DESIGN OF THE VITRIFICATION PLANT FOR HLLW GENERATED FROM THE TOKAI REPROCESSING PLANT

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ABSTRACT

Power Reactor and Nuclear Fuel Development Corporation (PNC) is now designing a vitrification plant. This plant is for the solidification of high-level liquid waste (HLLW) which is generated from the Tokai Reprocessing Plant, and for the demonstration of the vitrification technology. The detailed design of the plant which started in 1982 was completed in 1984. At present the design improvement is being made for the reduction of construction cost and for the licensing which is going to be applied in 1986. The construction will be started in autumn 1987. The plant has a large shielded cell with low flow ventilation, and employs rack-mounted module system and high performance two-armed servomanipulator system to accomplish the fully remote operations and maintenance. The vitrification of HLLW is based on the liquid-fed Joule-heated ceramic melter process. The processing capacity is equivalent to the reprocessing of 0.7 ton of heavy metals per day. The glass production rate is about 9 kg/h, and about 300 kg of glass is poured periodically from the bottom of the melter into a canister. Produced glass is stored under the forced air cooling condition.

INTRODUCTION

The Japan Atomic Energy Commission (JAEC) initiated a high-level radioactive waste management program in 1976. Since then, the Advisory Committee on Radioactive Waste Management of JAEC made recommendations on the program in 1980 and 1984. This program is a basic policy on the radioactive waste management in Japan and covers the developmental schemes of the treatment, storage and disposal of radioactive waste.

The major features in the program on the treatment of high-level liquid waste (HLLW) which arises from the reprocessing plant operation are as follows:

1. In the development of the HLLW solidification technology, emphasis should be put on the vitrification into borosilicate glass;
2. The Power Reactor and Nuclear Fuel Development Corporation (PNC) should lead the program in cooperation with governmental and industrial organizations;
3. Vitrification technology should be demonstrated by the early 1990s through the construction and operation of the vitrification plant.

In accordance with this program, PNC has developed the vitrification technology since 1975 under the cooperation with many universities, national research institutes and private companies.

In particular, full-scale cold mock-up vitrification tests and laboratory-scale hot vitrification tests have been performed since 1981 and 1982, respectively, for the process development and waste glass characterization.[1] Vitrified waste storage technology, remote technology[2] and many related others have also developed.

The various stages of design of the vitrification plant have successively carried out since 1980. The detailed design of the plant was completed in 1984. At present the design improvement is being made for the reduction of the construction cost and for the licensing which is going to be applied in 1986. The construction will be started in autumn 1987.

Table I shows a schedule on the development of HLLW vitrification technology.

The plant has a large shielded cell with low flow ventilation, and employs rack-mounted module system and high performance two-armed servomanipulator system. The vitrification of HLLW is based on the Liquid-Fed Joule-heated Ceramic Melter process (LFCM).

In this paper, outlines of the plant is described.

SPECIFICATION OF THE PLANT

The LFCM process is employed in this plant. The processing capacity is equivalent to the reprocessing of 0.7 ton of heavy metals a day. The glass production rate is about 9 kg/h. About 300 kg of glass is poured periodically from the bottom of the melter into a canister. Filled canister is sealed by TIG welding and 140 packages are produced annually.

Packages are stored under the forced air cooling conditions for the glass to be kept below a temperature of 450 °C.

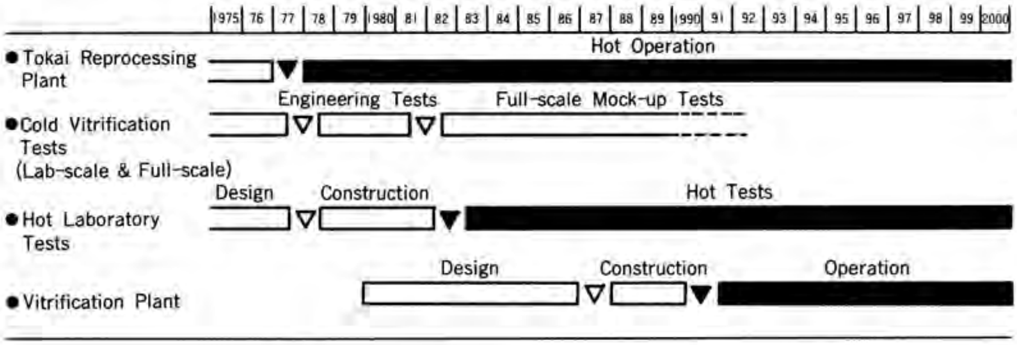
Characteristics of HLLW are estimated both from the calculation by the ORIGEN computer code and from the operational and analytical data of the reprocessing plant. Calculation is based on the Tokai Reprocessing Plant specific conditions:

Burnup of spent fuel	28,000 MWD/MTU;
Decay heat	35 MW/MTU;
Initial U-235 content	4 %;
Cooling time before reprocessing	0.5 y;
Cooling time before vitrification	5 y;
Volume of HLLW generated	1 m^3/MTU(max.); 0.5 m^3/MTU(nominal).

The waste glass produced in this plant is borosilicate glass. The waste oxide content in the

TABLE I

Schedule for the Development of HLLW Vitrification Technology



glass is 25 wt% as a standard. In this case, the fission products content is about 10 wt% and about 300 kg of glass is produced from one metric ton of heavy metals of spent fuel.

Table II shows typical composition and characteristics of the glass.

About 300 kg of glass is poured into a stainless steel 304L canister. The activities and heat generation rate for each package are about 4×10^5 Ci and 1.4 kW, respectively, just at the time of its production.

A large shielded cell with low flow ventilation is applied to the vitrification cell, where all of main vitrification equipment is installed. This vitrification cell has fully remote operations and maintenance system, and process equipment in the cell is mounted in the standardized rack modules.

Secondary gaseous waste in the plant is released from a stack into the atmosphere. Solid waste is transported to the reprocessing plant after stored for some period of time in the plant. Liquid waste is treated by evaporator in the plant, and then transferred back to the reprocessing plant in order to be discharged to the sea using a common effluent discharge pipe line.

VITRIFICATION PROCESS

Vitrification process is composed of the following steps:

1. reception of HLLW;
2. pretreatment of HLLW;
3. vitrification of HLLW;
4. handling of canisters and packages;
5. treatment of off-gas;
6. forced air cooling storage of packages;
7. treatment of secondary liquid wastes.

Figure 1 is a block flow diagram of the vitrification process.

TABLE II

Typical Composition and Characteristics of The Glass

Composition	
Glass additives	(75) (wt%)
SiO_2	43−47
B_2O_3	14
Li_2O	3
ZnO	3
Al_2O_3	3.5−5
BaO	0−3
Waste oxides	(25)
F.P.	10
Na_2O	10
Others	5
Characteristics	
Density(R.T.)	2.7−2.8g/cm^3
Thermal conductivity(R.T.)	0.9w/m℃
Thermal expansion coefficient	80−90×10^{-7}/℃
Transformation temperature	~500℃
Softening temperature	~600℃
Young's modulus(R.T.)	8×10^{10} N/m^2
Poisson's ratio(R.T.)	0.25
Leach rate (static test for one day in distilled water using 250−420μm sample)	2×10^{-5}g/cm^2.day(100℃) 4×10^{-7}g/cm^2.day(25℃)

Reception of HLLW

The HLLW is transferred from the reprocessing plant to a receiving tank in the vitrification plant through pipes placed in the underground trench. The frequency of HLLW transfer is about one time every week, and elemental and radioactive analyses are carried out for samples taken from the tank.

The receiving tank is duplicated for the safety of HLLW transfer and for a spare in an emergency (Fig.2).

Pretreatment of HLLW

The composition of HLLW is adjusted by the addition of chemicals and/or by concentration in a evaporator. Concentration is performed in batch for the diluted HLLW to the volumes corresponding to the amount of 500 1/MTU in order to reduce the water fed into the melter and to keep the melting capacity. Pretreated HLLW is transferred by a steam jet to a feed tank. Feeding of this HLLW into the melter is made continuously using a two-stage airlift (see Fig.2).

Denitration of HLLW with formic acid was studied in PNC to suppress the volatilization of ruthenium from the melter. The measurement of ruthenium volatility from the melter and the performance of off-gas equipment, however, have made us decide to drop the denitration process. Therefore, denitration of HLLW is not employed in the pretreatment of HLLW in the latest design.

Vitrification of HLLW

Figure 3 shows the structure of the melter. The HLLW fed into the melter is soaked into glass fiber cylinder just before they are fed into the melter. The size of the cylinder is typically 70 mm in diameter and 70 mm in length.[1] The diameter of glass fiber is about 10 micrometer. The soaking capacity of this cylinder is 4 ml-HLLW/g of additive at the maximum.

Cylindrically shaped glass additives were first proposed by W. H. Hardwick et al. in Harwell[3]. PNC has developed this concept and applied to the LFCM process.

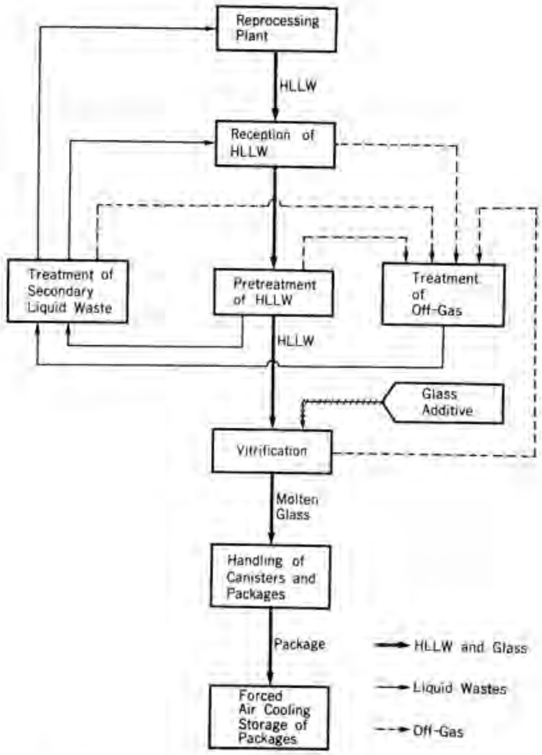


Fig. 1. Block Flow Diagram of the Vitrification Process

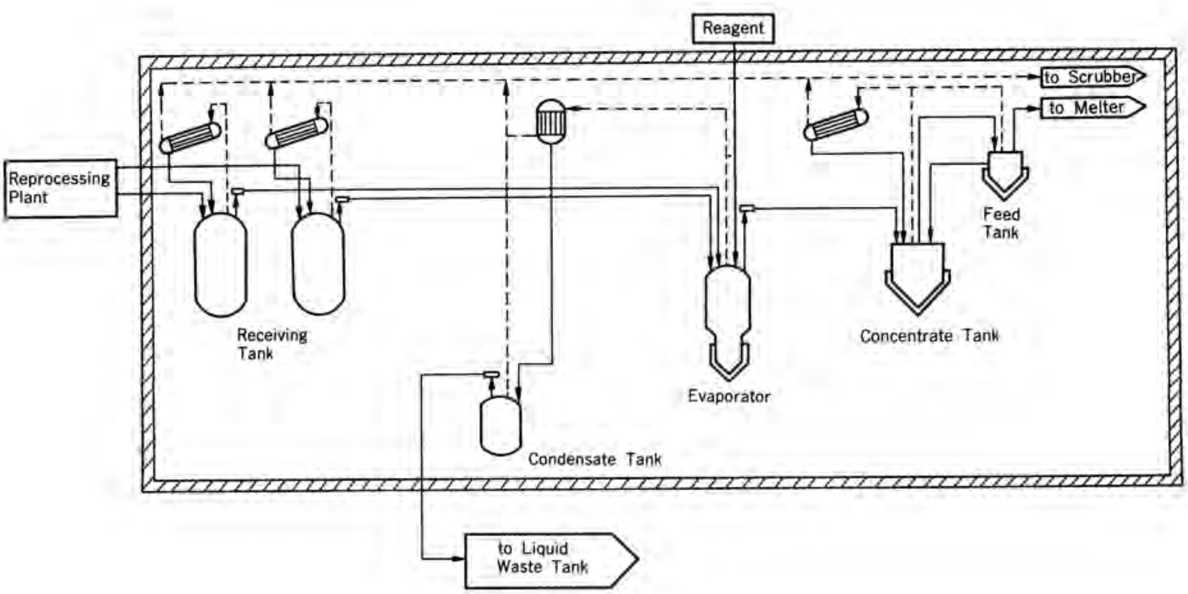


Fig. 2. Receiving and Pretreatment System of HLLW

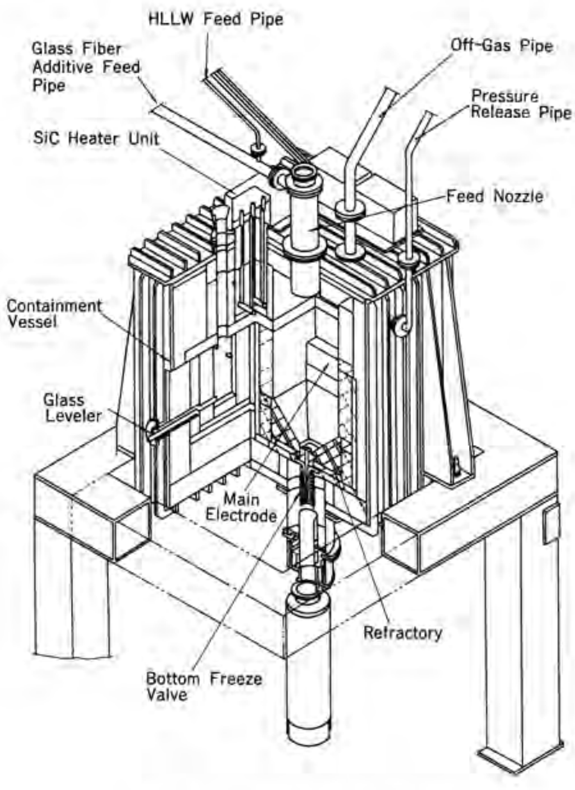


Fig. 3. Structure of Melter

Glass beads additive, in particular as the start-up materials of the melter, can also be applied to this melter.

Melting rate of the LFCM is about 9 kg/h. Start-up and/or restart-up is carried out by SiC resistance heating which is followed by Joule-heating. The SiC heaters can be remotely replaced.

The melter utilizes a composite refractory concept in the refractory design. Four refractory layers are used in the melter tank wall, and three layers in the lid design. Glass contact refractory is fused-cast chromia-alumina refractory. This is backed up by successive layers of mullite, alumina castable material and finally a ceramic fiber board next to the containment vessel which is cooled by natural air convection. Refractory layers are structured to have resistance against earthquake.

Metallic material including electrode which has contact with molten glass is Inconel 690. A temperature of the glass is maintained at 1100 to 1250 °C by controlling the input power. The electrode is cooled by forced air which passes through the channel incorporated inside it, and its current density is restricted below a limited value to assure the corrosion resistance.

The molten glass is discharged periodically from the bottom of the melter into a canister. A bottom freeze valve heated by induction is designed for this purpose. The discharge rate is 150 kg/h on an average, and 300 kg of molten glass is poured in two hours.

The electroconductive deposits, such as ruthenium oxide and noble metal alloys, on the bottom of the melter, which may cause the short circuit of main electrodes, are discharged through the bottom freeze valve with the molten glass. This eliminates their accumulation on the floor of the melter. The bottom refractory of the melter is sloped to facilitate the discharge of those deposits.

The design life of the melter is five years, or more. The inside of the melter is planned to be remotely inspected periodically during the service lifetime.

Handling of Canisters and Packages

Figure 4 shows the flow of the handling of canisters and packages. During the discharge of the molten glass into a canister, the weight of the glass in the canister is successively measured by load cells equipped on the transfer car. After the canister is subsequently cooled for two or three hours at the position, the transfer car is driven from there to the welding position, where a lid is welded by TIG welder to seal the canister.

After the packages are cooled in the vitrification cell, their surfaces are decontaminated by high pressure water jet spray and wire brushing, and then inspected by smear method. Finally some other inspections on size and appearance are made before the packages are transported to the storage cell.

Treatment of Off-gas

Figure 5 shows the melter off-gas treatment system. Melter off-gas is cleaned by dust scrubber, venturi scrubber, perforated plate water scrubber, high efficiency mist eliminator, ruthenium adsorber (silica gel), HEPA filter and so on. In this system, high efficiency equipment is introduced in order to remove submicron particles, mist and volatile ruthenium, and to expect high decontamination factor of the system.

The off-gas from the receiving tank, evaporator of HLLW and secondary liquid waste treatment system has a separate system from the above.

Forced Air Cooling Storage of Packages

The packages are stored in vertical storage pits having slightly larger diameters than them in storage cell situated close by the vitrification cell.

The storage cell has 52 pits. 13 pits of them are designed for the future demonstration of the closed circuit cooling.

The ventilation system is designed so that the maximum temperature of forced air may not exceed the acceptable limit. The air is taken from the amber area of the plant through filters, injected at the bottom of the pits and flows up the annular space between pit wall and packages. Figure 6 is a schematic of the storage pits.

Treatment of Secondary Liquid Wastes

The secondary liquid wastes produced from the vitrification process, analytical works and others are treated by evaporation. The concentrates are recycled to the vitrification process, and condensates are transferred back to the reprocessing plant.

REMOTE MAINTENANCE

This plant employs fully remote maintenance technology for the operations and maintenance in the large vitrification cell. The objectives are as follows:

1. Enhancement of the plant availability;
2. Reduction of the radiation exposure to the workers during maintenance;
3. Reduction of the secondary waste amount.

Vitrification process equipment is placed in the standardized rack-mounted modules which are installed in two lines along the cell wall. The size of rack-mounted module is 3 m in length, 3 m in width and 6.5 m in height, and total weight is below 20 tons. Pipes between rack-mounted modules are connected with remote connectors.

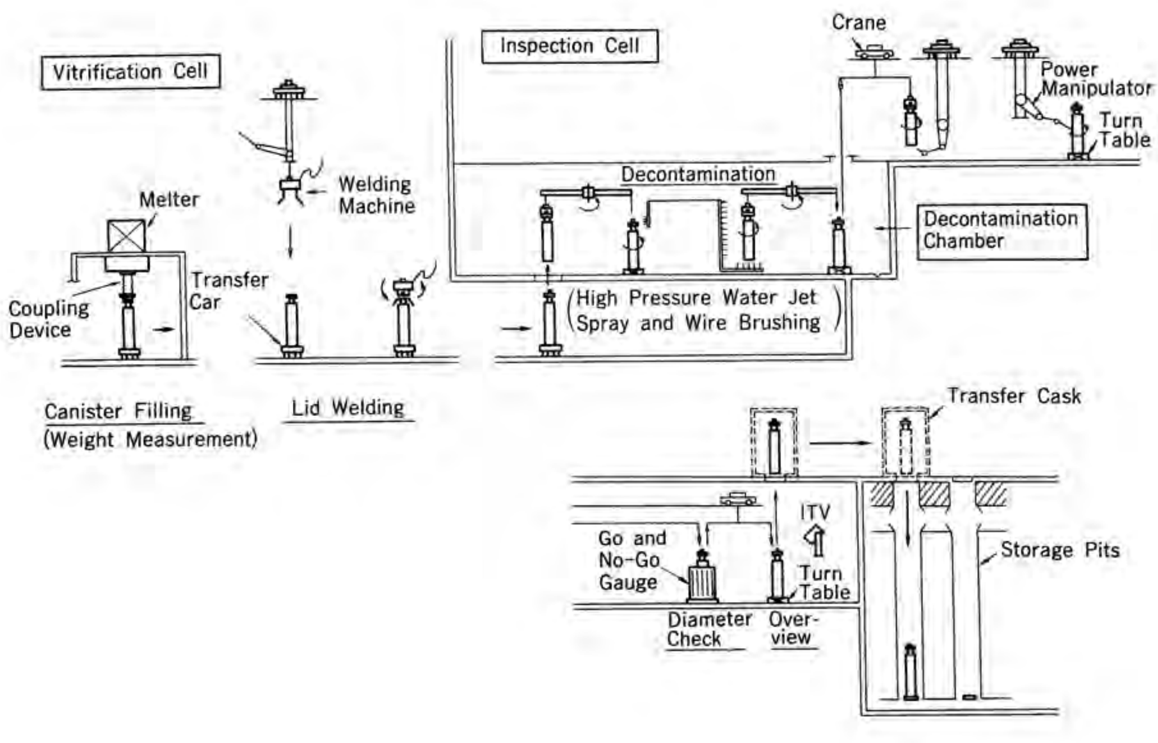


Fig. 4. Handling Flow of Canisters and Packages

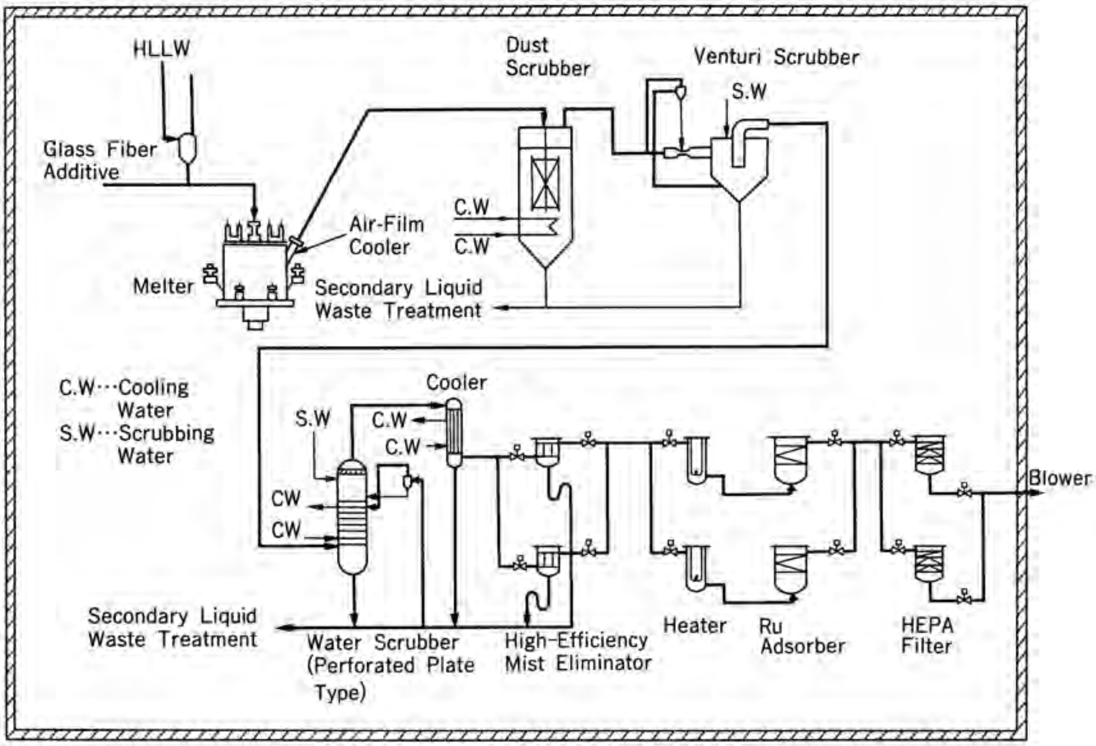


Fig. 5. Melter Off-Gas Treatment System

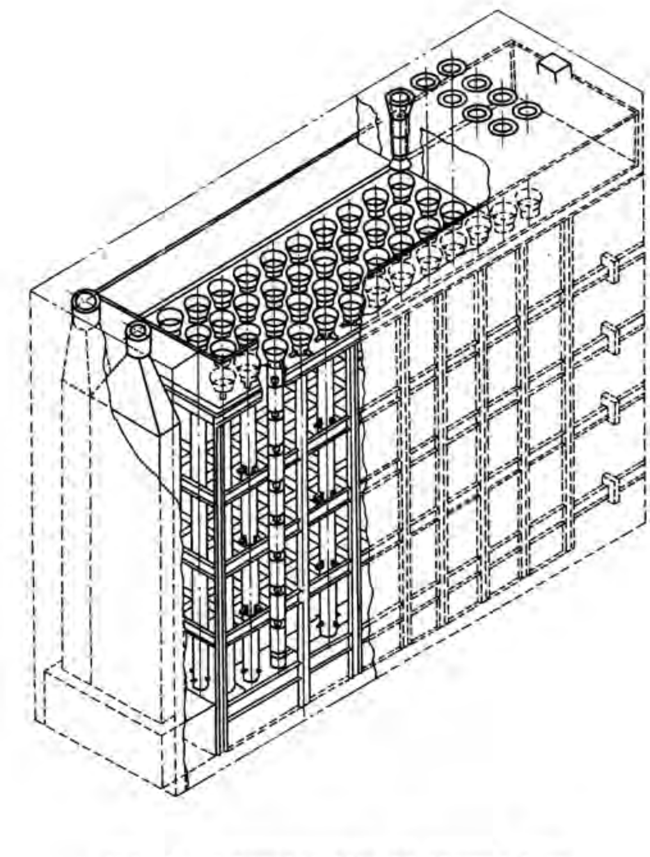


Fig. 6. Schematic View of Storage Pits

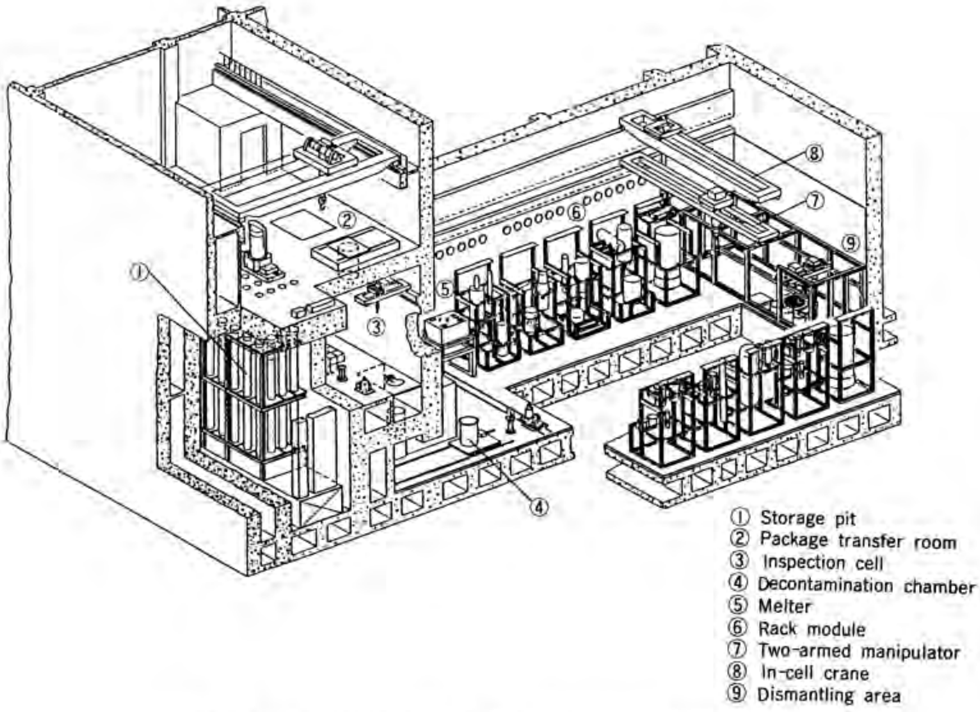


Fig. 7. Conceptual Drawing of Vitrification Cell

Figure 7 shows the conceptual drawing of the vitrification cell. As remote maintenance tools, in-cell cranes and two-armed servomanipulators are equipped to make in-situ maintenance. Rack-mounted module is replaceable by disconnecting the remote connectors, if necessary.

Some wall-through plugs are remotely exchangeable with in-cell cranes.

ITV is a main viewing system: few shielding windows are used in the vitrification cell.

Repair hoist is used for the maintenance of in-cell cranes.

VENTILATION AND TEMPERATURE CONTROL OF THE VITRIFICATION CELL

As being mentioned above, a low-flow ventilation system is used in the vitrification cell. This is because it needs to avoid the large amount of ventilation volume to reduce the ventilation cost. Therefore, the cell is designed to have a very low leak rate which gives, in turn, low leakage probability of cell air.

Some in-cell coolers are used to control the temperature in the vitrification cell.

CONCLUSIONS

The vitrification plant for the Tokai Reprocessing Plant is a demonstration facility both of the vitrification technology of HLLW and the fully-remote maintenance technology, and has an important role for the completion of the nuclear fuel cycle in Japan.

The vitrification technology is based on the LFCM process, which is developed in PNC under the international cooperation with the United States, the Federal Republic of Germany and other countries.

At present, design improvement and R&D works are being carried out. The construction will be started in 1987, and the hot operation is expected to start in 1991.

For the completion and the share of the LFCM process, more extention of the international cooperation.

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