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DESIGN AND CONSTRUCTION OF THE DEFENSE WASTE PROCESSING FACILITY PROJECT AT THE SAVANNAH RIVER PLANT

by

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ABSTRACT

The Du Pont Company is building for the Department of Energy a facility to vitrify high-level radioactive waste at the Savannah River Plant (SRP) near Aiken, South Carolina. The Defense Waste Processing Facility (DWPF) will solidify existing and future radioactive wastes by immobilizing the waste in borosilicate glass contained in stainless steel canisters. The canisters will be sealed, decontaminated and stored, prior to emplacement in a federal repository. At the present time, engineering and design is 90% complete, construction is 25% complete, and radioactive processing in the $870 million facility is expected to begin by late 1989. This paper describes the SRP waste characteristics, the DWPF processing, building and equipment features, and construction progress of the facility.

SRP HIGH LEVEL WASTE CHARACTERISTICS

In the 32 years of SRP operations, approximately 300,000 m^3 of high-level liquid waste has been produced; waste generation is expected to continue at the rate of about 10,000 m^3 a year depending upon production requirements. The generated waste has been evaporated to about 120,000 m^3 containing a billion curies of radioactivity which is stored in 51 carbon steel tanks of sizes varying up to 4,900 m^3 capacity. Approximately 10% of the stored waste is a sludge composed of precipitates of the hydroxides of iron, aluminum and manganese; the remainder of the waste is liquid and saltcake which consists primarily of sodium nitrate, sodium nitrite, sodium aluminate and sodium hydroxide. The sludge contains most of the strontium-90 and small amounts of actinides not recovered in the reprocessing plants. The salt-supernate fraction contains most of the cesium-137. A typical distribution of components in the washed sludge to be pumped from the tank farm to the DWPF is shown in Table I.

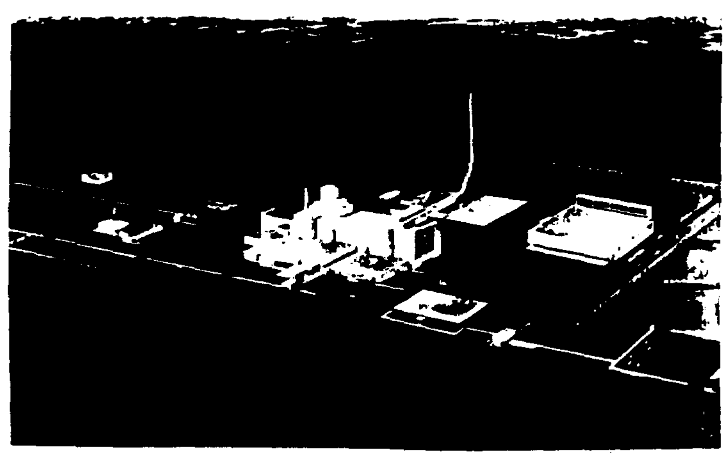
DESIGN BASIS

The DWPF is located in proximity to the two separations areas and tank farm to minimize the distance of transfer of radioactive liquids through pipelines. The site is provided with combined rail and truck facilities in the main process building with direct access to the process cell to permit loading large building equipment from the process cell directly into a container on a railroad car or truck bed within the shielded area of the process building.

An overall view of the DWPF is shown in Fig. 1 and a plan view of the vitrification building in Fig. 2. The building length is 110m by 35m wide by 27m high, and is divided by a system of barriers designed to separate the highly radioactive center section from the regulated perimeter operating areas. The 1.4m thick reinforced concrete walls are designed to reduce personnel exposure to less than 0.5 mrem/hr in occupied zones of the building. The ventilation system is designed so air flows from the lowest contamination zone to successively higher zones of contamination. The process cell air is combined with air from process tank vents and the melter off-gas system and pumped through a 2.5m thick sand filter bed for exit to the atmosphere through a 46m stack. Nominal stack air flow is 3000 m^3/min.

The facility is designed to contain radioactive materials as specified in 10CFR100 under a design-basis earthquake with a peak horizontal ground acceleration of 0.20g. Similarly the structures will withstand a design basis tornado which has a rotational speed of 103 m/sec at a radius of 70m and a maximum translational speed of 22 m/sec.

DEFENSE WASTE PROCESSING FACILITY



Process cell operations are controlled from outside the cells, and all equipment is removed from the cells for decontamination before repair, replacement, or disposal. Process piping and service connections are made to the process equipment with connectors operated remotely from the main crane which is equipped with closed-circuit television viewing.

MAIN PROCESSING BUILDING 221-S

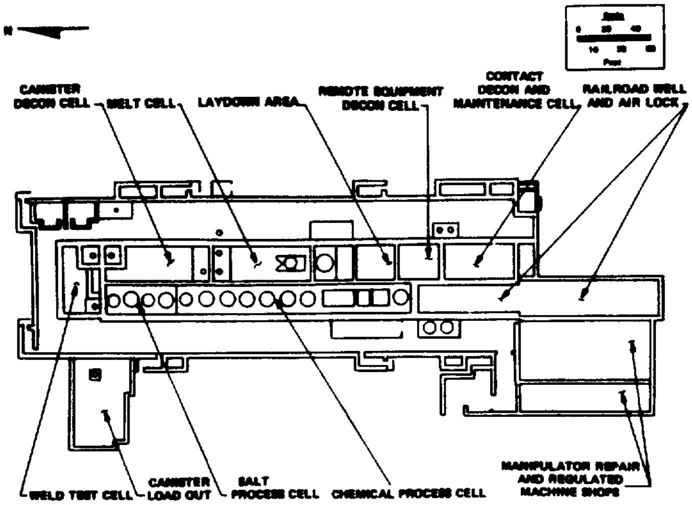


Fig. 2

DWPF PROCESSING

A diagram of the DWPF processing steps is shown in Fig. 3. The principal operations consist of waste transfer from the tank farm to the DWPF, feed adjustment, melter operation, canister filling, decontamination, welding, final inspection and storage. These operations are discussed below:

THE DWPF PROCESS

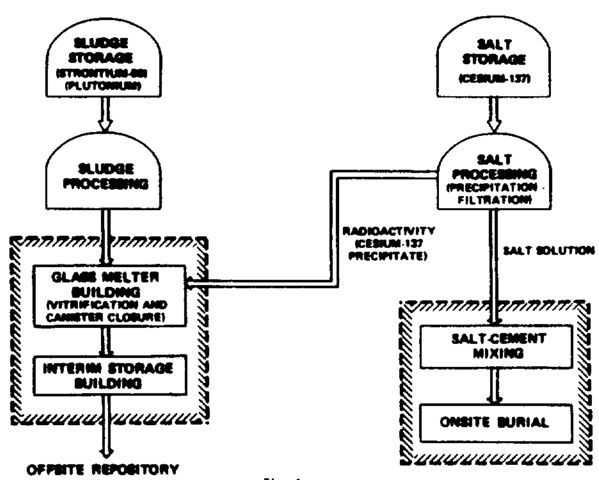


Fig. 3

Feed Preparation in the Tank Farm

Sludge containing high aluminum is washed with caustic, while in the tank farm to remove aluminum, then water washed to remove nitrate salts prior to feeding the DWPF. The salt fraction is dissolved after which cesium is precipitated by treating the solution with sodium tetraphenylborate. The slurry is concentrated to 10 wt% solids and pumped to the DWPF.

Waste Transfer from the Tank Farm to the DWPF

Three transfer lines of 2 km in length, plus one spare are provided for transfer of sludge, precipitate and recycle waste between DWPF and the tank farm. The sludge line and spare are paired within a single jacket, and the precipitate and recycle waste lines are paired within a second jacket. The lines are sloped to drain to a low point pump tank and are shielded to a surface radiation level of 1.0 mr/hr.

Two pump pits with three tanks each are provided to transfer the waste. Each tank contains a transfer pump, agitator, two independent level detection dip tube assemblies, temperature indication and a backup steam jet. The pump pits are lined with 304L stainless steel sheet and contain sump level detection and water sprays for pit decontamination. The pits are ventilated with outside air which is discharged through monitored HEPA filters. Each tank is ventilated with an air flow which exits the tank vent piping through a condenser, demister, heater, HEPA filter, blower and stack. The filters are shielded with 20 cm of concrete and are remotely changeable.

Sludge Slurry Receipt, Adjustment and Evaporation

The 13% solids sludge, which has been washed with caustic to remove aluminum, is pumped to a 35 m^3 sludge receipt and adjustment tank located in the main process cell. The sludge stream is mixed with the cesium slurry transferred from the salt processing cell (Table II). The slurry is cooled, agitated, sampled, formic acid added, and concentrated by boiling under total reflux for about four hours at 90°C, to reduce mercury to the elemental state. The formic acid also reduces yield stress of the slurry, provides a reductant to the melt which minimizes foaming, and reduces ruthenium volatilization. The mercury is steam stripped and routed to a mercury water wash tank where the condensate is decanted from the mercury layer and transferred back to the slurry receipt adjustment tank. After cooling, the adjusted sludge slurry is transferred to the slurry mix evaporator where frit as a 60% slurry, and frit from the canister decontamination operation are combined with the sludge. The evaporated batch, concentrated to 40 wt% solids, is sampled, analyzed and transferred to the melter feed tank. Condensate from the slurry mix evaporator is transferred to a condensate tank, then to a recycle collection tank to be returned to the waste tank farm. Mercury which accumulates in the slurry mix evaporator condensate tank is transferred periodically to the mercury water wash tank where it is purified to remove entrained sludge, formic acid and other contaminants. A final scrub is made in the mercury purification cell, followed by vacuum distilling, and loading into containers for shipment to storage and for use in the spent fuel reprocessing facility. The melter feed tank slurry is agitated and sampled for determining the radionuclide and chemical content of the material going into the glass waste form. The melter feed tank contents are fed to the melter through two independent continuously recirculating feed loops with remotable lines. Each feed system is capable of supplying feed to the melter in the range of 1.5 to 2.7 l/min, so that normal operation can be maintained even if one feed line plugs.

TABLE I

Washed Sludge from the Tank Farm to DWPF

	Weight %
$Al(OH)_3$	14.7
$CaCO_3$	3.1
$Fe(OH)_3$	37.2
HgO	2.1
MnO_2	6.3
$NaNO_3$	3.3
NaOH	4.2
$Ni(OH)_2$	3.1
SiO_2	4.9
$UO_2(OH)_2$	6.3
Zeolite	4.5
Other	10.3
Total	100.0

TABLE II

Salt Slurry Feed to the DWPF

	Weight %
$(C_6H_5)_2$	5.0
$C_6H_5B(OH)_2$	6.1
C_6H_5OH	2.1
H_3BO_3	19.1
KCOOH	28.9
Na_2SO_4	2.4
$NaAl(OH)_4$	2.1
NaCOOH	13.1
$NaNO_3$	5.0
$NaTi_2O_5H$	5.7
Other	10.6
Total	100.0

Precipitate Process

The salt decontamination process is based upon treatment of the salt fraction, while in the waste tanks, with sodium tetraphenylborate and sodium titanate. The precipitated solids, which contain virtually all of the salt radioactivity, are separated from the liquid by passage through a cross-flow filter. The tetraphenylborate precipitate product is heated for 5 hours at 100°C with formic acid to produce the formate salt, boric acid and benzene. The benzene is steam distilled, collected and incinerated as low-level waste. The aqueous phase and titanate product containing cesium, strontium and plutonium are fed to the sludge receipt and adjustment tank for later feeding to the glass melter. Cement and fly ash are added to the decontaminated salt solution and the resulting "Saltstone" grout is placed in an engineered surface disposal vault at SRP as shown in Fig. 8.

Melter Operation

Vitrification of SRP waste is accomplished in a slurry-fed Joule-heated ceramic melter as shown in Fig. 4. The melter is operated with a crust, or cold cap, composed of waste calcine and frit which covers about 90% of the melt surface and ranges in thickness up to 15 cm. The feed slurry is introduced onto the cold cap where water is evaporated and drawn into the off-gas system. The glass melt temperature beneath the cold cap is 1050°-1170°C which enables the cold cap to melt from the bottom and form the waste-borosilicate glass matrix. The vapor space above the cold cap is kept at a pressure of 750mm Hg and a temperature between 650-800°C to provide additional heat for water evaporation and frit melting. The glass melt volume varies between $2.2m^3$ - $2.8m^3$ over the expected melter life span of 3 years, due to refractory erosion. For a nominal pour rate of 100 kg/hr, and a nominal melt weight of 6500 kg, the residence time in the melter is about 65 hours.

The melter consists of a water cooled steel cylinder of 3.8 cm wall thickness, approximately 2.6m in outside diameter by 3.2m high, with a riser section projecting an additional 1.6m from the melter side. The shell is lined with refractory to give an internal diameter of 1.8m by 2.2m high. The glass contact refractory is Monofrax K3(R), 30 cm thick, and the lid refractory is Mullfrax 202(R) which is 22 cm thick. Power to the glass melt is supplied by two lower electrodes with a surface area of 3,100 cm^2 each, and two upper electrodes with a surface area of 3,450 cm^2 each. Under normal operating conditions the electrodes will draw up to 300 kW.

In order to initiate melting of glass, four pairs of lid heaters rated at 150 kW each are used to raise the glass waste temperature to at least 700°C. In addition, the heaters assist in glass melting, keep the melter vapor space free of glass buildup, and burn hydrocarbons in the feed that are not consumed within the cold cap. A riser heater (15 kW), a pour spout heater (15 kW), and a drain valve heater (30 kW) are designed to keep the glass above 1050°C in all portions of the melter. The melter has ten top head assemblies which can be remotely replaced by an overhead crane. These consist of two feed tubes, two TV cameras, two thermowells in the melt, one vent line to a seal pot, one vent line to the off-gas system, one level indicator and one thermowell in the melter vapor space. The drain valve located in the center of the melter bottom is fitted with a hollow ram designed to penetrate a sludge layer that may deposit on the melter floor, and can drain the melter contents into five canisters located on a turntable directly beneath the melter. Draining of the melter will take place after the refractory side walls have reduced in thickness to about 20 cm; this is expected to take at least 3 years.

DWPF MELTER

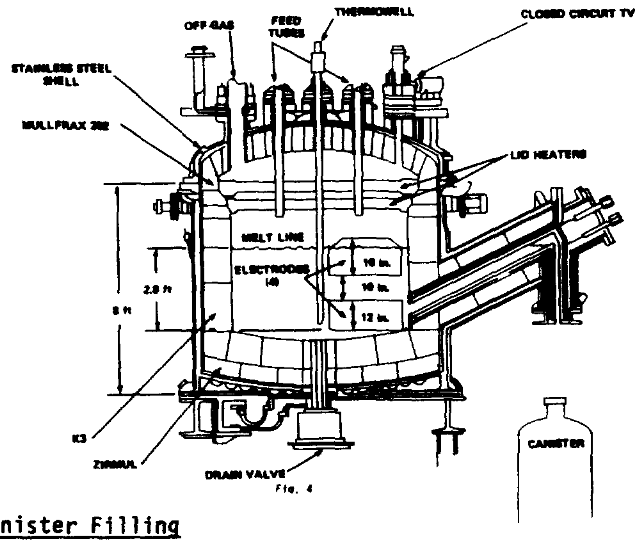


Fig. 4

Canister Filling

After melting of the glass frit and incorporation of the sludge oxides into the glass matrix, the molten glass is poured into steel canisters. Pouring is accomplished by lowering the pour spout pressure to 740 mm Hg while the melter vapor pressure space is 750 mm Hg. Glass flow at the exit temperature of 1050°C has a viscosity of 100 poise which ensures a smooth continuous flow to the canister perimeter. After completion of the 17-hour fill, the canister is vented to the off-gas system while still connected to the melter. This venting contains the release of volatile radionuclides such as Cs-137. The canister is then rotated from beneath the melter pour spout on a turntable and the inner canister shrink fit closure is inserted into the canister nozzle. The canister is cooled by normal cell ventilation for a period of 13 hours while on the turntable until the top surface center glass temperature is below the softening point of 550°C. The partially cooled canister is then lifted by the in-cell crane and placed in a cooling rack for an additional 18 hours until the canister surface temperature reaches 100°C. Control of the canister fill is accomplished by four methods: weight measured by load cell, level measured by fast neutron transmission detection, level measured by detecting gamma radiation from the canister, and by visual observation of color change of the canister external surface. Application of these methods ensure consistent canister fill level and weight.

Inner Canister Closure

After the canister is filled to the reference level of 230 cm, a shrink fit plug is inserted into a sleeve previously installed during canister fabrication. The plug is inserted by manipulator after the filled canister rotates from beneath the melter pour spout. The cooling canister neck and sleeve shrink around the expanding plug creating a water leak tight seal to better than 10^{-4} atm-cc/sec. After the canister decontamination step by frit blasting, the sleeve and plug are pushed into the canister neck, in the weld test cell, before the final plug weld is made.

Canister Decontamination

Frit slurry blasting is used to remove contamination and metal oxides from the canister surface. Cleaning is performed by rotating the canister in an enclosed chamber and using air injected wet glass frit blasting on all exposed surfaces. The slurry contains 8 wt% frit, and each jet sprays slurry at a rate of 45 l/min and air at 2800 l/min. The frit slurry is recycled to the slurry mix evaporator for feed to the melter. The wet frit blasting method has demonstrated the ability to clean the canister surface below the required contamination level of:

$$\alpha: \; 220 \text{ d/m/100 cm}^2$$
$$\beta\gamma: \; 2200 \text{ d/m/100 cm}^2$$

Welding

The canister is sealed by welding a 12.7 cm diameter plug into the canister nozzle using an upset-resistance weld. The inner canister closure sleeve and temporary plug are pressed down in the neck of the canister to make room for the weld plug. The plug, which is slightly larger in diameter than the nozzle bore and has a tapered edge, is centered in the nozzle. The canister is supported by its flange on the welder bottom electrode, then the upper electrode is lowered onto the plug and a welding force of 35,000 kg exerted. A welding current of 250,000 amps is applied. As the weld interface heats, plastic deformation occurs and the plug is forced 1.3 cm into the nozzle forming the solid state weld.

Canister

The DWPF canister is shown in Fig. 5. The canister is made of 304L stainless steel, is 300 cm high and 61 cm in diameter with a 0.95 cm wall. The unit is made under ASME Code Section VIII, and leak checked to 1×10^{-6} atm-cc/sec helium. The canister is filled with waste glass over a pour period of 17 hours to a volume of $0.63 m^3$ which corresponds to a fill height of 230 cm and a nominal weight of 1700 kg of glass. The steel canister weighs 500 kg when empty. The concentration of waste oxide in the glass is approximately 28%. When filled with glass waste made from sludge cooled 5 years and supernate cooled 15 years, and a nominal glass density of 2.7 g/cm^3, the canister generates approximately 700 watts and contains about 235,000 curies. The facility is expected to produce about 400 canisters per year at an attainment of 75%.

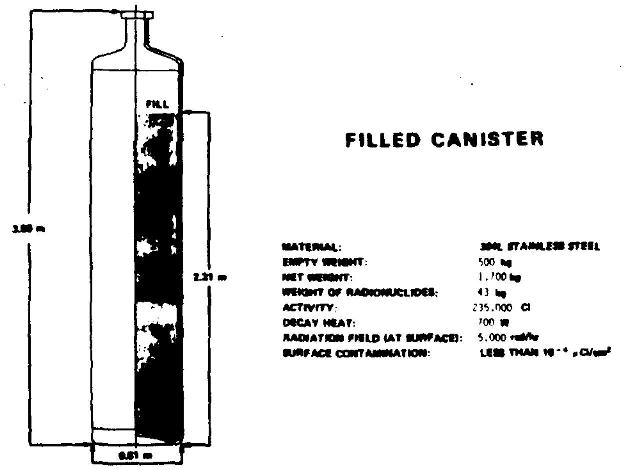


Fig. 5

Canister handling steps are shown in Fig. 6. The general flow is from receiving, inspection, to melt cell, for filling, cooling, inner canister closure, to decontamination cell for temperature measurement, decontamination, smear check, to weld test cell for welding, smear check, radiation survey and load out.

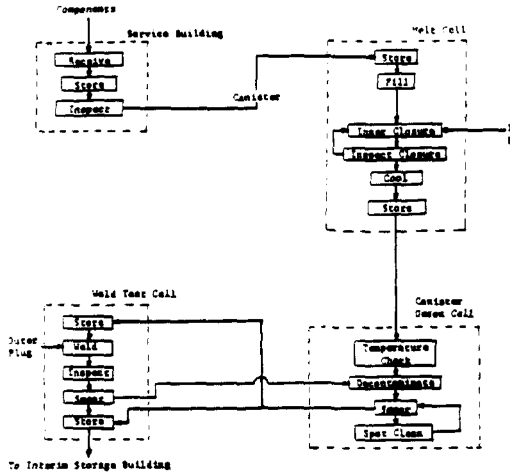


FIGURE 6. CONTAINERIZATION PROCESS

Off-Gas System

The off-gas system equipment arrangement is shown in Fig. 7. The off-gas exits the melter film cooler at a temperature of about 400°C and flows through an Inconel 690 section with a flow rate of $30 m^3$/min, then enters a quencher where the gas is cooled to 48°C to condense water vapor, semi-volatiles, and aromatic hydrocarbons. Two stages of steam atomized scrubbing follow where the gas is decontaminated by a factor of 50. The gas is cooled to 10°C in a condenser to remove water, then further decontaminated in a high efficiency mist eliminator, which has an estimated decontamination factor of 40. The gas is heated to 20°C prior to entrance to two stages of HEPA filtration, passed through a sand filter and exhausted through a 46m stack. The overall decontamination factor between the melter vapor space and release to the atmosphere is 8×10^8 for semi-volatiles and condensing products.

To reduce deposition of particulates in the off-gas as it exits from the melter, a film cooler is located in the line just at the off-gas exit. The device consists of a slotted sleeve through which steam or air is passed to form a gas film on the exit pipe. The film reduces the tendency of the particles to deposit in the line and a rotating wire brush is used to periodically clean the sleeve of deposits. A duplicate backup off-gas system is provided so any equipment piece in the primary system can be replaced without shutting down the vitrification operation.

MELTER OFF-GAS PRIMARY & BACK-UP SYSTEM

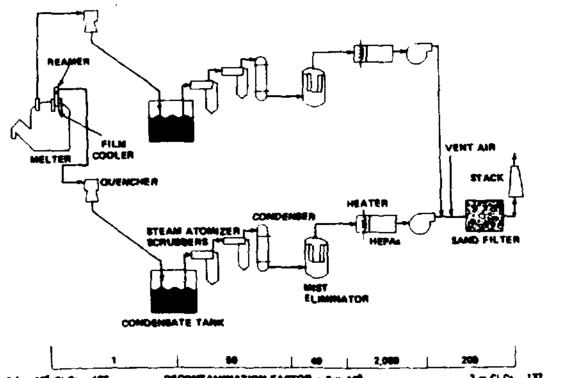
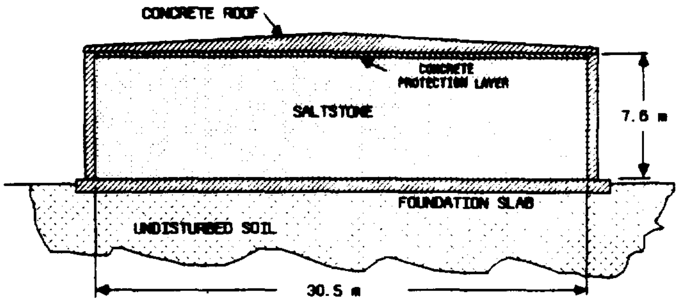


Fig. 7

FIG. 8
SALTSTONE SURFACE DISPOSAL VAULT
CROSS-SECTION



Utilities

Electrical running load and available capacity for the DWPF facilities is 11M VA and 14 M VA respectively. Emergency power is supplied by two 2,000 kW diesel generators. Batteries are used to provide uninterruptable power until the emergency power diesels are at operating speed.

	Running Load	Capacity
All DWPF facilities	11,000 kVA	14,000 kVA
Emergency Power	1,975 kW	4,000 kW
Uninterruptable Pwr Supply	220 kVA	360 kVA

Special Equipment

The main process cell crane has the capability to lift 106,000 kg on the main hoist, 9,000 kg on the auxiliary hoist and 900 kg on a third hoist, plus an impact wrench suspended from the 900 kg hoist trolley. The crane is remotely operable using a closed circuit TV system with cameras and lights mounted on the crane bridge. Four remotely operated in-cell cranes are located in the melt cell, canister decontamination cell and two in the weld test cell. Each crane is equipped with two hoists; one 9,000 kg hook and a 900 kg hook for an impact wrench.

Master-slave manipulators are provided in the melter cell opposite the melter pour spout, at the inner canister closure station, the canister decontamination cell, weld test cell, equipment decontamination cells, mercury recovery cell, and sample cells. Sleeves are provided at other selected locations for later manipulator installation, if required.

Cooling Towers

Cooling water for cooling coils is supplied from a closed-loop circulating process cooling water system to ensure confinement of radioactivity in the event of a cooling coil leak. A positive pressure is maintained on the cooling water coils, so that if a leak occurs, flow is into the tank.

Process Control and Data Acquisition

The process control and data acquisition system consists of a distributed control system whose primary function is process control, and a backup host computer whose primary function is data collection and analysis. Included in the distributed control system are ten field operating stations used to control individual process steps. These systems are interconnected through a data highway with the displays divided between two control rooms. The operators control room has ten displays connected to host, and backup host computers with seven connections to two networks. In addition, four CCTV displays are available to view specific building operations. The supervisors control room has five displays connected to host, backup host computers, with two connections to two networks. In addition, nine CCTV displays are available to view specific building operations and eight programmable logic controllers operate individual process steps. The host computer is a DEC VAX 11/750, the backup host a DEC VAX 11/785, the nine display consoles are DEC VAX 11/73's and there are 40 Intel 8088 microcomputers distributed throughout the building.

Interim Storage Building

The filled and decontaminated canisters are moved by a shielded transporter and stored in a natural convection air cooled storage building until transferred to a federal waste repository. The building has a capacity of 2300 canisters - equivalent to about five years production.

CONCLUSION

The DWPF production facility is the first in the United States for the solidification of HLW, and is the largest facility operating, under construction, or planned in the world. When the facility starts radioactive processing during late 1989, it will demonstrate that a major quantity of existing high-level nuclear waste can be safely and permanently immobilized.

ACKNOWLEDGEMENT

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