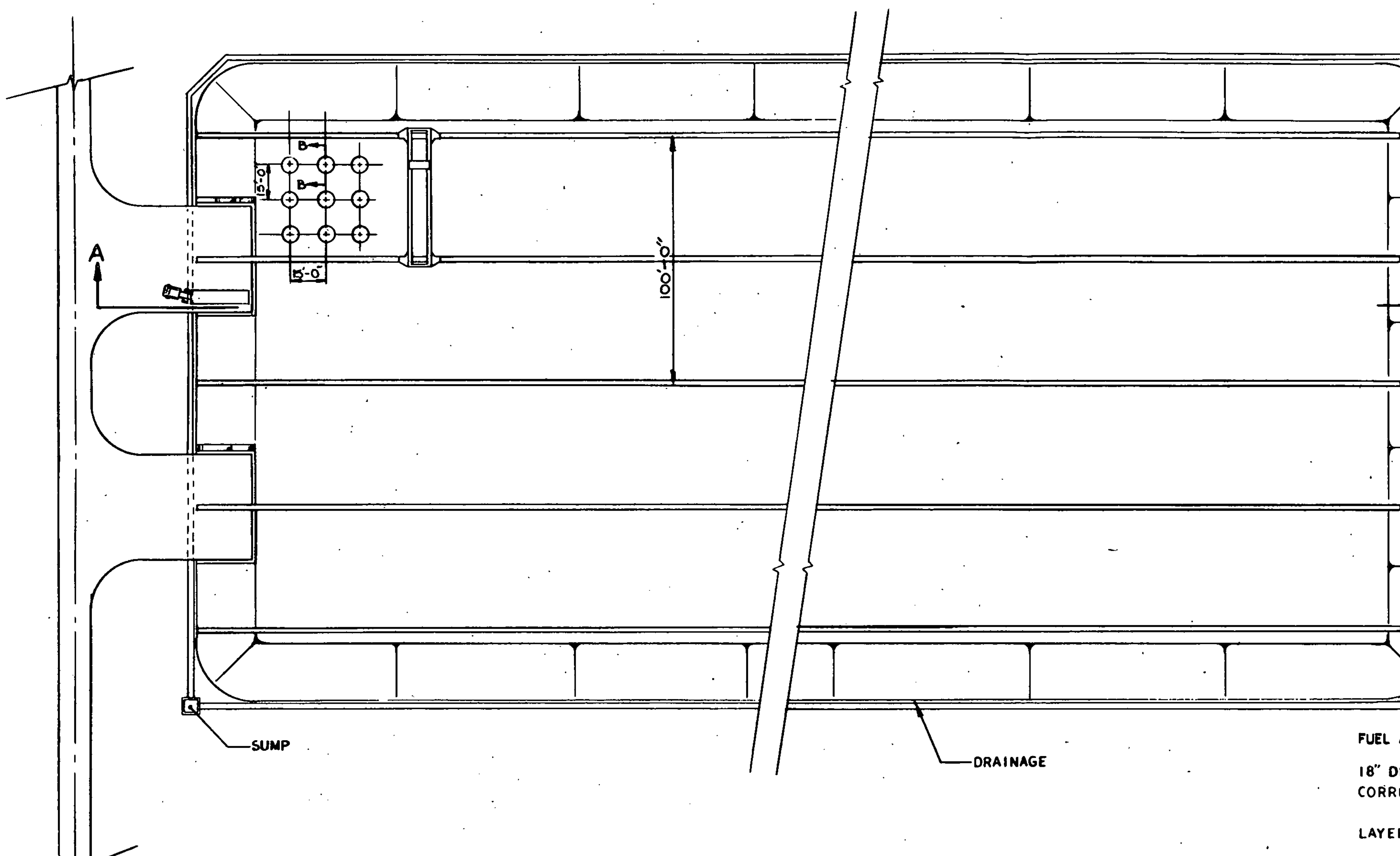
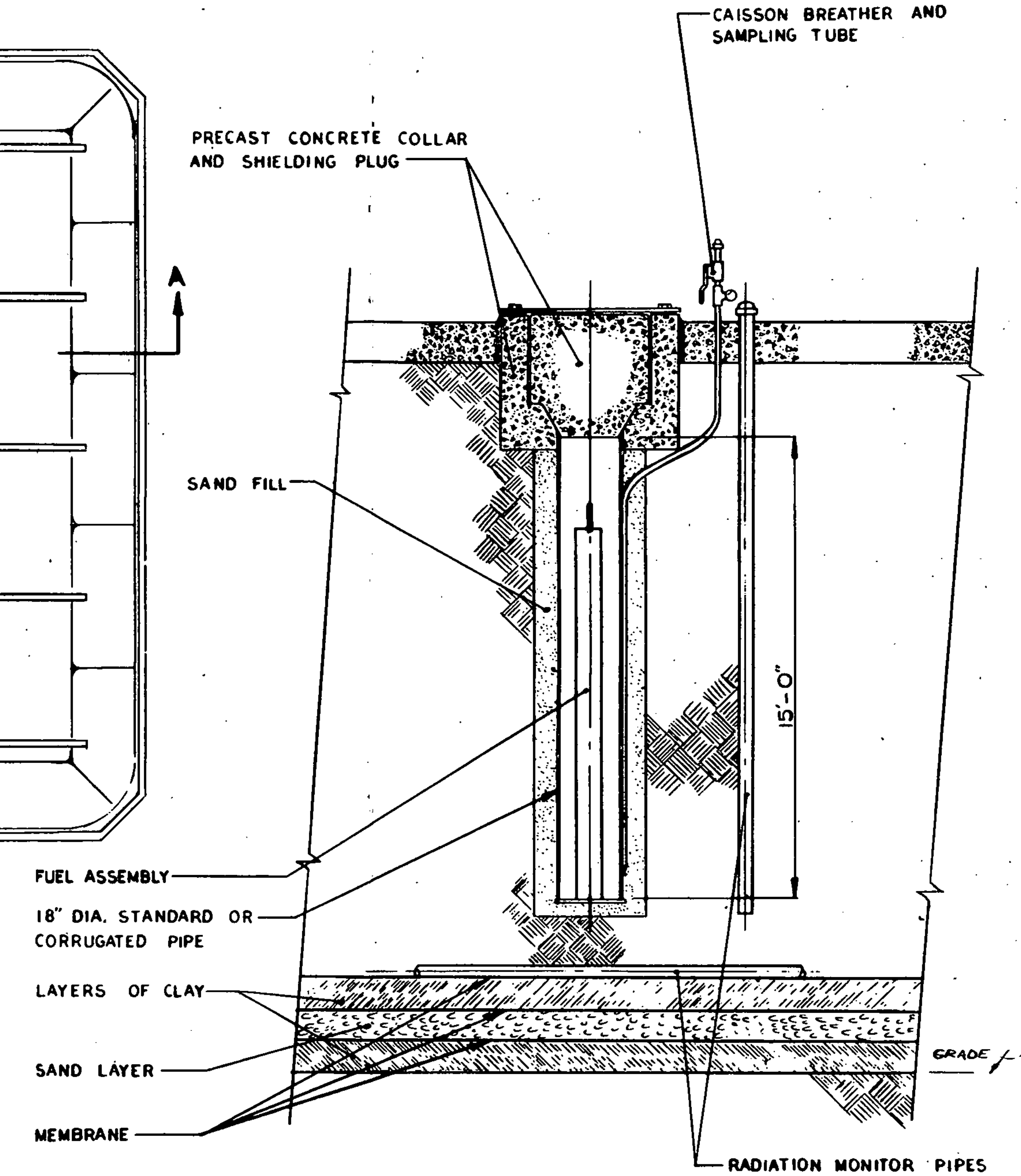
AS NOTED	3051003	533D-A-5016	A



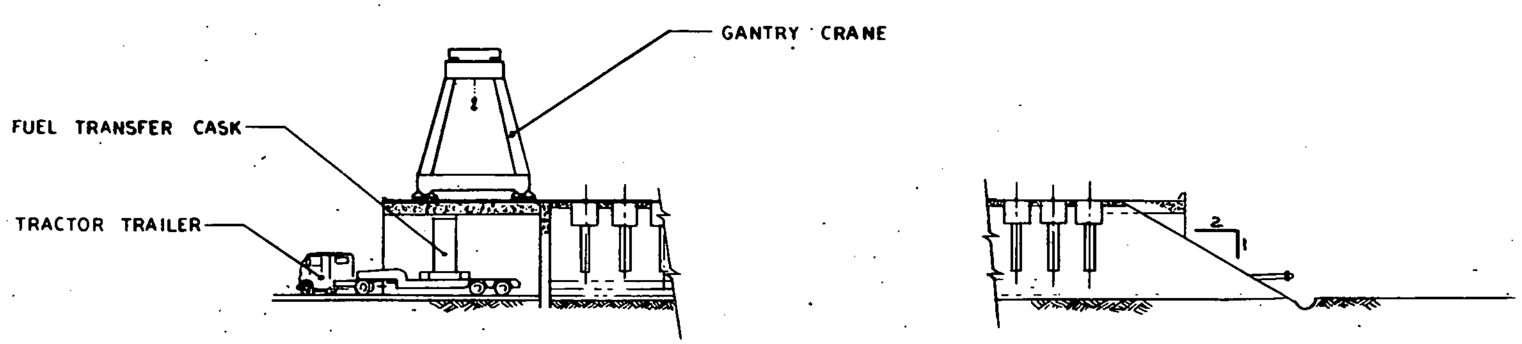
BELOW GROUND CAISSON STORAGE - PLAN VIEW

NO SCALE



SECTION B-B

NO SCALE



SECTION A-A

NO SCALE

NOTES:

1. 497,025 SQ. FT. OF LAND (11.4 ACRES) WILL BE REQUIRED FOR THE STORAGE OF 2000 MTU. THIS IS BASED ON 15'-0" SPACING OF CAISSONS CONTAINING ENCAPSULATED FUEL ASSEMBLIES.

ISSUE NO.	DATE	DESCRIPTION	BY	CHK			APP'L	APP'L	APP'L
A	8/4/80	CONCEPTUAL DRAWING	HPE	PB	KJA		KJA		

REFERENCE DRAWINGS: 533D-A-5001; 533D-A-5014; 533D-A-5016

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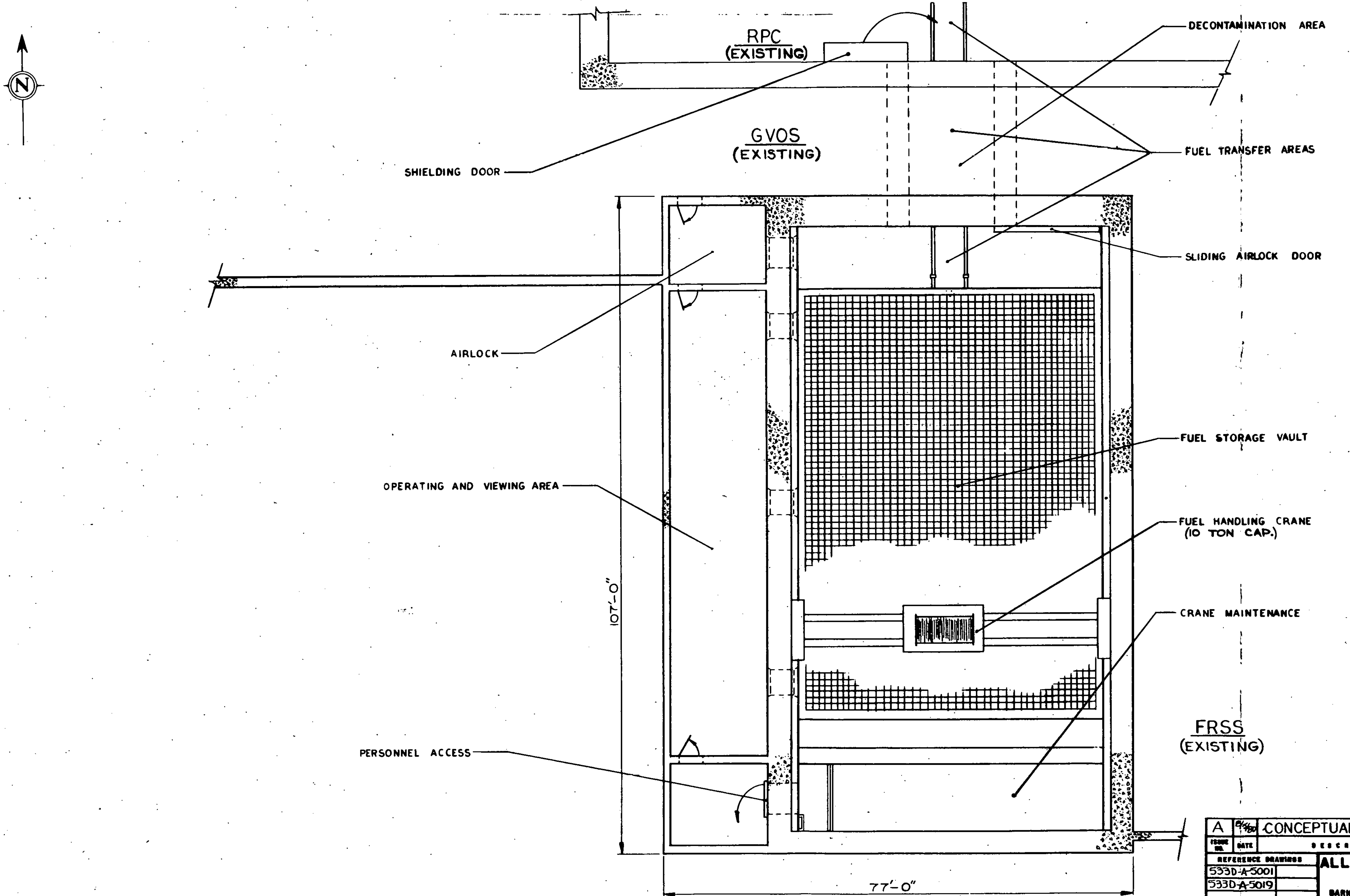
BELOW GROUND CAISSON STORAGE CONCEPT FOR SPENT LWR FUEL

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051005	533D-A-5017	A



STORAGE VAULT— PLAN VIEW
NO SCALE

NOTES:
1. CAPACITY: 2025 MTU AS SHOWN (COMBINED BWR AND PWR STORAGE).

ISSUE NO.	DATE	DESCRIPTION	BY	CKR	ENG.	MGR.	APP'L	APP'L	APP'L
A	9/4/80	CONCEPTUAL DRAWING	HPS	PoS	KJA	[illegible]	KJA		

REFERENCE DRAWINGS
533D-A-5001
533D-A-5019

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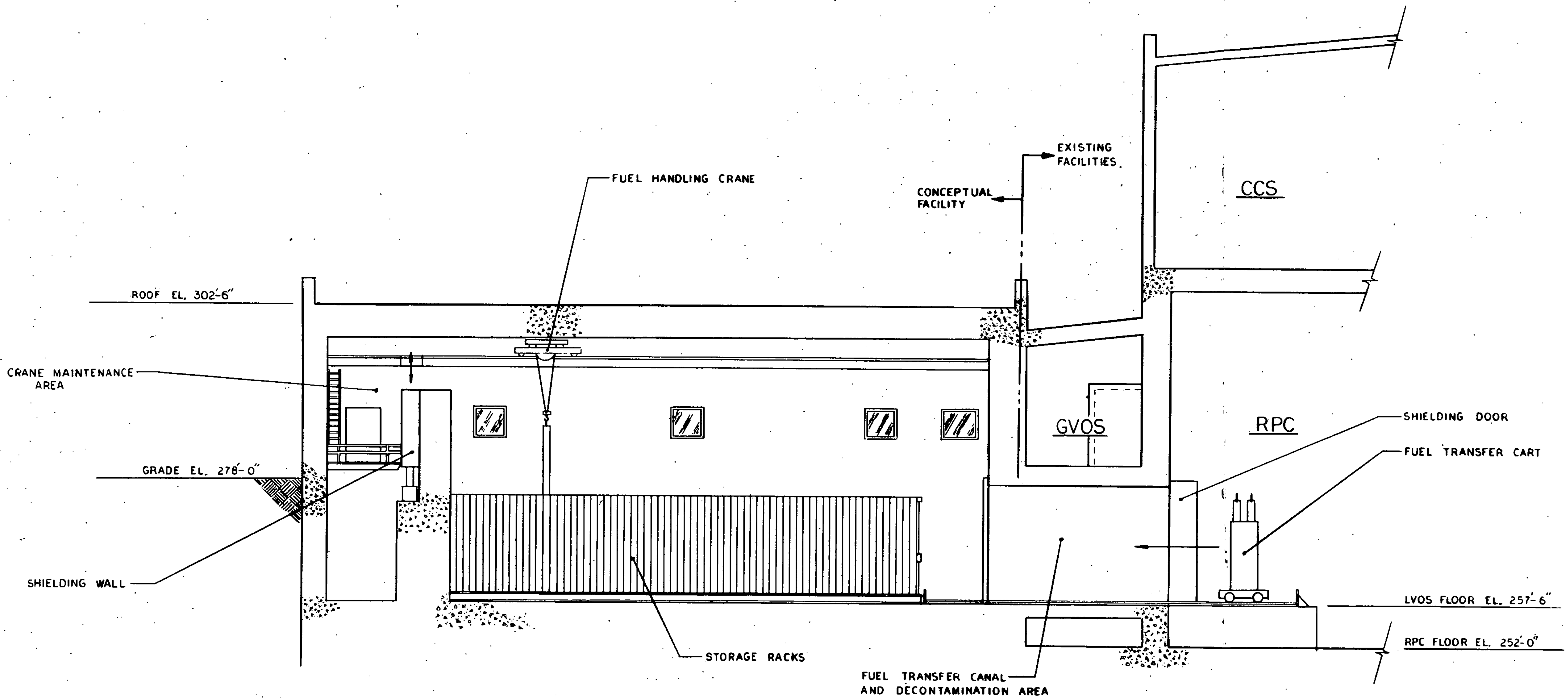
VAULT FOR STORAGE OF SPENT LWR FUEL— PLAN VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5018	A

DWG. TYPE
PROCESS



STORAGE VAULT—ELEVATION VIEW
NO SCALE

ISSUE NO.	DATE	DESCRIPTION	BY	CHK	DESIGN ENG.	DESIGN MGR.	APP'L	APP'L	APP'L
A	8/5/80	CONCEPTUAL DRAWING	HPG	PO	KJA	[illegible]	KJA		

REFERENCE DRAWINGS
533D-A-5001
533D-A-5018

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VAULT FOR DRY STORAGE OF SPENT LWR FUEL ELEVATION VIEW

SCALE	FACILITY	DRAWING NO.	ISSUE
NONE	3051003	533D-A-5019	A

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