A PASSIVE AIR-COOLED DRY STORAGE FACILITYFOR VITRIFIED HIGH-LEVEL WASTES

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ABSTRACT

A conceptual design of an air-cooled dry storage vault facility for vitrified high-level waste (HLW) canisters is developed for a site in northern Japan. The facility is designed for the reception and unloading of shielded seagoing transportation casks of vitrified HLW canisters, for the inspection of these canisters, and for their temporary storage for a period of up to 50 years. The waste is to be at least 9 years old when received, and the facility will be capable of storing up to 2,500 canisters.

The intent of this work is to provide a conceptual design to identify construction requirements, materials, and space requirements that are unique to the vitrified HLW storage facility. It also identifies the types of special systems and equipment needed in such a facility.

INTRODUCTION

A conceptual design of an air-cooled dry storage vault facility for vitrified high-level waste (HLW) canisters was developed for a site in northern Japan. The facility was designed for the reception and unloading of seagoing transportation casks of vitrified HLW canisters, for the inspection of these canisters, and for their temporary storage for a period of up to 50 years. The conceptual design contains design bases, 32 engineering drawings, 10 outline specifications, an equipment list, a preliminary safety analysis, two major engineering tradeoff studies, numerous support calculations, and a three-dimensional computer material-handling simulation model.

The conceptual design was conducted in two phases over a 9-month period. In the first (5-month) phase, an initial conceptual design was developed for the HLW handling building. The first phase generated a detailed design basis report, two major engineering tradeoff studies, a preliminary equipment list, initial facility staffing estimates, an order-of-magnitude construction cost estimate, and 13 engineering drawings. In the second phase, specific recommendations and modifications of the first-phase design were implemented. As the second-phase conceptual design developed, 19 additional engineering drawings for the main HLW handling facility and the associated support facilities at the site were prepared. In addition, an equipment list, 10 outline specifications, a preliminary safety analysis, and a summary of the construction materials and quantities were prepared.

This paper provides an overview of the design bases, the main vitrified HLW storage facility design features, key operational aspects (such as mechanical and material handling time requirements and facility staffing), and discusses some of the major design alternatives considered during the design. Additional technical details are given in a paper written by Machida et al.(1).

DESIGN BASES

Design bases were developed for material handling, radiological protection, HVAC (heating, ventilating, and air conditioning), and structural requirements. The design bases were generated from client design criteria, site-specific criteria, and other requirements for a site in Japan, and from U.S. regulations, codes, standards, and design practice. Some major considerations in the design bases are discussed below.

The facility receives 18 ocean transport shipping casks per year. Since a transport ship holds 6 casks, the casks arrive at the inland site (by truck and trailer) in groups of 6 casks. Each loaded cask weighs 120 metric tons and contains 14 canisters of vitrified HLW. The stainless steel canisters have an O.D. of 43 cm, are 1.345 m high, and weigh 480 kg. The facility operates 8 hr/day, 250 days/yr; receives 250 canisters/yr; and has a total storage capacity of 2,500 canisters.

The main waste-handling structure is designed for static seismic loads, in accordance with the U.S. Uniform Building Code (2), using a seismic zone coefficient of 1.0 and an importance coefficient of 1.5. The maximum allowable concrete steady-state temperature in the storage vault is 200°F. To account for the fact that temperatures are 50F above the normal 150°F American Concrete Institute (ACI) values, the allowable concrete stresses in the vault are reduced by 10 percent from the generally accepted ACI values(3).

The radiological protection design objectives for dose (whole-body) exposure limits are:

• 2 mrem/yr	offsite public - normal operations
• 500 mrem/yr	onsite workers - normal operations unrestricted area
• 5,000 mrem/yr	onsite workers - normal operations restricted area
• 5,000 mrem/incident	offsite publi - accident condition

All exhaust air from potentially contaminated areas is continuously monitored and is exhausted through high-efficiency particulate air (HEPA) filters. Owing to the specific design features, the main storage vault cooling exhaust air is not filtered. For HVAC, the design temperatures are:

• 77°F(25°C)	occupied areas - summer
• 68°F(20°C)	occupied areas - winter
• 104°F(40°C)	unoccupied areas - summer
• 50°F(10°C)	unoccupied areas - winter

HLW STORAGE FACILITY DESCRIPTION

The main vitrified HLW storage building includes separate areas for shipping cask receiving and handling, cask preparation, cask unloading, canister inspection and handling, canister storage, and the various support functions. These areas are separated to facilitate the different operations and for radiological protection purposes. Walls, doors, shielding, or other barriers separate these different areas so that (1) radiation sources (HLW canisters and casks in one area) will not cause excessive radiation exposures to operators in other areas and (2) any potential contamination inadvertently released in one area will not spread in an uncontrolled manner to another area. The areas are arranged within the building to facilitate the flow of HLW canisters from receipt to storage and the access and movement of operating personnel.

Figure 1 presents a cutaway isometric view of the vitrified HLW storage facility. Figures 2 and 3 show general arrangement plan and section views of the facility.

The cask receiving area (75'x155'x40'H) is a steel frame structure with metal siding and a concrete slab on grade. The area is arranged to provide efficient use of space and a minimum span for the 150-ton overhead bridge crane. A below-grade (27 ft) pit, located in this area, contains a cask transfer car for moving casks to and from the cask preparation area.

The cask preparation area is connected to the cask receiving area by means of a roll-up door. The cask preparation area has a 15-ton overhead bridge crane, a work platform, laydown space for the cask outer lid, a cask seal adapter, and provisions for cask decontamination operations.

The cask unloading hot cell is a thick concrete structure with a personnel operating gallery, viewing shield windows, master-slave manipulators, and remote viewing systems. The hot cell contains a canister storage rack, a canister inspection station, and a 15-ton overhead bridge crane with an electromechanical manipulator. Shield plugs in the hot cell floor allow the transfer of canisters between two other hot cells used for canister decontamination, canister overpacking, and irradiation experiments. A canister transfer car moves single canisters from the cask unloading hot cell to the storage vault area.

The storage vault area is a combination steel frame structure with metal siding and a modular below-grade concrete structure. Figure 4 shows a section of the HLW storage vault and illustrates some of these details. The two slabs (El. -28'-0" and -36'-6") and the space between them are used to protect against potential water intrusion into the vault due to the high groundwater level. A 60-ton overhead bridge crane is supplied for transporting canisters and a shielded transfer cask from the canister transfer car to the appropriate storage vault locations.

The storage vault is 36.5 ft below grade and consists of five rectangular storage modules (21'x54'x23'H each). Four modules contain 102 (6x17) storage sleeves with each sleeve holding up to 5 stacked canisters. One module contains 84 (6x14) storage sleeves for normal canisters and 10 oversize storage sleeves holding up to 4 stacked, overpacked, oversize canisters. Each storage sleeve has a concrete shield plug.

The shielded transfer cask is designed to accommodate and transport HLW canisters, overpacked canisters, or shield plugs. A hoist system and a grapple are included in the transfer cask. The thick concrete walls, floor, and ceiling of the storage vault provide shielding for the high radiation emitted from the stored canisters. The canisters in the storage vault are cooled by natural convection. Inlet air flows through a shield labyrinth into the storage vault, then primarily horizontally across the storage sleeves, and finally passes through another shield labyrinth before exiting through an elevated, unfiltered exhaust stack.

Because of the specific design of the canister storage sleeves, the storage vault exhaust air is not filtered. The sleeves are sealed at both the top and bottom so that cooling air must flow on their outside surfaces. Therefore, during normal operations, there can be no airborne contamination in the vault exhaust air due to the potentially contaminated canister surfaces contained within the sealed storage sleeves. Figure 5 illustrates the type of storage sleeve design. The interior of each sleeve is vented to a separate, HEPA-filtered exhaust system by a common pipe header system to prevent any contamination release from the interior of the sealed sleeves. A differential negative pressure is maintained in each sleeve to prevent the spread of contamination out of the sleeve.

The airflow through the vault allows the cooling air to flow predominantly horizontally across the closed sleeves that contain the HLW canisters. Preliminary heat transfer analyses indicate that a passive unfiltered storage vault concept will provide acceptable maximum centerline temperatures of the stored HLW. Additional computer modeling and some experimental measurements are required to validate the design concept to the level required before an application can be submitted to a licensing body.

If necessary, additional storage vault modules can be added on the end opposite the unloading hot cell. Such an addition will not interfere with the inlet and exhaust plenums for cooling air or the overhead crane rails. However, if storage for more than 10,000 canisters is ever required, reorientation of the storage vaults and the general building arrangement should be evaluated.

In addition to the vitrified HLW storage facility, conceptual designs were also developed for several support

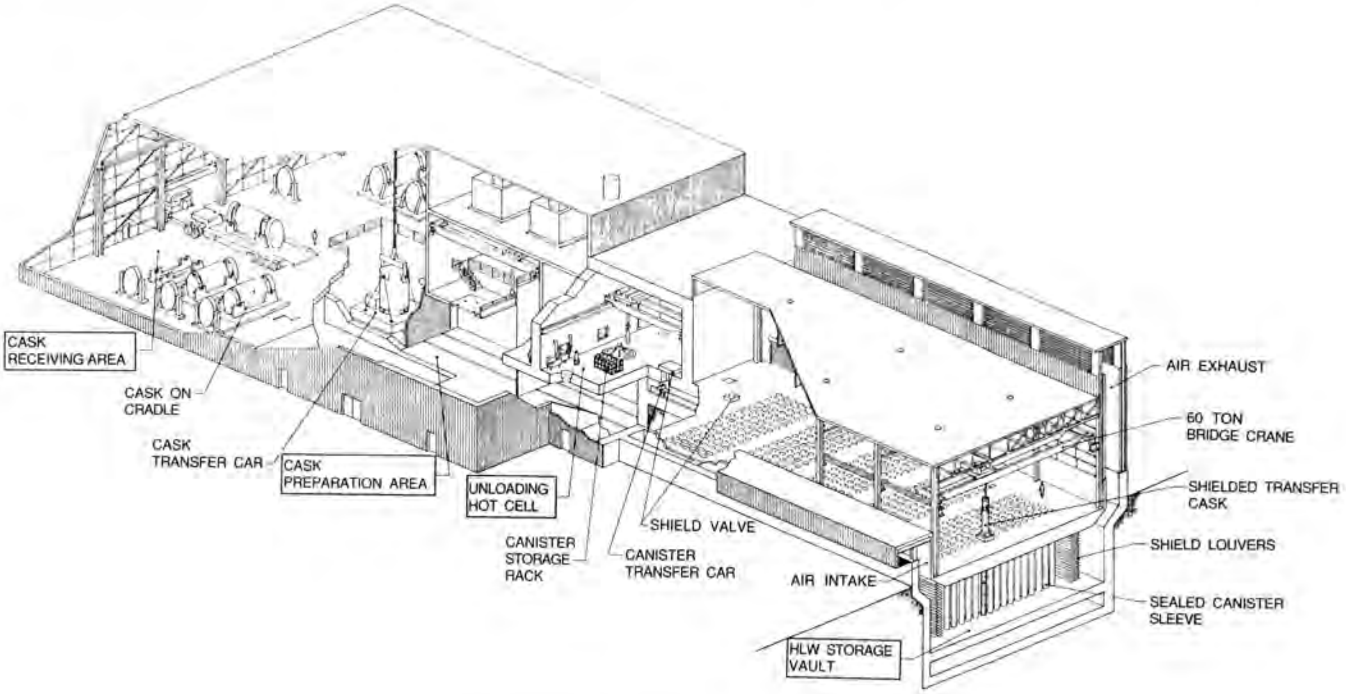

Fig. 1. Cutaway Isometric View of the Vitrified HLW Storage Facility.

buildings. These buildings are listed in Table I, along with their dimensions, floor areas, and volumes.

PERATIONAL ASPECTS

Time Estimates

To verify the required vitrified HLW throughput capacities and to select the specific number of pieces of equipment, estimates were developed of the time required to perform all major waste handling operations. The operations include handling both loaded and empty casks, cask preparations prior to both unloading and shipment off site after loading, canister inspections, canister transfers, and canister storage. Estimates were also developed for the infrequent, nonroutine canister decontaminations and overpacking of damaged canisters.

Assuming sequential operations (i.e., no simultaneous operations) and making other conservative assumptions, the total time to unload a cask, transfer and store the 14 canisters in the cask, and prepare an unloaded cask for an offsite destination was calculated to be 58 hours. From the

TABLE I

Dimensions, Floor Areas, and Volumes of Support Buildings

Type of Building	Dimensions (ftxft)	Floor Area (ft^2)	Building Volume (ft^3)
Warehouse/Maintenance Building	50x83	4,150	62,250
Visitor Center	45x55	2,475	37,125
Boiler Building	25x40	1,000	20,000
Sewage Treatment Building	40x50	2,000	40,000
Administration Building	84x69	5,796	92,736

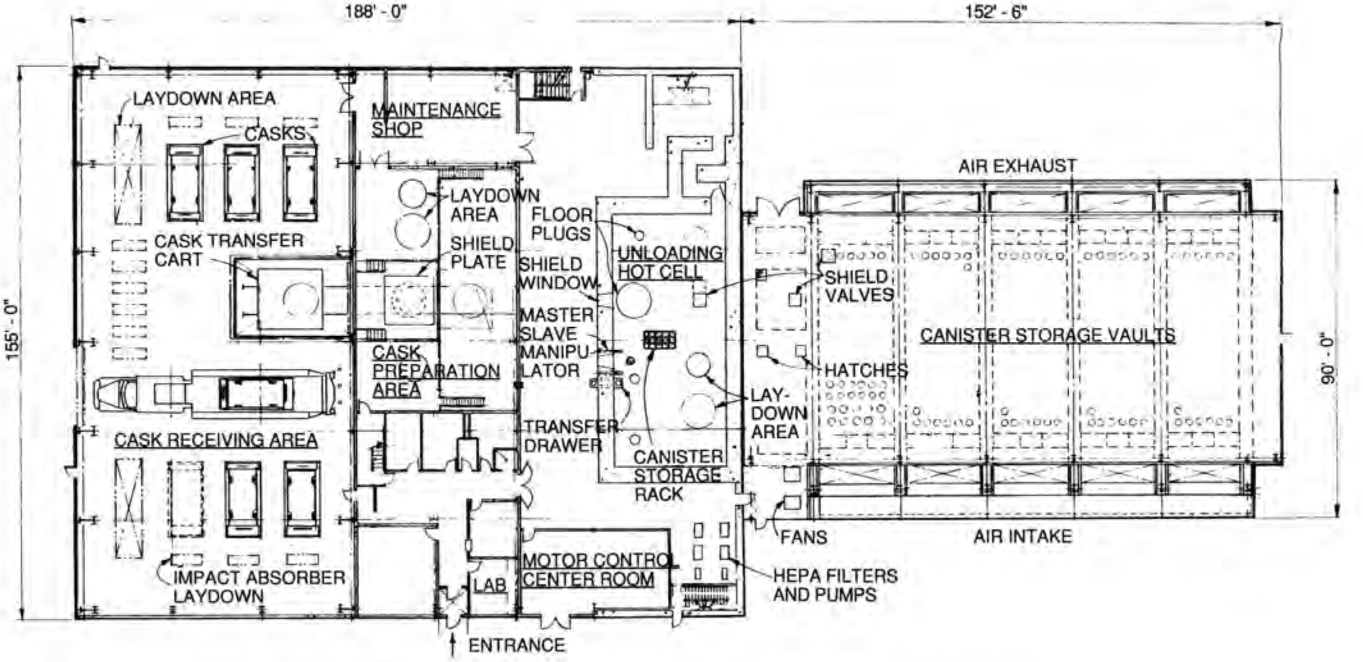

Fig. 2. Plan View of the Vitrified HLW Storage Facility.

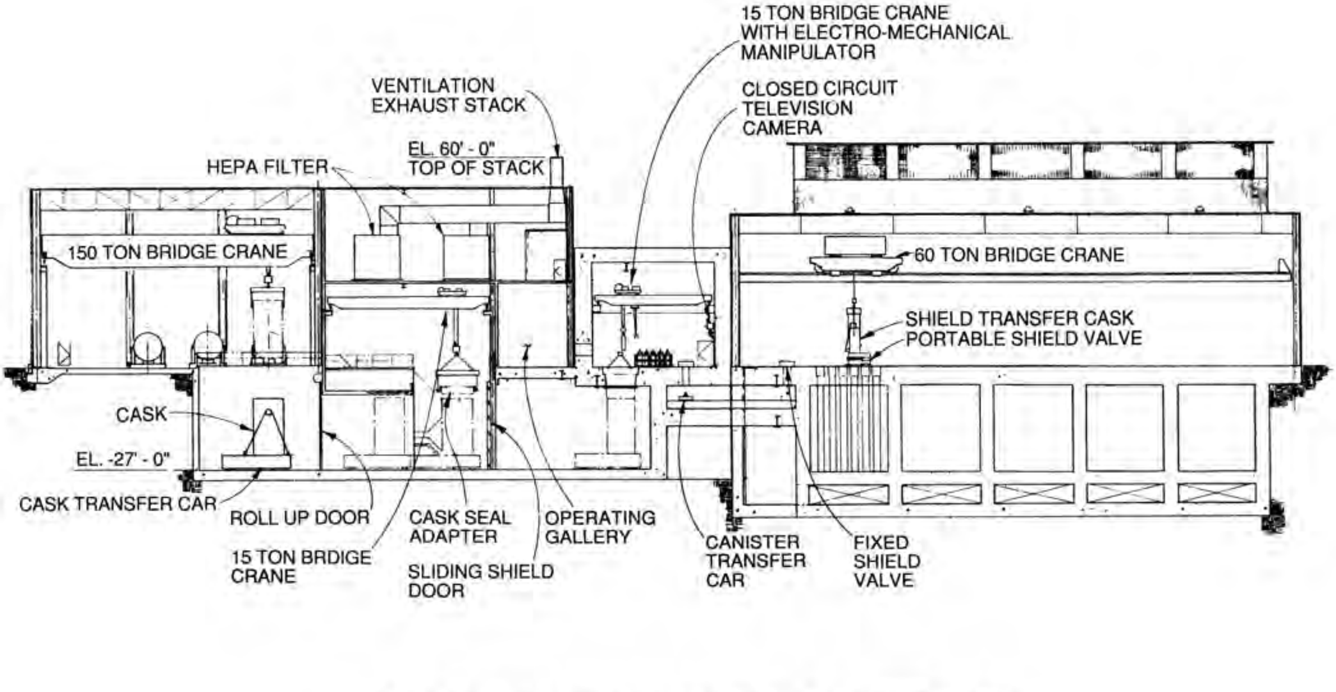

Fig. 3. Section View of the Vitrified HLW Storage Facility.

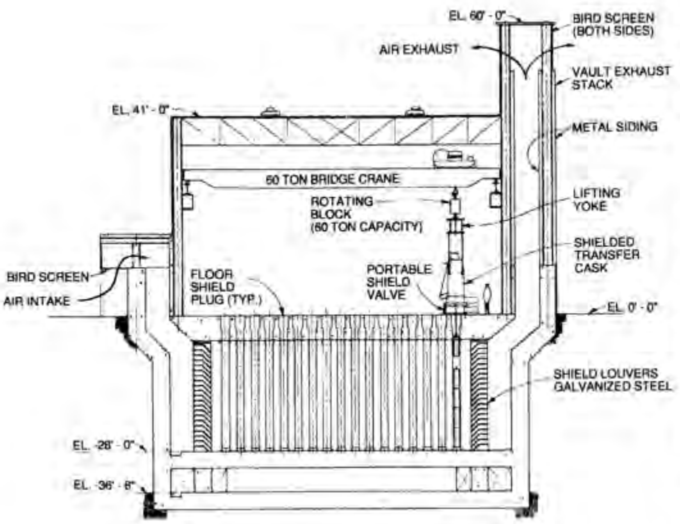

Fig. 4. Storage Vault Section.

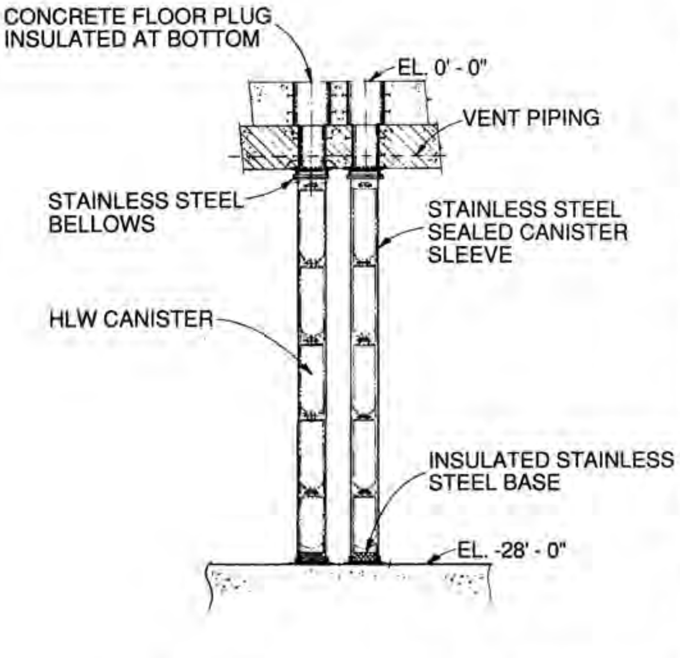

Fig. 5. Canister Storage Sleeve Section.

calculation, one concludes that approximately 4 hours are required to completely process 1 canister. Therefore, for the required design bases of 250 canisters/yr with a 1 shift/day, 250/day/yr operation, the facility has sufficient throughput capacity and reserve margins.

Because of the conservatisms in these calculations, sufficient time is also available to conduct any anticipated maintenance, repair, or likely off-normal recovery operations.

Personnel Estimates

The types and numbers of personnel required to operate the facility during its 1 shift/day operation were also estimated. These estimates, which were based on the required facility throughputs, the estimated times for waste handling operations, and other design basis parameters, were used to size the waste handling facilities, the support facilities, and utilities. The total number of operations personnel was estimated at 30: 14 in the main HLW building, 10 in the administration building, and 6 in the support buildings. HLW building personnel include a building supervisor, cask handlers, crane operators, hot cell equipment operators, maintenance staff, lab technicians, health physicists, and security guards.

OF DESIGN FEATURES WITH POSSIBLE ALTERNATIVES

The specific design features of the conceptual design discussed here were based on several preliminary engineering tradeoff studies, other published conceptual designs of similar facilities, design experience with operating similar nuclear facilities, judgment, and other factors. In the process of developing this design, definitive and firm numerical criteria were not prepared. Other combinations of specific design features could have been selected to generate alternative conceptual designs of equal technical feasibility. The design described here is appropriate, technically feasible, and economical, and was judged to be either superior or comparable in quality to the possible alternatives. Some of the reasons for this judgment are given below.

The dry storage method in the present design - as opposed to the alternative wet storage method - is a generally accepted technique for interim HLW storage in France, Great Britain, and Germany. The United States is actively developing dry storage techniques for its commercial spent fuel storage at either a monitored retrievable storage facility or a geologic repository and for vitrified HLW storage from its defense operations.

Sealed storage sleeves - as opposed to open storage sleeves in an alternative design - were selected for the vault so that cooling air would not directly contact the exterior of the potentially contaminated canisters. In contrast with open sleeves, the closed sleeve concept eliminates the need for providing HEPA filtration of all the main vault exhaust cooling air. The concept also results in a passive primary cooling system design (i.e., no active mechanical fans) which facilitates the resolution of some key licensing issues. In addition, in the closed sleeve design each sleeve is ducted and filtered, but only an extremely small volume of stagnant air from the interior of the sealed sleeves is filtered prior to its exhaust.

The configuration selected for the vault design allows the entering cooling air to flow predominantly horizontally across the closed sleeves as it travels toward the exhaust air exit. This air is driven by thermal buoyancy forces. Compared to the vertical and parallel alternative design concept, the selected concept requires a smaller vault volume because it eliminates bottom and/or top air plenums. The placement of the cooling air inlets and outlets at the sides of the vault, rather than inlets at the sides and outlets at the center, also reduces the air plenum or volume of the storage vault. These features result in economic advantages.

The storage vault concept for emplacing and removing vitrified HLW canisters in the storage sleeves uses an overhead bridge crane and portable shield transfer cask. This concept is based on current straightforward technology, and the crane can be used for other lifting duties. Two alternatives to the selected concept are (1) a mobile, wheeled vehicle with an integral shielded transfer cask system, and (2) a low bridge crane with an integral shielded transfer cask. A mobile vehicle can be used for applications involving the transfer of canisters between buildings, but introduces additional structural loads to the vault. The low bridge crane may allow a simplification of the vault overhead structure support system and an easier positioning of the location of specific storage sleeves, but can impede the movement of material and personnel within the storage vault. At this point in the design, these three alternatives are considered equally viable.

CONCLUSIONS

The conceptual design is based on technically feasible concepts. Although the concept was developed for a site-specific application and site-specific throughputs, the design concept can be readily adapted to other storage applications, such as (1) vitrified HLW storage at a reprocessing plant in Japan or elsewhere, (2) vitrified HLW storage of larger canister sizes from U.S. defense reprocessing wastes, and (3) spent fuel from nuclear reactors.

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