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INTERIM STORAGE OF SPENT HTGR FUEL

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INTRODUCTION

Various cost studies (Refs. 1,2)* on nuclear fuel reprocessing show that both reprocessing plant capital and operating costs are relatively insensitive to plant capacity. As a result, unit reprocessing costs decrease with increased plant capacity if sufficient spent fuel is available to permit plant operation at or near its design capacity. In a developing HTGR economy, it is reasonable to expect that the lowest over-all recycle costs would occur if the startup of the reprocessing plant is delayed until a suitable processing load becomes available. Economic assessments made by the Oak Ridge National Laboratory show the validity of this supposition (Ref. 3). As a result, the first few spent fuel discharges from early HTGRs will undergo a protracted period of preprocessing storage. The storage space needed is greater than the normal working storage space at an HTGR, and additional space must be provided for this interim storage. Conceptual designs and estimated costs associated with interim storage are included in this report.

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*References will be found at the end of the report.

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SUMMARY

Uncertainties in the projected growth of an HTGR economy and in the timing of an HTGR fuel reprocessing plant startup and difficulties in operating a very large interim storage facility make it unfeasible to consider only a single interim storage unit. A more prudent approach is to build multiple storage units on one or more sites as the need for the individual unit becomes apparent. Storage units each capable of holding the spent fuel from three 1000-Mw(e) HTGR cores is judged to be a reasonable size. If a processing plant is later built on the same site, part or all of these interim storage facilities can be used to provide the necessary reprocessing plant surge storage.

The spent HTGR fuel is sealed in four-element containers for shipment and may be stored either in air or under water. Since the HTGR fuel particles can react with water, special precautions are needed with underwater storage for the detection, isolation, and repair of containers that develop leaks.

The first interim storage unit built on a site must include many ancillary facilities and is, therefore, more expensive than additional units later built at the same site. The estimated interim storage facility capital and operating costs are given in Table 1.

Table 1
CAPITAL AND OPERATING COSTS

	In-air Storage (\$)	Underwater Storage (\$)
Capital cost:		
First unit	4,942,000	6,980,000
Each additional unit	2,084,000	2,762,000
Annual operating cost:		
One unit	481,000	531,600
More than one unit	577,800	531,600

If a reprocessing plant is later built on the same site, the reprocessing charge, exclusive of any interim storage charge, would not differ from those for a reprocessing plant built at a separate site.

STUDY BASIS

In this evaluation of interim storage facilities for spent HTGR fuel, the following assumptions and criteria are used:

1. The fuel elements are received in a 17-in.-diameter by 11-ft-long stainless steel containers. Each container holds four fuel blocks and is closed by a seal weld.
2. Large shipping casks affixed to railroad cars are used for fuel transport.
3. The interim storage facility is to be designed to permit future incorporation into a reprocessing plant built later at the same site.
4. The interim storage facility is to be self-sufficient (i.e., all of the ancillary facilities required for sustained operation are included).
5. Interim storage is limited to HTGR fuel elements.
6. The storage facility is located in the United States and meets AEC licensing requirements.
7. The HTGR economy consists of 1000-Mw(e) units discharging an average of 890 fuel elements annually (1/4 of a core) beginning with the second year after reactor startup.

STORAGE CAPACITY

The primary use of an interim storage facility is to store the spent fuel discharged from HTGRs before a fuel reprocessing plant designed to process HTGR fuel has been started up. This storage facility must then be large enough to contain all of the HTGR fuel shipped until the reprocessing plant is able to process the fuel at a rate at least equal to the shipping rate. The quantity of fuel involved depends on the timing of HTGR sales, reactor startup and operational performance, and the timing of the reprocessing plant startup. Because of the uncertainties in these factors, the fuel quantities involved are uncertain and cannot be predicted with any reasonable degree of accuracy. As an illustration, the HTGR economy growth used as the principal basis for an ORNL economic study (Ref. 3) is listed in Table 2. All of the HTGRs in this case are taken to be of the 1000-Mw(e) size.

The ORNL study (Ref. 3) indicates that the minimum recycle cost is incurred when the reprocessing plants start up in 1981 (i.e., seven years after the first large HTGR). Since the first fuel discharge from an HTGR is two years after startup, interim storage facilities need to be ready about five years before the reprocessing plant startup. Based on a six-month delay between reactor discharge and fuel receipt at the storage facility, the year-by-year quantity of fuel placed into storage is shown in Table 3.

Based on the ORNL study, the reprocessing plant would come on line in 1981. From a study of Table 3, it is evident that a slight variation in the reprocessing plant startup time would have a very profound effect on the interim storage requirements and, consequently, on the facility design. The design of the initial interim storage unit would be started seven or eight years before

Table 2
HTGR ECONOMY GROWTH

Year	New HTGRs On Line	Total HTGRs On Line
1974	2	2
1975	2	4
1976	3	7
1977	5	12
1978	7	19
1979	8	27
1980	7	34
1981	5	39

Table 3
FUEL QUANTITIES TO INTERIM STORAGE

Year	No. of HTGRs Dis- charging Fuel	No. of Cores Discharged During Year	Total No. of Cores In Storage	Total No. of Four-element Containers In Storage
1974	0	0	0	0
1975	0	0	0	0
1976	2	0.5	0.25	223
1977	4	1.0	1.0	890
1978	7	1.75	2.4	2,114
1979	12	3.0	4.75	4,228
1980	19	4.75	8.6	7,675
1981	27	6.75	14.4	12,794
1982	34	8.5	22.0	19,580

the scheduled startup of the reprocessing plant. If only a single interim storage unit is provided, it would be necessary to substantially oversize the unit to ensure sufficient storage space should unexpected delays be experienced in the reprocessing plant completion and startup. If multiple storage units are used, they would be constructed as their need becomes apparent. In this way, the lead time between storage unit construction and anticipated reprocessing plant startup can be reduced to as little as three years and the amount of "insurance space" minimized. Small storage units are simpler to operate and to maintain than larger units. Considering operational problems, the surge storage needs of an operating reprocessing plant, the anticipated growth pattern of the HTGR economy, and the costs, storage units capable of containing three cores appear to be of reasonable size. This study is based on an interim storage unit sized to hold about 2670 four-element containers (three 1000-Mw(e) HTGR cores).

STORAGE UNIT DESIGN

With the spent HTGR fuel elements packaged in metal containers that have welded closures, storage may be either in air or under water. Storage in air requires a shielding structure, such as concrete, and a reliable air-flow system for the removal of the fission-product decay heat. With underwater storage, the water serves both as the shield material and as the heat sink. It is assumed that the fuel shipping cask is not removed from its railroad car and an in-air unloading system is needed regardless of the storage method used.

In-air Storage

A conceptual design of an interim storage vault utilizing air cooling is shown in Figs. 1 and 2. The internal dimensions of the storage area are 40 ft wide by 80 ft long by 44 ft high. The fuel containers are placed in a triangular array and held in position by a tubular metal support structure that is anchored to the storage area floor. An overhead bridge crane transports the containers from the receiving area at one end of the building to storage and eventually to the transfer tunnel connected with the reprocessing plant. A transfer tunnel is needed because construction of the reprocessing plant will take place while the storage facility contains spent fuel.

Container placement within the storage area when used for interim storage differs somewhat from that used for reprocessing plant surge storage. For surge storage, the containers are stacked two high, which permits crane access to any stack in storage. A working inventory slightly in excess of 1900 containers can be handled in this manner. When the facility is used for interim storage, the containers can be stacked three high over 75% of the storage area. This gives, in essence, a last-in-first-out type of storage. The upper layer of containers is held in place by a tubular support structure fitted to the permanently installed structures. These temporary support structures are installed by the bridge crane simultaneously with the placement of the third layer of containers.

The receiving area has two levels. The lower level is below the grade immediately surrounding the structure and has tracks for the rail car carrying

Fig. 1--In-air interim storage unit for HTGR fuel

Fig. 2--In-air interim storage unit for HTGR fuel

the shipping cask. Before spotting the cask beneath the access hole to the upper level, the cask lid is unfastened and prepared for removal. A ventilation barrier is then manually installed between the ceiling of the receiving area and the cask. A cable operated by a hoist on the roof is connected to the cask lid, personnel are evacuated from the fuel unloading and cask receiving areas, and the lid is raised into a recess in the ceiling. The heavy shield doors to the storage area are opened and the crane moved into the receiving area to transfer the now-exposed fuel containers from the cask to the storage area.

The operations are viewed directly through periscopes that penetrate the shield wall and indirectly by means of a closed-circuit television system that has the cameras attached to the periscopes and to the bridge crane. Lights mounted on the bridge crane furnish the necessary lighting in the storage area. An operating area surrounds the building on three sides and houses the controls and operating personnel. Any necessary crane maintenance is done in the cask unloading area.

Ancillary facilities for the self-sufficient operation of the storage units are included in the interim storage site. Where feasible, these facilities are designed and sized to serve an HTGR fuel reprocessing plant constructed later on the same site. The major ancillary items include the following:

1. A cask decontamination building.
2. A service building containing a change room, maintenance shops, air compressors, and an oil-fired boiler system.
3. A small analytical laboratory.
4. An exhaust air treatment system consisting of off-gas filters, blowers, and a stack.
5. A treatment system for low-level radioactive wastes.
6. A water supply system.
7. An emergency power supply.
8. Access roads, a railroads spur line, electrical power supply, fences, etc.

Additional storage units may be built at the same site with no additional ancillary equipment and facilities. However, each storage unit for in-air storage requires its own receiving area.

Underwater Storage

Underwater storage of HTGR fuel introduces a few problem areas not encountered with in-air storage. Carbide fuel reacts readily with water and as a result, special precautions are necessary to prevent significant amounts of fuel from coming in contact with water. Although the particles of uranium and/or thorium carbide in HTGR fuel elements initially have essentially impervious coatings, it is anticipated that a small percentage of the fuel particles will have broken coatings by the time the fuel is received at the storage facility.

The fuel shipping containers are checked for leak tightness before being shipped from the reactor, but it is possible that some of the containers may develop leaks during shipment or during prolonged storage. Any water leaking into a fuel container would then react with the fuel. Some of the radionuclides would dissolve, diffuse throughout the water, and thus penetrate the radiation shield. This could have serious contamination and radiation consequences. Early detection and repair of leaky containers is therefore an essential part of the underwater storage.

A water-filled monitoring tank and a recanning station are included in the underwater storage facility. Fuel containers unloaded from the shipping casks are placed into a monitoring tank for a day or two to check for leakage. An increase in the radionuclide content of the water would indicate the presence of a leaky container. The recanning station is a remotely operated cell having equipment to open a container, transfer the fuel blocks to a new container, and seal weld a new lid in place. Since a container may develop a leak during prolonged storage, it is necessary to arrange the stored containers so that ready access is possible to any container at any time. Submerged sampling probes and weighing devices can be used to aid in identifying a leaky container.

A conceptual design of an underwater storage unit is shown in Figs. 3, 4, and 5. Although the storage capacity is the same as for an in-air storage unit, an underwater storage unit is much larger in size. The reasons for this size difference include:

1. Ready access to any container in storage in case a leak should develop requires a transfer aisle for every two rows of stored fuel.
2. The required thickness of water for a radiation shield is more than twice that of ordinary concrete.
3. Monitoring and recanning facilities are required for underwater storage.

The general arrangement of the fuel receiving area is similar to that for in-air storage. There are, however, several differences. In addition to the inclusion of the monitoring tank and repackaging station discussed above, a swing-arm conveyor operating in a water-filled channel (see Fig. 5) is used to transfer the fuel to the storage area.

The water-filled storage basin is divided into 20 storage bays, each accessible from a central transfer aisle. The fuel containers are stored vertically in a single layer and are covered by 14 ft of water. The over-all dimensions of the storage area and its surrounding walkway are 294 ft by 68 ft. A light, insulated structure contains the basin and walkways. As with in-air storage, the fuel is transferred to the main reprocessing plant through an underground tunnel. Fission-product decay heat absorbed by the basin water is removed by pumping the water through air-cooled heat exchangers located outside the building. A side stream is diverted through an ion-exchange system that maintains basin water purity and removes any fission products that may be present.

Fig. 3--Underwater interim storage unit for HTGR fuel

Fig. 4--Underwater interim storage unit for HTGR fuel

Fig. 5--Underwater interim storage unit for HTGR fuel

The basic operations of receiving and unloading a shipping cask are similar to those described above for in-air storage. The fuel containers are placed into the monitoring tank rather than directly to storage. A leaky container is moved into the recanning station by the unloading area bridge crane. Shielding around the recanning station permits some limited operation in the unloading area during recanning operation. Recanning is carried out remotely with manipulators and is viewed through a shielding window.

The principal operations within the storage area are conducted from a bridge crane spanning the water pool. Interlocks prevent excessive elevation of the bridge crane grapples so as to reduce the thickness of the water shield below a preset limit. After movement by the crane to their assigned locations, the fuel containers are placed in short pipe supports anchored to the basin floor.

Additional storage basins can be built close to the first basin and connected with it by a water channel. In this way, only one receiving area and one transfer tunnel to the reprocessing plant are needed. The underwater storage basins can be used not only for surge fuel storage, but also for the interim storage of calcined high-level radioactive waste (Ref. 4).

COSTS

Both the capital and operating costs used here are derived from studies on HTGR fuel reprocessing (Refs. 1,4). Building costs were estimated by applying unit cost (dollars per cubic foot) obtained from similar facilities in the reprocessing plant study (Ref. 4), and equipment costs were similarly developed. Indirect costs (contractors' fee, design, and contingency) are taken as the same percentages of the direct construction cost as in the reprocessing plant studies.

Costs for In-air Storage

Estimated capital costs for both the initial in-air storage unit and each additional unit built on the same site are contained in Table 4.

The startup cost is taken as 50% of the annual operating costs for the initial unit and 50% of the incremental annual operating for the additional units. These costs are those as of September 1967, and do not include state sales or use taxes, licensing, client costs, escalation, interest charges during construction, working capital, or research and development. The cost of the reuseable fuel containers are also not included.

Manpower is the principal item in the operating expenses. An operating crew of 39 is needed to man the initial unit. For more than one storage unit, the manpower is increased by 9 to 48. Table 5 gives the estimated annual operating expenses.

Table 4
CAPITAL COST FOR IN-AIR INTERIM STORAGE FACILITY

	Initial Unit (\$)	Additional Unit on Same Site (\$)
Direct Construction Cost:		
Storage unit	1,185,600	1,133,100
Ancillary facilities	<u>1,152,800</u>	<u>---</u>
Total	2,338,400	1,133,100
Contractor's overhead and profit, 25%	<u>584,600</u>	<u>283,300</u>
	2,923,000	1,416,400
Design, 15%	<u>438,500</u>	<u>212,500</u>
	3,361,500	1,628,900
Contingency, 25%	<u>840,400</u>	<u>407,200</u>
	4,201,900	2,036,100
Land	<u>500,000</u>	<u>---</u>
	4,701,900	2,036,100
Startup	<u>240,000</u>	<u>48,000</u>
TOTAL	4,942,000	2,084,000

Table 5
OPERATING COSTS FOR IN-AIR INTERIM STORAGE FACILITY

	Operating Costs (\$/year)	
	Initial Unit	Multiple Units Same Site
Manpower	421,100	517,800
Chemicals	30,000	30,000
Utilities	<u>30,000</u>	<u>30,000</u>
TOTAL	481,100	577,800

Costs for Underwater Storage

Estimated capital costs for underwater storage units on the same basis as for in-air storage are given in Table 6. The estimated annual operating costs for such units are given in Table 7.

Table 6
CAPITAL COST FOR UNDERWATER INTERIM STORAGE FACILITY

	Initial Unit (\$)	Additional Units Same Site (\$)
Direct Construction Cost:		
Storage unit	2,301,100	1,537,300
Ancillary facilities	<u>1,157,200</u>	<u>---</u>
Total	3,458,300	1,537,300
Contractor's overhead and profit, 25%	<u>864,600</u>	<u>384,300</u>
	4,322,900	1,921,600
Design, 15%	<u>648,400</u>	<u>288,200</u>
	4,971,300	2,209,800
Contingency, 25%	<u>1,242,800</u>	<u>552,500</u>
	6,214,100	2,762,300
Land	<u>500,000</u>	<u>---</u>
	6,714,100	2,762,300
Startup	<u>265,800</u>	<u>---</u>
TOTAL	6,980,000	2,762,300

Table 7
OPERATING COSTS FOR UNDERWATER INTERIM STORAGE FACILITY

	Operating Costs (\$/year)
Manpower	461,600
Chemicals	35,000
Utilities	<u>35,000</u>
TOTAL	531,600

Since additional underwater storage basins are closely coupled to the initial basin, no significant increase in the annual operating cost is anticipated as the additional basins are placed in service.

Effect on Reprocessing Cost

The basic study on reprocessing HTGR fuel in a central plant (Ref. 4) included spent fuel receiving and surge storage as integral parts of the plant. Building the reprocessing plant on the interim storage site obviates the need not only for these receiving and storage areas but also for many of the ancillary facilities vital to the operation of a self-sufficient plant that are provided with the initial interim storage unit. In the central reprocessing plant study (Ref. 4), the storage facility was designed to handle uncanned HTGR fuel elements. The storage area, then, included expensive captive storage containers.

Since this interim storage study is based on receiving and handling only canned fuel, no captive storage containers are needed. The cost savings realized by eliminating the captive storage containers are partially offset by the inclusion of fuel container opening and decontamination facilities. The capital cost of a central HTGR fuel reprocessing plant is estimated to be \$30,803,000. A similar reprocessing plant could be added to a site having an in-air storage facility at an estimated incremental capital cost of \$25,731,000. Since an underwater storage unit could also serve as the calcined waste storage area, the reprocessing plant added to an underwater storage site would have the somewhat lower estimated incremental capital cost of \$23,553,000. The total capital cost attributable to the reprocessing plant would also include much of the interim storage facility cost. Neglecting the charges for the interim storage, the reprocessing charges would not differ from those estimated in the earlier central plant study (Ref. 4).

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