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OPERATING EXPERIENCE DURING HIGH-LEVEL WASTE VITRIFICATION AT THE WEST VALLEY DEMONSTRATION PROJECT

Topical Report

By
P. J. Valenti
D. I. Elliott

January 1999

Work Performed Under Contract No. AC24-81NE44139

Prepared by
West Valley Nuclear Services Co., Inc.
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U.S. Department of Energy
Assistant Secretary for Nuclear Energy

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ABSTRACT

This report provides a summary of operational experiences, component and system performance, and lessons learned associated with the operation of the Vitrification Facility (VF) at the West Valley Demonstration Project (WVDP). The VF was designed to convert stored high-level radioactive waste (HLW) into a stable waste form (borosilicate glass) suitable for disposal in a federal repository. Following successful completion of nonradioactive testing, HLW processing began in July 1996. Completion of Phase I of HLW processing was reached on 10 June 1998 and represented the processing of 9.32 million curies of cesium-137 (Cs-137) and strontium-90 (Sr-90) to fill 211 canisters with over 436,000 kilograms of glass. With approximately 85% of the total estimated curie content removed from underground waste storage tanks during Phase I, subsequent operations will focus on removal of tank heel wastes.

1.0 INTRODUCTION

1.1 Background of the West Valley Demonstration Project

The West Valley Demonstration Project (WVDP) is located approximately 30 miles south of Buffalo at the former nuclear fuel reprocessing plant in West Valley, New York. One of the primary objectives of the WVDP is to solidify High-level Waste (HLW) stored in underground tanks into a form suitable for transportation and disposal at a federal repository.

The fuel reprocessing plant was built in 1966 by Nuclear Fuel Services., a subsidiary of the W.R. Grace Company. When the plant was built, management of high-level radioactive liquid waste at federal installations employed underground storage in carbon steel tanks. Following this precedent, the site was licensed to operate with the expectation that the HLW generated during the fuel reprocessing would be stored underground in steel tanks for an indefinite period. Operations ceased in 1972 after reprocessing approximately 700 tons of spent commercial nuclear fuel. This site was the only commercial nuclear fuel reprocessing facility ever to operate in the United States.

As a result of reprocessing operations, approximately 2,200 cubic meters (600,000 gallons) of HLW plutonium-uranium extraction (PUREX) waste was produced. This waste was neutralized with sodium hydroxide and stored in an underground carbon steel tank. A sludge layer of insoluble hydroxides, mostly ferric hydroxide, precipitated to the bottom of the tank, leaving a relatively clear liquid supernatant above the sludge. The primary radioactive isotope that remained in the supernatant was cesium-137 (Cs-137). The other radioactive isotopes, primarily strontium-90 (Sr-90), became part of the sludge layer.

Additionally, as a result of special reprocessing operations for fuel containing thorium, approximately 30 cubic meters (8,000 gallons) of acidic thorium extraction (THOREX) waste was produced. This waste was stored separately in an underground stainless steel tank.

In 1980, the United States Congress passed the West Valley Demonstration Project Act authorizing the U. S. Department of Energy (DOE) to carry out a high-level nuclear waste management demonstration project at the Western New York Nuclear Service Center at West Valley, NY. In 1983, the DOE selected borosilicate glass as the final HLW glass form for the WVDP. This waste form is produced by mixing the HLW with glass-forming chemicals and heating the mixture to a temperature sufficient to convert the constituents into borosilicate glass.

1.2 Pretreatment of HLW for Vitrification Processing

The supernatant portion of the HLW was pretreated, between 1988 and 1991, by transferring it through zeolite-filled, ion-exchange columns that removed more than 99% of the radioactive Cs-137. The resulting effluent solution was processed as low-level waste, effectively removing a majority of the sodium from the HLW. The PUREX waste sludge also contained nearly 20 tons of sulfate in the form of interstitial sulfate salts.

After the supernatant treatment was completed the sludge was washed in a series of three steps, completed between 1991 and 1994. In each of these washes the HLW tank was first filled with demineralized water, then treated with sodium hydroxide to keep uranium and plutonium in the precipitate. The resulting supernatant was finally processed through the ion-exchange system to remove the salts. This combination of the supernatant and sludge wash pretreatments (to remove sodium and sulfate salts) resulted in approximately a 90% overall reduction in the total amount of HLW borosilicate glass production required.

Once the pretreatments were completed, the Cs-137-laden ion-exchange media and the acidic THOREX wastes were transferred to the HLW tank and mixed with the existing PUREX sludge to form one homogeneous waste slurry to feed the Vitrification Facility (VF).

1.3 Checkout and Testing of the Vitrification Systems

Full-scale testing of the vitrification process was conducted from 1984 until 1989. This test program was referred to as the Functional and Checkout Testing of Systems, or FACTS Program. During FACTS testing, the WVDP successfully demonstrated the ability of the VF to produce high-quality glass on a production schedule. Approximately 150,000 kg of glass were produced and 37 FACTS tests were performed using nonradioactive isotopes in lieu of radioactive species to produce a waste glass as close as practical to the projected HLW glass. The testing demonstrated the WVDP waste glass qualification approach as well as process system, subsystem and component performance. The systems/subsystems tested included the: melter and canister turntable; melter off-gas cleanup and ventilation system (excluding oxides of nitrogen [NO_x] abatement components); and slurry feed preparation system.

Following the final FACTS run, the vitrification system, including the melter, was disassembled for examination of test components and conversion for radioactive service. Based on the successful FACTS Program, portions of the test facility (Melter Feed Hold Tank [MFHT], Concentrator Feed Makeup Tank [CFMT], Cold Chemical System [CCS]) were reassembled and reused.

In preparation for radioactive operation, a phased program of integrated testing and operations was carried out. Performance testing progressed from component and subsystem demonstration using water first, then test (nonradioactive) slurry to fully integrated system test runs known as integrated operations (IO). The IO runs culminated with government approval for radioactive operation in June 1996.

1.4 Vitrification Process Overview

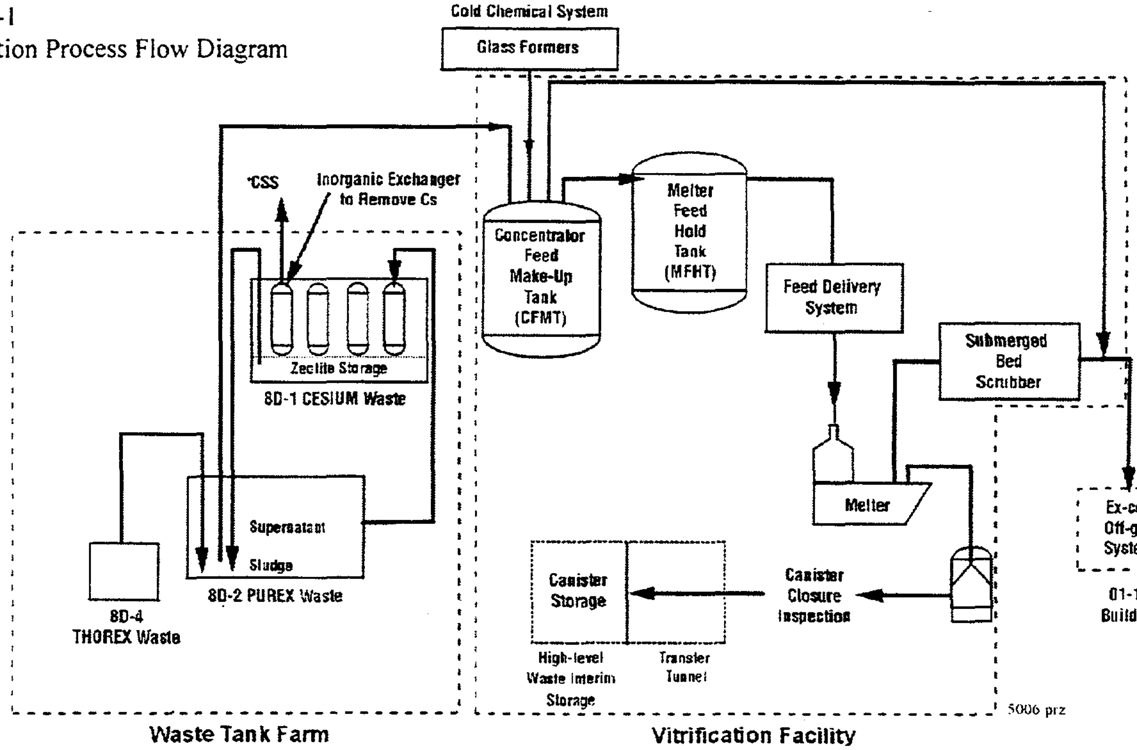
The goal of the vitrification process (see figure 1-1) is to convert the HLW from its initial sludge/liquid form into a borosilicate glass waste form contained within stainless steel canisters. The canisters can then be stored temporarily in the High-level Waste Interim Storage Facility (HLWISF) in the existing Main Plant.

The HLW is transferred from Waste Tank Farm (WTF) HLW Tank 8D-2 into the VF concentrator feed makeup tank (CFMT) where it is combined with a stream from the off-gas scrubbing submerged bed scrubber (SBS). CFMT samples are collected and the contents are concentrated, removing excess water. Meanwhile, samples are transferred to the Analytical Lab for chemical and radiochemical composition analysis. Based on this analysis, glass-forming chemicals are premixed in the Cold Chemical System (CCS). Once ready, the chemicals are transferred into the CFMT and mixed with the HLW from the WTF. The CFMT is again sampled to ensure the feed composition will result in target glass characteristics.

Following verification of the desired feed composition, the mixture is transferred into the melter feed hold tank (MFHT). The melter is fed continuously from the MFHT.

In the melter, water evaporates from the feed and the remaining solids calcine. The calcined wastes and glass-formers melt into the glass pool where they homogenize. The glass is periodically airlifted into a stainless steel canister. The canister is positioned under the melter by the canister turntable—a four-position, four-canister device that provides one position for filling, one position for canister removal and replacement, and two positions for filled canisters to cool.

Figure 1-1
Vitrification Process Flow Diagram



The cooled canister is removed from the turntable and moved to the weld station, where a stainless steel lid is welded to the canister. From the weld station, the canister is then moved to the canister decontamination station, where decontamination of the canister surface is accomplished by chemical etching. Welded and decontaminated canisters are moved from the Vitrification Process Cell to the HLWISF where they are placed into racks for interim storage.

During the glass-melting process, steam, volatile elements evaporating from the glass pool, and feed particles entrained in the process off-gas are vented to the off-gas treatment system. The first component of the system is the SBS, where off-gases are quenched and particulate is scrubbed through a submerged bed of ceramic spheres. After the SBS, the off-gas is drawn through a mist eliminator and then through a high-efficiency mist eliminator (HEME) to remove mist and fine particulate. It is then heated and passed through a high-efficiency particulate air (HEPA) filter to remove particulate. At this point, the off-gas is essentially free of radiological pollutants. It then flows, via an underground trench, into another building where a final stage of HEPA filtering is provided. Finally, oxides of nitrogen (NOx) are abated by catalytic reaction with ammonia prior to venting the off-gas to the environment through the Main Plant stack.

The primary process vessels are all maintained at relative vacuums by the vessel vent system. The vessel vent gas passes from a header through a condenser until it joins the off-gases prior to the HEME. The vessel vent system also provides a means to bypass the SBS in the event the melter off-gas line becomes plugged.

The primary process cell is maintained at a vacuum by a Heating, Ventilation, and Air Conditioning (HVAC) system used for contamination control. Any air leakage associated with the cell's shield walls will be into the cell, where it is exhausted through a series of HEPA filters.

A canister load-in facility is provided for introducing canisters into the processing facility. Canisters are inserted horizontally through a cylindrical shield door into the Equipment Decontamination Room (EDR). The canisters are then upended and placed on a transfer cart using a crane. The transfer cart transports them into the primary process cell, where they are moved into a canister storage rack for eventual loading into the turntable.

2.0 EQUIPMENT DESCRIPTION

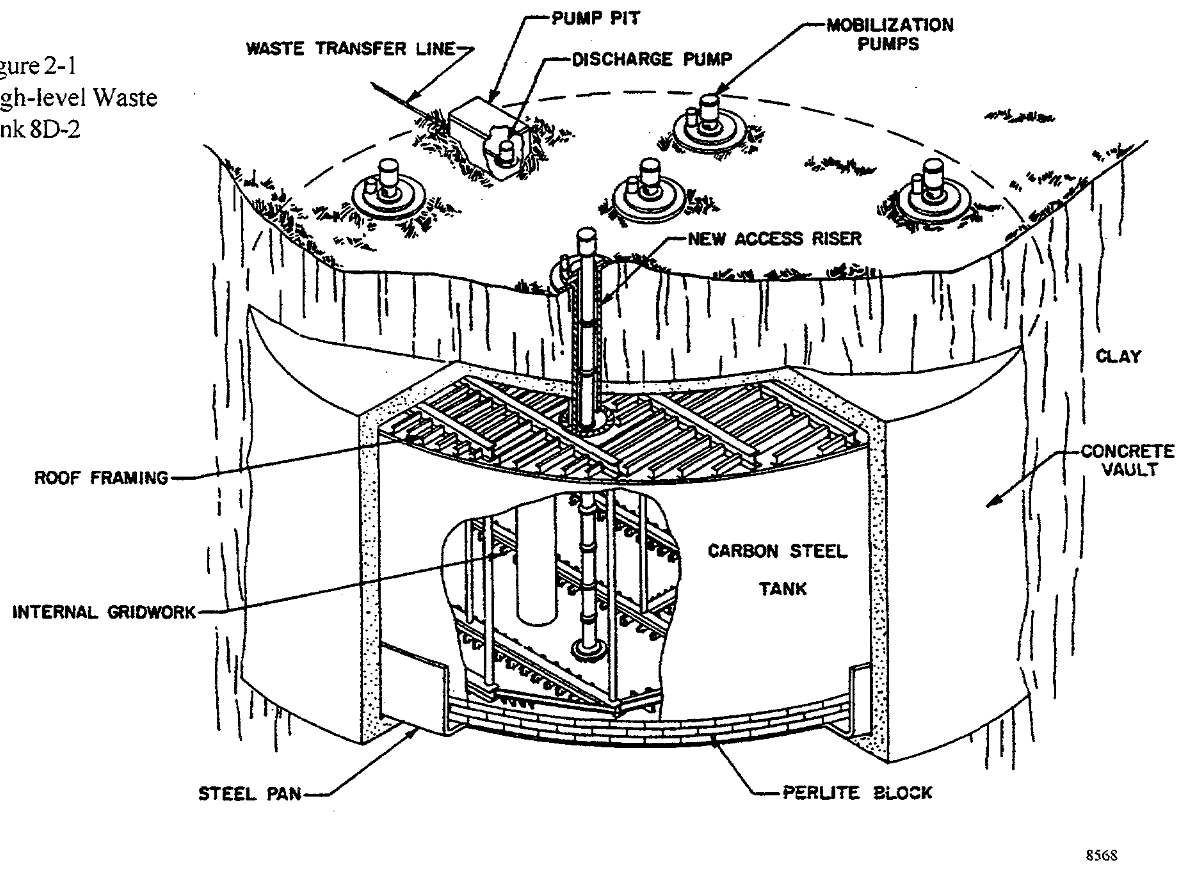
2.1 Sludge Mobilization and Waste Transfer System

The Sludge Mobilization and High-level Waste Transfer System (SMTS), is located in the WTF. Its primary functions are to resuspend the settled waste sludge, remove wastes from the tanks, and deliver HLW slurry to the VF for processing. The HLW transfer piping runs (double-walled) are housed in a common containment trench, connecting the valve/pump pits to the Vitrification Facility. The pits provide a means to remotely access valves, instruments, and mechanical jumpers for maintenance, line flushing, and future decontamination.

2.1.1 Waste Storage Tanks and Transfer Equipment

Tank 8D-2 (see figure 2-1) holds the combined HLW (PUREX waste, THOREX waste, and cesium-loaded zeolite) that feeds the vitrification process. Six sludge mobilization pumps are installed in Tank 8D-2. These pumps provide the mixing action to ensure waste feed homogeneity. They are deep-well, long-shafted, low-pressure, high-flow, centrifugal pumps that discharge below the complex internal gridwork on the bottom of the tank. Each pump is supported from a 15.2 m (50 ft) long, 360 mm (14 in.) diameter, pipe column that houses the pump drive shaft. The shaft is filled with water to lubricate the shaft bearings and provide radiation shielding. The column of water provides a static pressure on the shaft's lower seal to inhibit the tank contents from entering the pump column. Each pump has two tangential discharge nozzles that rotate continuously during operation. The pumps operate at a flow rate of roughly 2,270 liters per minute (600 gpm) out of each nozzle.

Figure 2-1
High-level Waste
Tank 8D-2



Tank 8D-2 is also equipped with a centrifugal, multistage, turbine-type, transfer pump. The pump consists of a series of pump bowls that house the impellers and a vertical column through which the pump shaft rises to the motor. The pump transfers waste slurry to the VF at a flow rate of roughly 3,800 liters per minute (100 gpm).

Tank 8D-1 houses the zeolite columns used to process the supernatant from Tank 8D-2. It contains 5 sludge mobilization pumps and a transfer pump similar to those in Tank 8D-2.

2.2 Primary Process System

The primary process system consists of the CFMT, MFHT, slurry-fed ceramic melter (SFCM), canister turntable (TT), and auxiliary equipment. The functions of the system include concentration of waste slurry, mixing of glass-forming chemicals with waste slurry to form melter feed slurry, delivery of melter feed slurry to the SFCM, conversion of melter feed slurry to molten glass, delivery of molten glass to stainless steel canisters, and canister positioning beneath the SFCM.

2.2.1 Concentrator Feed Makeup Tank

The CFMT accepts HLW slurry from the WTF, solution from the SBS, and glass-forming chemicals from the CCS. The CFMT evaporates excess water from the slurry to achieve the desired waste concentration. After glass-forming chemicals are added to the concentrated waste, the CFMT is sampled to ensure acceptability as melter feed slurry before transferring the contents to the MFHT.

The CFMT, shown in figure 2-2, is a large cylindrical vessel, approximately 4.0 m (13 ft) in height, with a total capacity of 23,651 L (6,249 gal.). It has a maximum operating volume is 21,000 L (5,548 gal.) and a minimum volume of 839 L (222 gal.) corresponding to the point where the transfer jet stalls due to lack of suction.

All nonreplaceable vessel components that are wetted by waste slurry are made of Hastelloy™ C-22 to resist corrosion in a boiling environment. Components that are not wetted, as well as all replaceable components, are made of Type 304L stainless steel. The exterior of the tank is partially covered by two half-pipe heating/cooling coils covered with a fiber-glass blanket and stainless steel sheet.

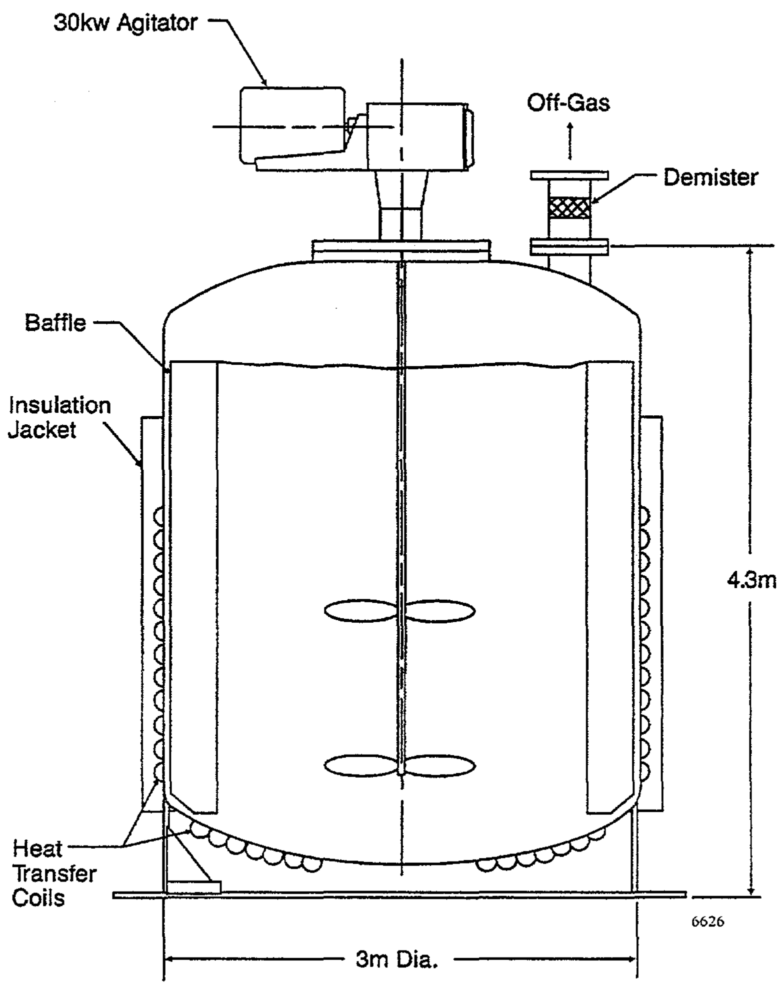


Figure 2-2. Concentrator Feed Makeup Tank

The CFMT is equipped with interior mixing baffles and an agitator driven at 188 rpm by a 30 kW (40 hp), single- speed, 1,800 rpm, 460-volt, 3-phase motor with a gearbox. The agitator has two 965 mm (3 ft, 2 in.) axial-flow impellers (three blades each) made of Stellited Hastelloy™ for erosion resistance.

Three separate, three-probe, bubbler assemblies are provided to measure level, density, and pressure within the tank. Two jets are provided to transfer slurry from the CFMT to the MFHT or to the WTF. The jets are driven by 690 kPa (100 psig) steam and have a nominal capacity of 280 l/min. (75 gpm).

2.2.2 Melter Feed Hold Tank

The MFHT accepts melter feed from the CFMT, mixes the slurry to maintain homogeneity, and delivers it to the SFCM.

The MFHT, shown in figure 2-3, is a large cylindrical vessel, approximately 3.05 m in height, with a total capacity of 20,906 L (5,523 gal.). It has a maximum operating volume of 18,900 L (4,993 gal.) and a minimum operating volume of 4,000 L (1,057 gal.) corresponding to the point where adequate mixing cannot be maintained.

All vessel components are made of Type 304L stainless steel. The exterior of the tank is partially covered by a cooling jacket with internal baffles that cause the cooling water to spiral within a rectangular channel.

The MFHT is equipped with interior mixing baffles and an agitator driven at 155 rpm by a 11 kW (15 hp), single-speed, 1,800 rpm, 460-volt, 3-phase motor with a gearbox. The agitator has two 914 mm (3 ft) axial-flow impellers (three blades each) made of Stellited Hastelloy™ for erosion resistance.

Three separate, three-probe, bubbler assemblies are provided to measure level, density, and pressure within the tank. Two jets are provided to transfer slurry from the MFHT to the CFMT or to the WTF (via the waste header). The jets are driven by 690 kPa (100 psig) steam and have nominal capacities of 280 L/min. (75 gpm) and 95 L/min. (25 gpm), respectively.

The melter feed pump is an air displacement slurry (ADS) pump and delivers feed slurry to the melter at a controlled rate between 20 L/hr (5 gph) and 150 L/hr (gph). The slurry inlet is located near the bottom of the tank.

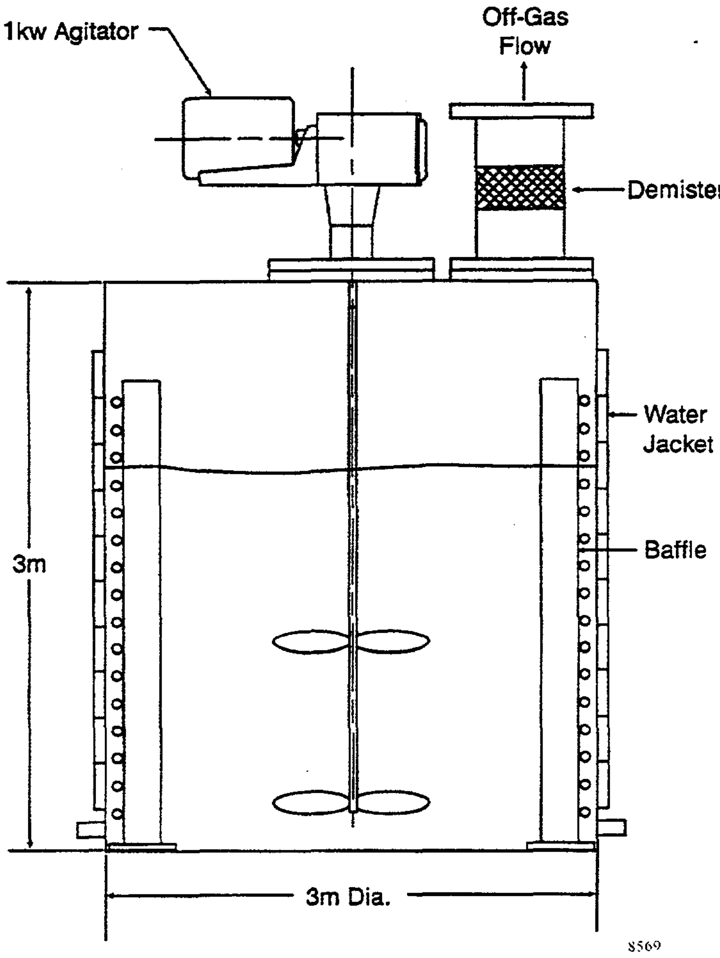


Figure 2-3. Melter Feed Hold Tank

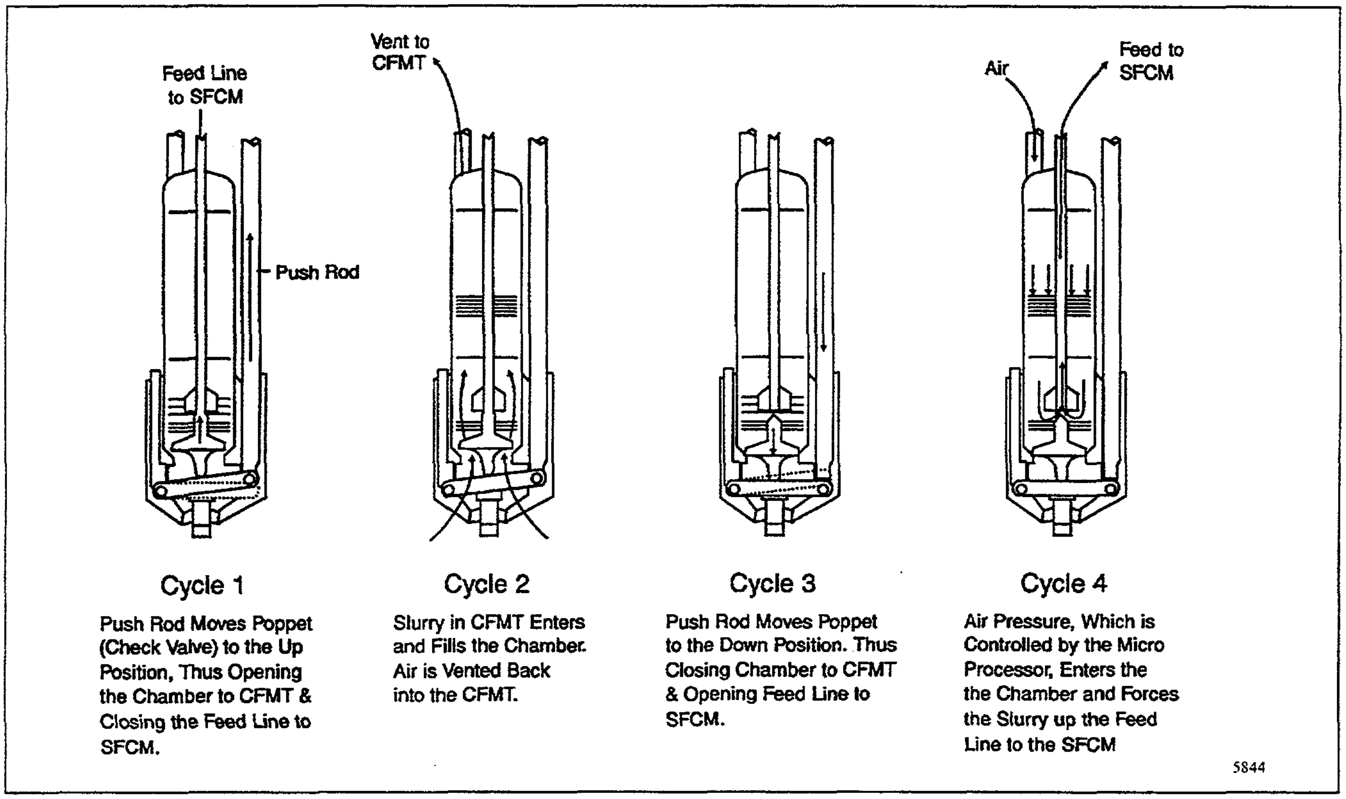


Figure 2-4. Melter Feed ADS Pump Operating Cycles

Valve actuation is accomplished through a programmed series of steps as shown in figure 2-4. At the start of the cycle, the bottom of the pump chamber is opened to allow the flow of slurry into the 1.41 liter (0.37 gal.) chamber. After the slurry has filled the chamber, but before the solids can significantly settle, the poppet drops to seal the lower seat and air is added to the chamber, pushing slurry out of the pump to the SFCM. The pump also has provisions for flushing water through the pump chamber to either the melter or the MFHT interior.

2.2.3 Slurry-fed Ceramic Melter

The joule-heated SFCM dries and melts the slurry fed to it, converts it into borosilicate glass, and delivers the molten borosilicate glass into canisters for solidification.

The SFCM, shown in figure 2-5, is a water-jacketed, stainless steel box with an interior comprised of various refractory materials in contact with molten glass and separate chambers for glass melting and glass pouring.

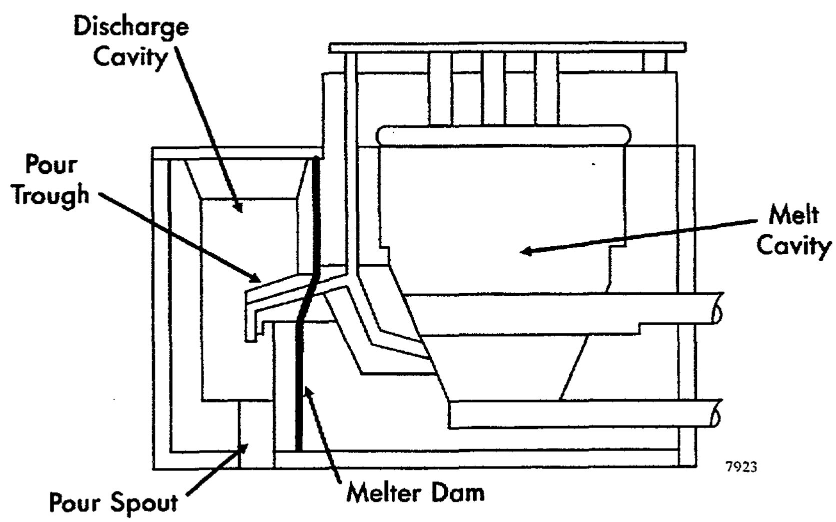


Figure 2-5. Slurry-fed Ceramic Melter

The overall dimensions of the melter are approximately 3.05 m wide by 3.05 m high by 3.05 m in depth (10 ft x 10 ft x 10 ft). The basic shape of the melter cavity is an inverted truncated rectangular pyramid. The walls of the melter cavity slope toward the bottom. There are two discharge chambers (one is an installed spare) equipped with pour troughs. These are separated from the main melter cavity by a refractory wall and air-cooled Inconel™ plates, called dams, to prevent glass migration through the wall.

The joule heating system uses three electrode plates in the melter cavity in contact with the molten glass. Two of the electrodes are located in the sides of the vessel. The third electrode serves as the floor of the cavity. Electricity is conducted through the molten glass through alternating pairs of electrodes and controlled to maintain a nominal glass temperature of 1,150° C (2,100° F). Electrode extensions penetrate the concrete shield wall. Air cooling is provided for the electrodes, as well as for the electrode shrouds for the wall penetration. The discharge chamber temperature is heated with silicon carbide radiant heaters to ensure the glass remains molten as it is poured into the canister below.

A bubbler assembly provides melter glass level and melter pressure. Arrangements of thermocouples provide temperature indications for the molten glass pool, melter plenum, melter refractory, and the discharge chamber.

The melter is maintained at a nominal vacuum of - 5 in. w.c. Melter off-gases are exhausted to the off-gas system via the SBS. The gas generation rate (derived from feed conversion) within the melter fluctuates significantly and the feed pump continuously pulses air into the melter. In order to adequately maintain the desired melter vacuum, a pressure control loop is provided to regulate air injection to the melter. The off-gas jumper, which connects the melter to the SBS, has an film cooler at its inlet. The film cooler consists of a louvered insert that supplies a cool air flow along the inner surface of the pipe. The film cooler cleaner, a pneumatically operated Inconel™ brush, is mounted atop the film cooler and is operated intermittently to keep the film cooler clear of sticky deposits.

2.2.4 Canister Turntable

The canister turntable (TT), shown in figure 2-6, provides for: in-loading and out-loading of canisters, positioning of canisters under the melter pour spout, a sealed passageway for the molten glass to fall from the pour spout to the canister, and a means to monitor the amount of glass being transferred from the melter to the canister.

The TT structure, mainly Type 304L stainless steel, consists of a stationary frame and a rotating frame. The rotating frame has positions for four canisters to move in a carousel-like fashion on a 1.69 m (66-1/2 in.) diameter circle. The carousel is driven by a 2.2 kW (3 hp) electrical gear motor.

The upper region of the TT is sealed to the melter discharge section to minimize cell contamination from radionuclides evaporating from the glass pour stream. The seal is accomplished by forcing two bellows on the stationary structure to expand up until the bellows seal plates contact the discharge section

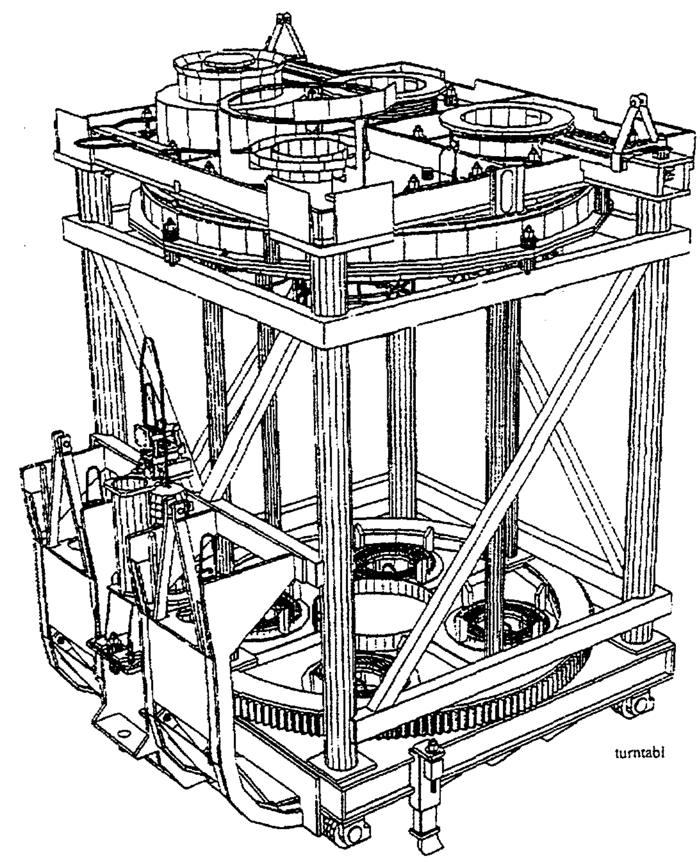


Figure 2-6. Canister Turntable

seal plates. A load-in/load-out port and its associated seals allow for loading canisters in and out of the TT. The port cover must be remotely removed and reinstalled each time a canister is loaded or removed.

Load cell platforms are provided to continuously monitor canister weight. The glass level within the canister is also visually monitored with an infrared level detection system (ILDS). A shielded camera scans the canister and detects an increased surface temperature as the thermally hot glass accumulates within the canister. The glass pour stream is also visually monitored by observing the gap between the bottom of the discharge section and the top of the canister using an air-cooled periscope assembly.

The canisters themselves are made from Type 304L stainless steel. Each canister, shown in figure 2-7, is a right cylinder, 610 mm (2 ft) in diameter, 3 m (10 ft) tall, with a large-mouth opening and a reverse-dished bottom head. They have a minimum wall thickness of 3.4 mm (0.13 in.). A collar around the opening provides a means for handling the canister with a grapple suspended from a crane. The flanged face around the opening provides the surface for welding a lid to the top to seal the canister.

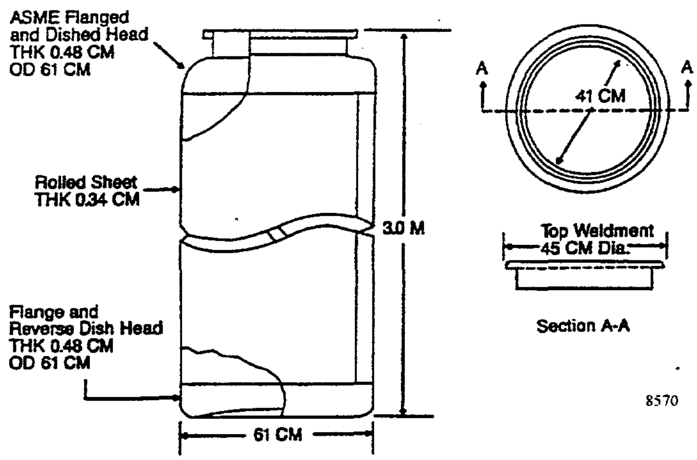


Figure 2-7. Canister Turntable

2.3 Slurry Sampling System

The slurry sampling system (SSS) is an integral part of feed preparation. It provides the means to sample the HLW from the CFMT (for determination of the chemical additions needed for feed make-up) and also to sample the feed slurry in the CFMT or the MFHT (for confirmation of feed composition following chemical additions). Slurry is circulated from the desired tank to a sampling station using an ADS pump. At the sampling station, operators use remote manipulators to draw the samples with in-line, closed-loop liquid samplers.

2.3.1 Slurry Sampling Station

The slurry sampling station is mounted to the cell wall in front of a shield window. The station holds two sampler modules. The sampler modules consist of an in-line sampler, a flow meter, and flow control valves. The station also holds an ultrasonic cleaner bath for cleaning sample vials.

The sample vials are manufactured from glass, with plastic caps having butyl septums to accept the needles of the samplers. Each vial has a volume of about 13 mL (15/32 fluid oz.).

2.4 Canister Lid Welding

The canister welding system remotely welds stainless steel covers to canister flanges after the filled canisters have been removed from the turntable. Prior to welding, glass fill height of the canister is measured and glass shards from the surface of the glass are collected for archiving and/or subsequent sample analysis.

2.4.1 Weld Station

The weld station (figure 2-8) located against the east wall of the cell, consists of a stainless steel work bench, weld head, hoist, flange conditioning tool, lid magazine, vacuum lid lifter, cover gas supply, and glass shard sampling equipment. The work bench structure measures approximately 3.96 m long by 1.22 m wide by 3.66 m high (13 ft x 4 ft x 12 ft). It has two canister-holding com-partments; one for welding, the other for backup canister storage. Primary lids are held in a lid magazine capable of holding 15 lids. The weld head assembly consists of a guide track and support ring about 686 mm (27 in.) in diameter,

a carriage drive unit, a torch, and a cable assembly. All weld head operations are managed through a welder control console located outside the cell wall.

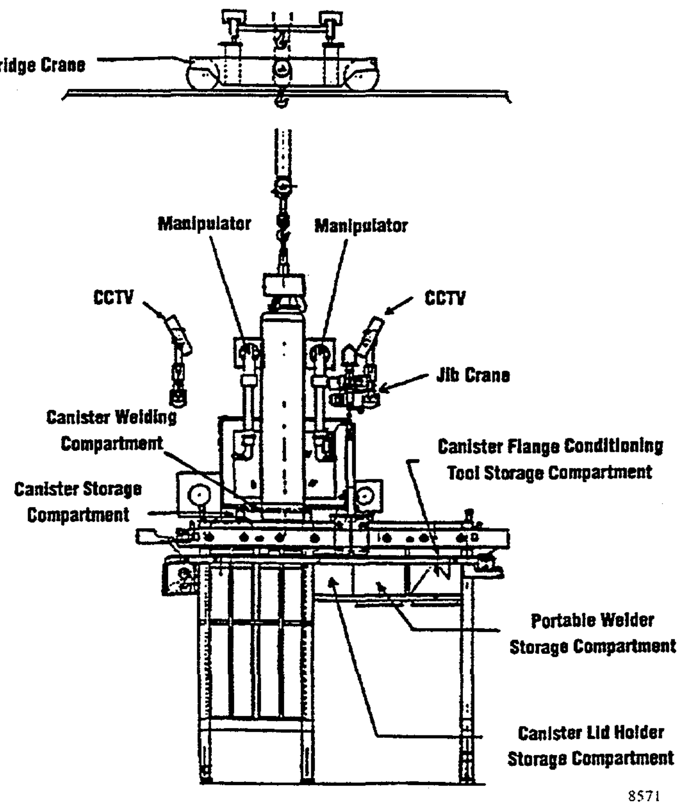


Figure 2-8. Canister Turntable

2.4.2 Shard Sampling

The shard sampler, basically a vacuum pickup assembly, is a stainless steel pipe with an air-operated eductor mounted on one end and a nozzle assembly at the other end. The replaceable nozzle assembly has an integral screen to capture the glass fragments. The assembly also doubles as a glass height indicator. The shard sampler has provisions for being handled with manipulators or with the overhead crane.

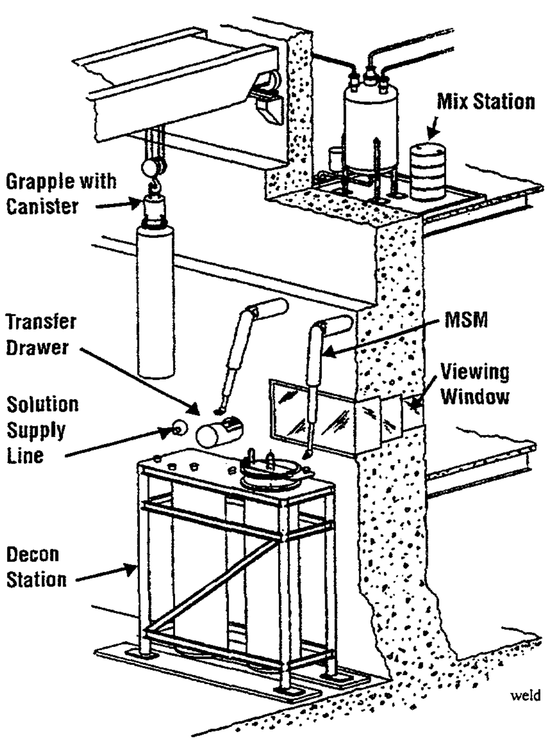


Figure 2-9. Canister Decontamination Station

2.5 Canister Decontamination System

At the decontamination station, filled and capped canisters are submerged in a nitric acid-cerium (+4) solution to etch off a thin layer of the canister's exterior (nominally 10 microns) that may contain submicron particles of fixed contaminants in the oxidized layer. The system also reintroduces the decontamination solution back into the vitrification process.

2.5.1 Decontamination Stations

The decontamination system, shown in figure 2-9, consists of an out-of-cell station for mixing chemicals and an in-cell decontamination station.

The in-cell station, located along the east wall of the cell, includes a stainless steel support structure and two tanks; one for canister decontamination and the other for neutralization (deactivation) of the used decontamination solution. The decontamination tank is made of titanium to resist attack from the decontamination solution. The tank is roughly 760 mm (30 in.) in diameter with a capacity of 1,550 L (410 gal.). The tank equipment includes a sparge ring for agitation of the solution, a level probe, heating and cooling coils (as the decontamination pro-cess takes place at 65 °C), a thermowell to support temperature control, a spray ring for removal of solution residue from the decontaminated canister, and a jet to transfer the used solution to the neutralizer tank.

The neutralizer tank, also made of titanium, is 760 mm (30 in.) in diameter, and has a capacity of 1,460 L (385 gal.). This tank includes a connection to the vent header, a sample nozzle, a level probe, a sparge ring, and a jet to transfer (deactivated) solution to the SBS.

2.6 Waste Header

The waste header, shown in figure 2-10, accepts waste/overflow liquids and slurries from the CFMT, the MFHT, the SBS, the neutralizer tank, and any wastes that spill or drain to one of the in-cell sumps. The waste header directs these liquids to the WTF.

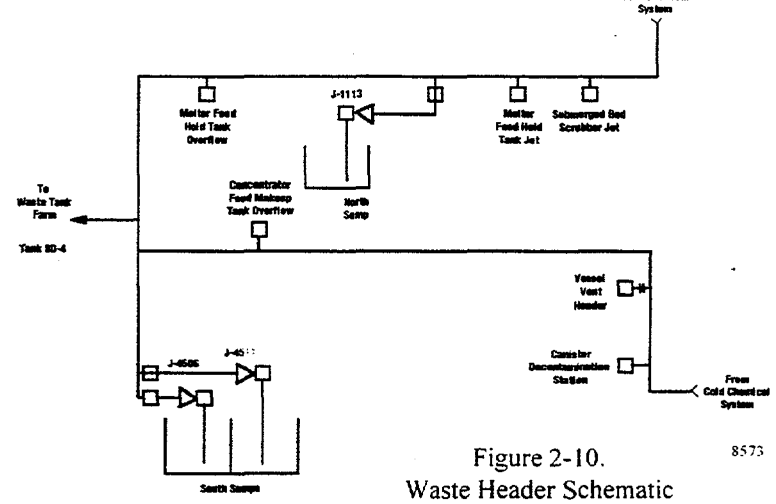


Figure 2-10. Waste Header Schematic

2.6.1 Waste Header Piping and Sumps

The waste header itself consists of roughly 58 m (190 ft) of 76 mm (3 in.) stainless steel pipe. It is sized to transfer waste slurry by gravity flow to the WTF at a rate of 95 L/min. (25 gpm).

There are two sumps in the Vitrification Cell. The north sump, which collects liquids and slurries from with the cell pit, has a capacity of about 20 L (5 gal.). The south sump is divided into two separate compartments, each having a capacity of 2,380 L (628 gal.). The sumps are equipped with level probes and jets to transfer the sump contents to the waste header.

2.7 Vessel Ventilation System

The vessel ventilation system, shown in figure 2-11, maintains a slight vacuum, about 1 kPa (5.0 in. w.c.), on the CFMT, MFHT, waste header, and canister decontamination station tanks by drawing gases and vapors from these process components and directing them into the off-gas system via the vessel ventilation condenser. The condenser condenses steam generated from CFMT boiling evolutions and returns the condensate to the WTF.

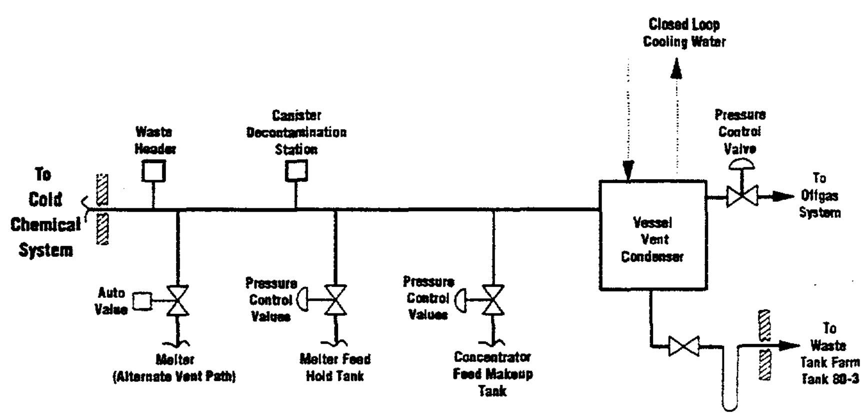


Figure 2-11. Vessel Ventilation System Schematic

The vessel ventilation system is also connected to the melter plenum (through a normally closed control valve) to provide an alternate vent path for the melter should the off-gas jumper become plugged.

2.7.1 Vessel Ventilation Header

The header is made from 150 mm (6 in.) stainless steel pipe. Six permanently installed expansion joints accommodate thermal expansion and contraction of the header. Pressure within the header is maintained by a control loop that regulates an air-operated butterfly valve which separates the header from the in-cell, off-gas system. The header also has provisions for chemical flushing.

2.7.2 Vessel Ventilation Condenser

The condenser is a vertical, 3 GJ/hr (3 x 10^6 BTU/hr) shell and U-tube heat exchanger. The condenser tubes are provided with cooling water at 380 L/min. (100 gpm). The condenser has instrumentation for differential pressure, temperature, and level. Condensate is directed, through a calibrated weir, to the WTF via a loop seal.

2.8 In-cell, Off-gas Treatment System

The in-cell, off-gas system, shown in figure 2-12, includes all vessels and equipment required to collect, quench, dry, and filter gases and vapors from the melter and other process vessels within the cell. Redundant blowers in the ex-cell, off-gas system provide the motive force for off-gas flow within the cell. Major components of the system include the SBS, the mist eliminator, the high-efficiency mist eliminators (HEMEs), filter preheaters, and prefilters.

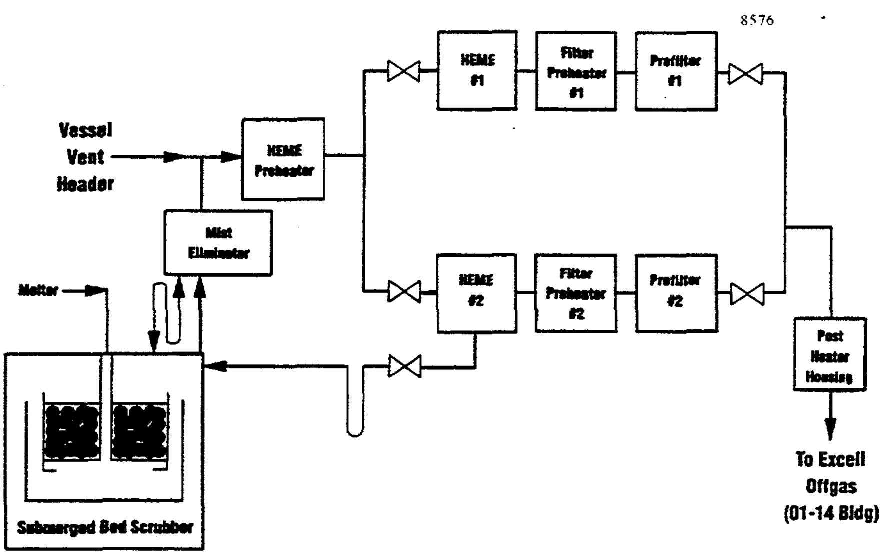


Figure 2-12. In-cell, Off-gas System Schematic

2.8.1 Submerged Bed Scrubber

The SBS provides quenching and first-stage scrubbing of the melter off-gases, cooling and condensation of melter vapor emissions, and interim storage of condensed fluids and used canister decontamination solutions.

The SBS, shown in figure 2-13, consists of two concentric right cylindrical vessels made from Hastelloy C-22™. This material was selected to resist pitting and crevice attack from mercury that may appear as vapor arriving from the melter and accumulating as liquid. The inner vessel (scrub section) contains the scrubbing bed which is 1.2 m (4 ft) tall, 910 mm (3 ft) in diameter and holds 9.5 mm (3/8 in.) ceramic spheres. Off-gases are introduced through a 250 mm (10 in.) diameter pipe. The outer vessel (receiver section) is 1.64 m (5 ft, 4 in.) tall by 1.83 m (7 ft) in diameter with a capacity of 3,330 L (880 gal.). The vessel's bottom is dish-shaped to facilitate solids collection and evacuation by jet transfer.

The SBS has bubbler assemblies for both the scrub and receiver sections, cooling coils for both sections, thermocouples, and a sampling port. Three jets are provided; one to transfer from the receiver section to the scrub section, a second to transfer from the scrub section to the CFMT, and a third to transfer from the receiver section to the WTF via the waste header.

In order to maintain solids in suspension, liquid is withdrawn from the receiver section and re-injected through nozzles near the bottoms of both vessels to scour the bottoms and create a swirling motion. The water is pumped with a 150 L/min. (40 gpm), self-priming, centrifugal pump. Continuous pump operation also serves to maintain the scrub section filled at all times.

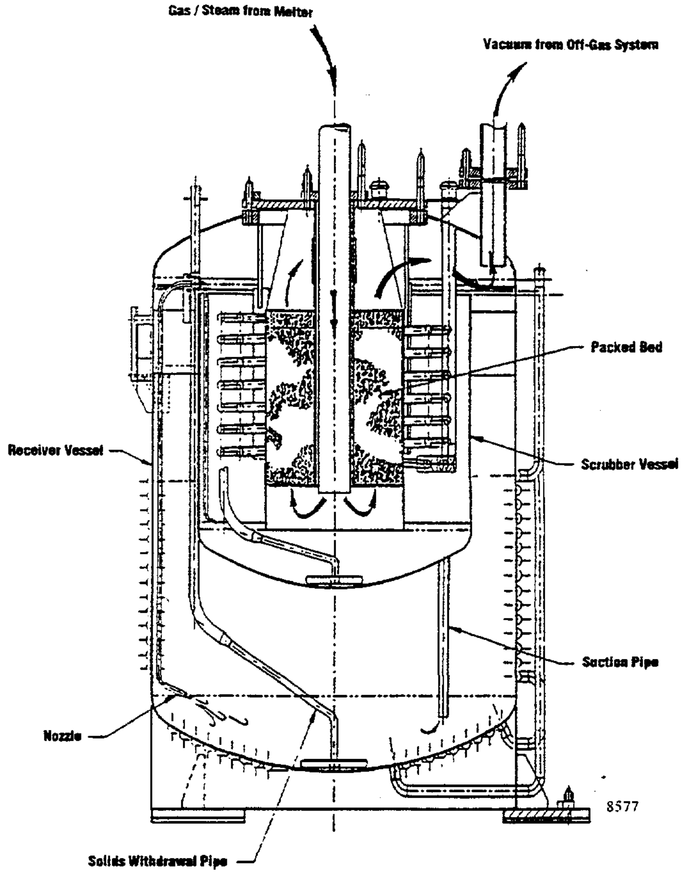


Figure 2-13. Submerged Bed Scrubber

2.8.2 Mist Eliminator and High Efficiency Mist Eliminators

The mist eliminator pretreats the off-gas exiting the SBS to prevent excessive liquid loading at the high-efficiency mist eliminators (HEMEs), located downstream. The mist eliminator is basically a series of four stainless steel mesh pads mounted within a 460 mm (18 in.) stainless steel housing. A 25 mm (1 in.) flexible hose returns accumulated liquid back to the SBS.

Two HEMEs are installed; one in each of two parallel, redundant, off-gas trains. The vessel ventilation gases are combined with the off-gas stream prior to entering the on-line HEME. The HEME collects and coalesces entrained liquid droplets to prevent moisture buildup on the downstream prefilter assembly, while also removing additional submicron particulate from the off-gas stream.

The HEME is a cylindrical, stainless steel vessel 1.1 m (3 ft, 6 in.) in diameter and 4.1 m (13 ft, 4 in.) tall. The internal pad is a cylindrical, wound-glass fiber element. The pad, which can be remotely replaced, is enclosed by a woven stainless steel screen. The HEME is equipped with an internal spray lance to spray the inside surface of the pad. A drain line directs any removed liquid back to the SBS via a loop seal.

2.8.3 Filter Preheaters and Prefilters

The off-gases from the HEME pass through an electric heater before entering a prefilter housing. The heater raises the off-gas temperature to about 85° C to assure that the prefilter elements do not become wetted. The prefilters are used to retain as much radioactive particulate in the vitrification cell as possible in order to minimize radiation exposure.

There are two preheaters, one in each off-gas train. The preheater element is a 50 kW, electrical-resistance heating element bundle operated with 480-volt, 3-phase electrical energy, and is sheathed in Incoloy^{TM} for high-temperature corrosion resistance.

There are two prefilter assemblies, one in each off-gas train. Each assembly holds two high-efficiency air particulate (HEPA) filters, which are 99.97 percent efficient for removing particles larger than 0.3 microns. The assemblies are changed remotely by removing and replacing the entire prefilter housing assembly.

2.9 Ex-cell, Off-gas Treatment System

The prefiltered off-gas from the Vitrification Cell is directed through an insulated duct to another building for additional treatment. The ex-cell, off-gas treatment system, shown in figure 2-14, supplies the motive force to maintain the in-cell vitrification process equipment at a slight vacuum relative to ambient cell pressure for contamination control. It also provides atmospheric protection by destroying acidic oxides of nitrogen (NO_x) and removing radioactive particulate that escapes the in-cell, off-gas treatment system.

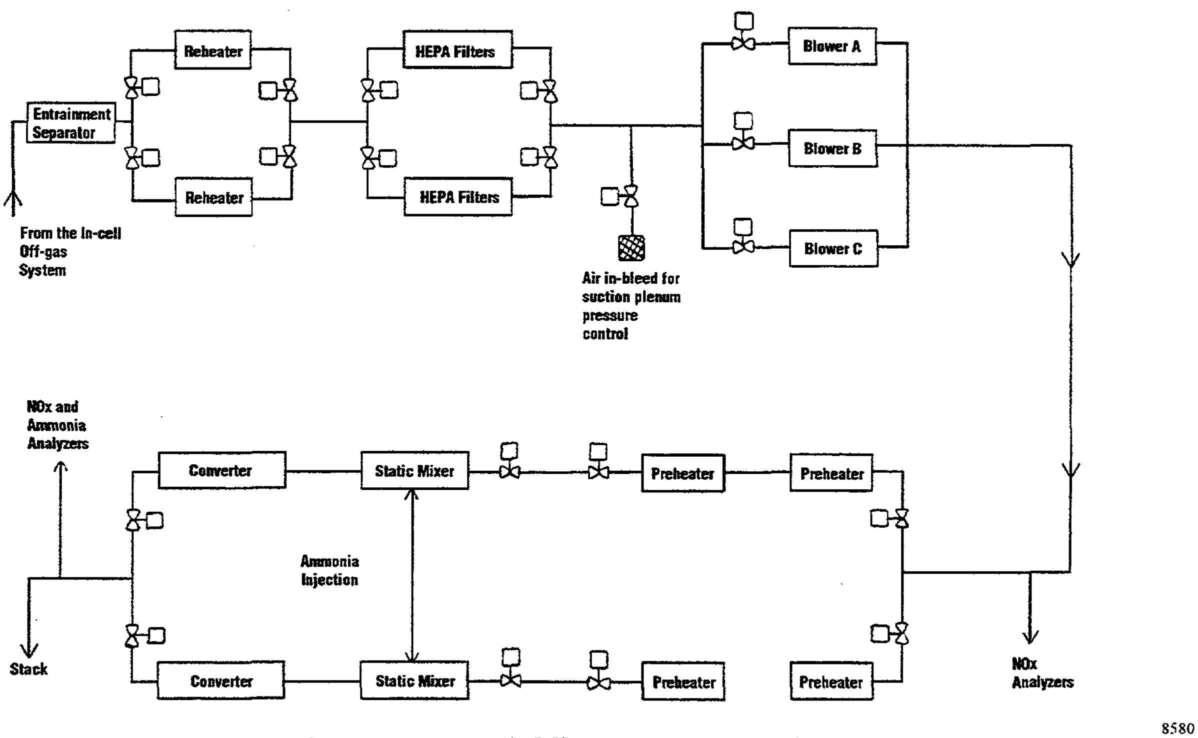


Figure 2-14. Ex-cell, Off-gas System Schematic

2.9.1 Reheaters

There are two redundant, off-gas reheaters connected in parallel. The off-gas arriving from the Vitrification Cell may have cooled to below its dew point. The reheater is used to elevate the off-gas temperature to a nominal 85° C (185° F) before entering the HEPA filters. The reheater element is a 60 kW, electrical-resistance immersion heating element bundle operated with 480-volt, 3-phase, electrical energy and is sheathed in Incoloy 800™ for high-temperature corrosion resistance.

2.9.2 Final High-efficiency Particulate Air Filters

Two redundant HEPA filter trains are installed in parallel. Both parallel HEPA filter trains, consisting of two HEPA filter elements in series, are contained in a single housing. The filter elements are held in place by air piston actuated, remotely operated, clamping devices. Each filter element has a bag-out port located behind a 150 mm (6 in.) thick carbon steel shield door. The HEPA filter elements are each 99.97 percent efficient for removing particles larger than 0.3 microns. The integrity of the filter elements, and the seals between the elements and the housing, is verified by in-place testing.

2.9.3 Blowers

Following filtration, the off-gases pass through one of three redundant blowers. One of the three blowers operates continuously, while the others provide reliable, full- capacity, backup service. The blowers are rotary, positive displacement, lobe-style blowers sized for 42.5 m^3/min. (1,500 acfm) flow at the blower inlet. They are controlled by adjustable frequency drives designed to operate at only two set points, and are normally operated at a speed to motivate about 27 m^3/min (950 acfm). Control of the blower suction vacuum to the designated set point is accomplished by automatic modulation of air in-bleed to the suction line.

The motors directly coupled to the blowers are 56 kW (75 hp), totally enclosed, fan-cooled, variable speed, 460-volt, 3-phase, electric induction motors.

2.9.4 NOx Destruction/Abatement

After the blower, the off-gases pass through the NO_x abatement equipment. The function of this equipment is to destroy the acidic oxides of nitrogen: NO and NO_2. Abatement is accomplished by selective catalytic reduction of the NO_x gases (using ammonia as the reactant) to produce nitrogen, oxygen, and water vapor. The equipment includes redundant preheaters for increasing the off-gas temperature to promote the desired reaction, redundant catalytic converters to accelerate the reaction, an ammonia supply system, and analyzers to monitor NO_x and ammonia levels.

Two redundant preheater trains, consisting of two electric heater assemblies arranged in series, raise the off-gas temperature to a nominal 320° C (610° F). Each heating element bundle is rated at 101 kW for 480-volt, 3-phase, electrical energy, and consists of 48, Incoloy 800™ sheathed elements.

The catalytic converter vessels are right cylinders, made from 6 mm (1/4 in.) Type 321 stainless steel, with the inlet at the conical top and the outlet at the conical bottom. The assembly has an overall height of 4.29 m (14 ft, 1 in.) and a cylindrical section diameter of 1.02 m (3 ft, 4 in.). Proprietary catalysts are used. The catalyst beds are 1.12 m (3 ft, 8 in.) deep. The primary bed consists of 890 mm (35 in.) of 6 mm (1/4 in.) catalytic Raschig rings. The polishing bed is located beneath the primary bed and consists of 230 mm (9 in.) of 1.6 mm (1/16 in.) catalyst extrudate.

The ammonia storage tank is a carbon steel right cylinder, 5.2 m (17 ft) tall, 1.07 m (3 ft, 6 in.) in diameter, with a maximum working capacity of 3,800 L (1,000 gal.). The tank is located out-of-doors so that any leakage can harmlessly disperse. There are two, redundant, 18 kW, 480-volt, 3-phase, electric immersions vaporizers. The liquid ammonia is fed to the vaporizers from the bottom of the tank and the ammonia vapor is routed to the upper portion of the tank. The vaporized ammonia is fed to the off-gas stream via one of two redundant, pressure-reducing, flow-control trains. The controllers modulate the ammonia flow based upon continuous NO_x analyses in the off-gases immediately upstream from the converters to ensure a proper molar ratio of the reactants.

Four analyzers are used to monitor NO_x and ammonia levels. One on-line, infrared analyzer is used to sense the amount of NO_x approaching the converters, while two infrared analyzers monitor NO_x and ammonia levels downstream of the converters. One spare chemiluminescent analyzer is available to sample for NO_x either upstream or downstream of the converters.

2.10 Canister Movement and Remote Handling

Several components work in conjunction to lift and transfer empty or filled canisters through the facility. Canister movement is accomplished by using cranes, grapples, and a radio-controlled transfer cart. Empty canisters are transferred from the Load-in Facility to the Vitrification Cell. Filled, capped, and decontaminated canisters are transferred from the Vitrification Cell to the High-level Waste Interim Storage Facility (HLWISF). See figure 2-15, for the facility layout. Cranes, an impact wrench, the transfer cart, various tools and fixtures, and remote manipulators are used to perform several remote handling and maintenance functions including; handling of samples, operation of in-cell manual valves, replacement of consumables (filters, thermowells/thermocouples, etc.), and removal and replacement of mechanical and electrical jumpers. In-cell piping, valves, instrumentation, and electrical components are incorporated into crane-removable jumpers.

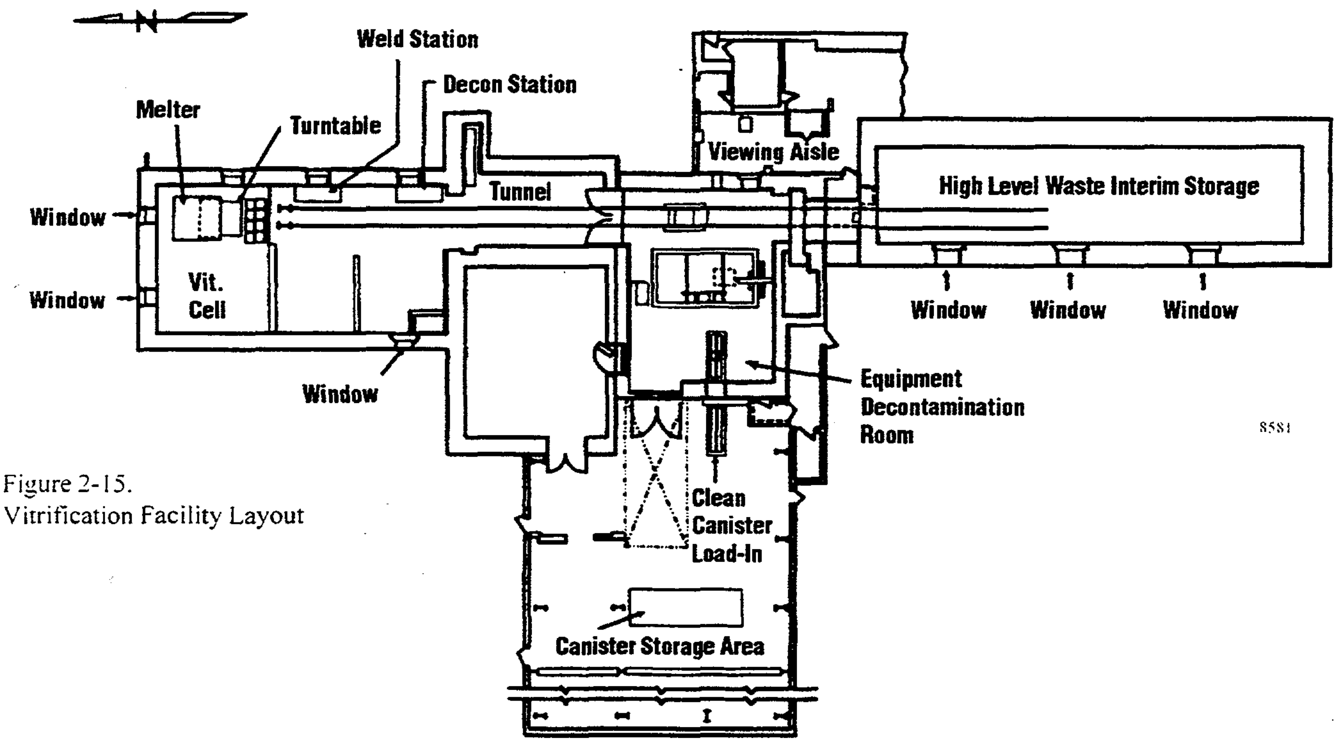


Figure 2-15.
Vitrification Facility Layout

2.10.1 Cranes

The Vitrification Cell process crane is a twin-hoist trolley, mounted on a bridge. The bridge span is 11.05 m (36 ft, 3 in.) and the trolley span is 1.37 m (4 ft, 6 in.). The twin 4.1 Mg (4.5 ton) hoists are mounted 810 mm (2 ft, 8 in.) from each other on a turntable. The turntable enables the hoists to rotate almost 360 degrees, which allows the hoists to reach closer to the cell walls than would be possible with only a single hoist. All motions on the crane are two speed and are relatively slow compared to nonremote cranes in order to reduce the possibility of lifting mishaps.

A back-up crane is also provided for the Vitrification Cell, which has a bridge identical to the process crane. The hoist/trolley on the back-up bridge has a 22.7 Mg (25 ton) capacity. This capacity is only required for major equipment change-outs or final decommissioning. This crane is normally stored in the Crane Maintenance Room (CMR) on the same runway as the process crane.

The HLWISF contains a 14.5 Mg (16 ton) capacity crane that is used to remove filled canisters from the transfer cart and place them into interim storage racks. This crane is equipped with a load-lowering device to lower a canister in the event of a total crane cable reel failure or hoist motor/mechanical failure.

The Equipment Decontamination Room (EDR) contains a 18.2 Mg (20 ton) capacity crane that is used to load empty canisters onto the transfer cart. Empty canisters are loaded into the EDR horizontally through a shielded port into an upending device.

2.10.2 Transfer Cart

A battery-powered, radio-controlled transfer cart is used to move empty canisters from the EDR to the Vitrification Cell and also move filled canisters from the Vitrification Cell to the HLWISF on a set of rails. The cart is stored at a battery charging station located in a low radiation area in the EDR.

The cart has four completely independent drive trains, any of which is sufficient to propel the cart. The cart travels at approximately 15 feet per minute and is designed to move a load of four, 100 percent filled canisters. In the event of a total cart failure, a tethered cart is available in the EDR for retrieving the failed cart.

2.10.3 Shield Doors

There are four doors that separate the Vitrification Facility, the transfer tunnel, the EDR, the HLWISF, and the Crane Maintenance Room. The doors along the transfer cart rails (between the Vitrification Cell and the HLWISF) are interlocked with the transfer cart control system software to ensure that the doors and the cart are not operated simultaneously. The doors are further interlocked to allow only one door to be open at a time during normal operation.

A 330 mm (13 in.) thick steel door is located between the Vitrification Cell and the transfer tunnel. The door opens horizontally, driven by a ball screw, at 0.43 meters per minute (1.4 feet per minute). A 51 mm (2 in.) thick steel, twin leaf ventilation control door is located between the transfer tunnel and the EDR. This door swings open, driven by two linear actuators, in approximately 2.5 minutes. The third door along the transfer cart path is a 1.2 meter (4 ft) thick concrete-filled door. This door opens horizontally, driven by a ball screw, at 0.6 meters per minute (2 feet per minute).

An additional vertical lift door is located between the Vitrification Cell and the crane maintenance room (CMR). This 0.23 meter (9 in.) thick steel door opens vertically, lifted by twin 52-ton hoists. This door allows for contact maintenance to be accomplished on the Vitrification Cell cranes.

2.10.4 Canister Grapple

The canister grapple is suspended from the process crane clevis and is actuated by raising and lowering a weighted portion of the assembly to drive a rotating ratchet assembly.

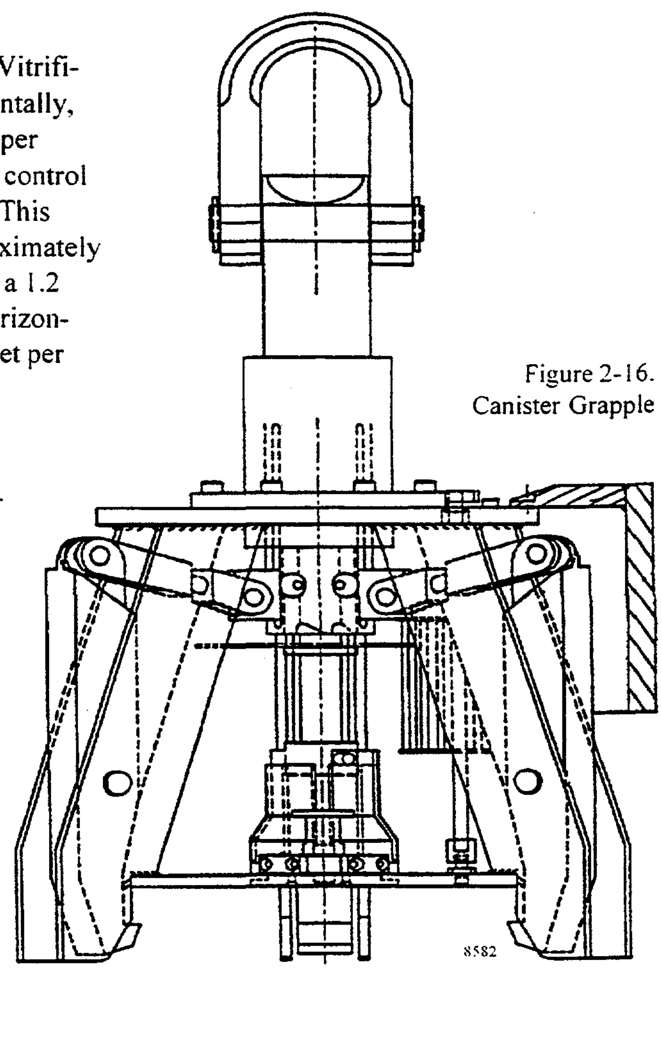


Figure 2-16.
Canister Grapple

The grapple, shown in Figure 2-16, is a three-hook mechanized lifter. It has one disengage position and two engage positions to avoid inadvertent disengagement should an engaged canister land on an obstacle. A status indicator is provided to show the operator the grapple position. A manipulator-operated override is also provided to disengage the grapple should the actuator mechanism fail.

2.10.5 Remote Connectors

Maintenance of most Vitrification Cell components is aided by a jumper system that uses a 3-jaw connector, called a PUREX connector. The jumper concept dates back to the 1940s, where it was used to support remote production of plutonium for the Manhattan Project. Other components, mainly piping and ducting larger than four-inch diameter, use a three-bolt flange system. The lower flange, with three studs, mates with an upper flange that has nut cups to hold the free nuts used to match the studs. A guide pin system is used to assure correct alignment of the flange prior to the studs engaging the nuts.

The free nuts and the 3-jaw connectors, which are equipped with two-inch hex operating screws, are operated using an electric impact wrench suspended from the process crane. The impact wrench can be positioned to operate horizontally or vertically. The wrench is driven by a 480-volt, three- phase electric motor.

2.11 Auxiliary Systems/Facilities

2.11.1 Cold Chemical System

The Cold Chemical System (CCS), shown in Figure 2-17, is independently housed in a building adjacent to the VF and provides for the receipt, staging, storage, and mixing of nonradioactive chemicals used in the vitrification process. The facility includes three slurry mix tanks, three solution preparation tanks, two day tanks (nitric and caustic solutions), one drain tank for waste collection, two material delivery subsystems (solid and liquid), a tank ventilation system, and the equipment necessary to transfer chemical slurries and solutions to the VF.

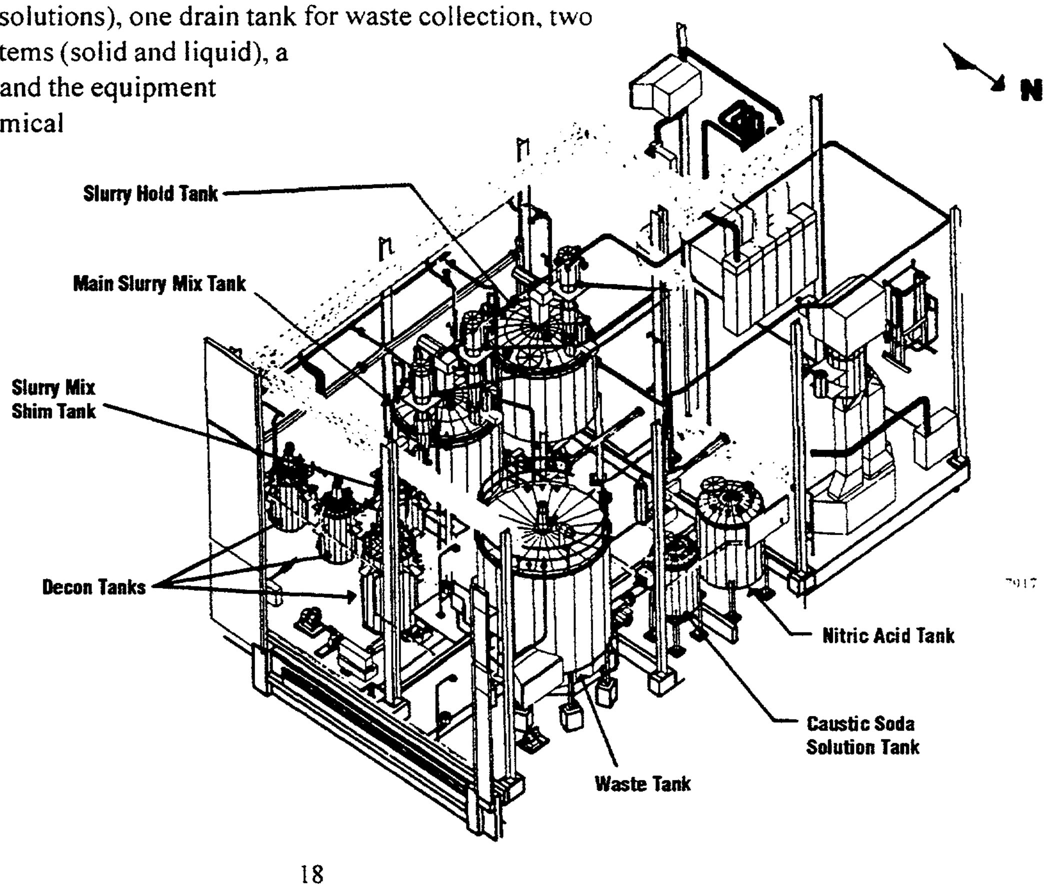


Figure 2-17.
Cold Chemical System

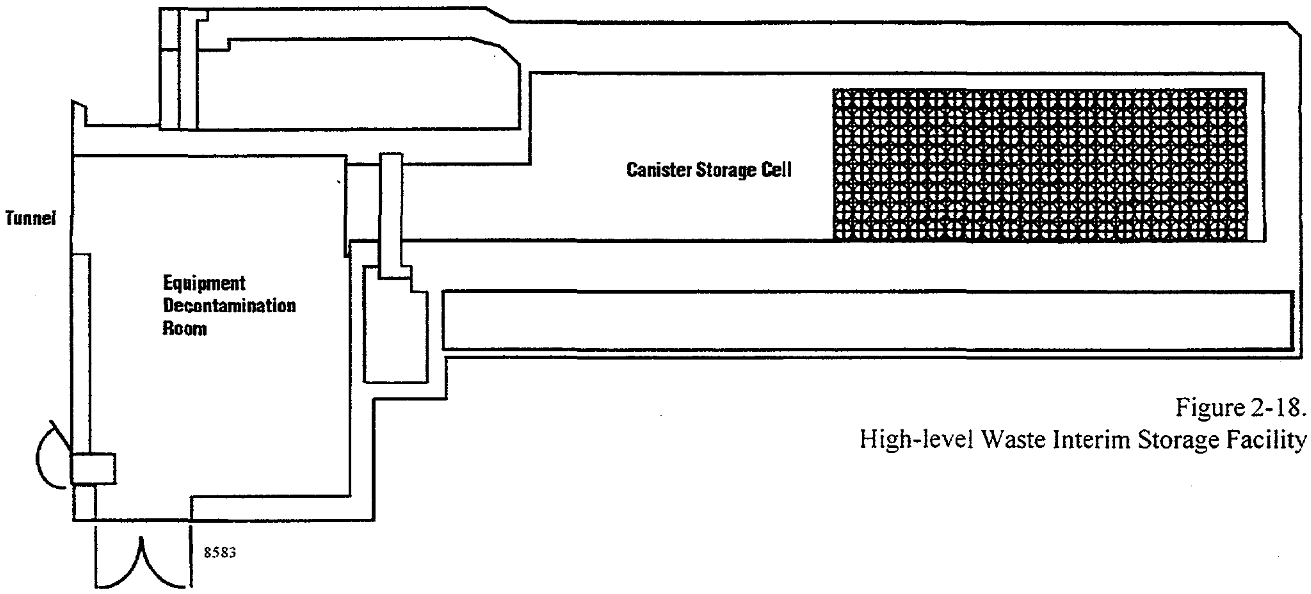


Figure 2-18.
High-level Waste Interim Storage Facility

2.11.2 High-level Waste Interim Storage Facility

The High-level Waste Interim Storage Facility (HLWISF) is housed in the Chemical Process Cell (CPC), an existing structure at the WVDP site located south of the VF and EDR (see figure 2-18). It provides controlled storage of up to 396 HLW canisters, as well as providing temporary storage for radioactively contaminated process equipment. The facility is a shielded cell, roughly 28.3 meters long by 6.7 meters wide by 13.1 meters high (93 ft x 22 ft x 43 ft). Its reinforced concrete walls are approximately 1.8 meters thick (5 ft, 9 in.) and are painted with an epoxy coating to permit washdown and decontamination. Four shield windows permit viewing of the CPC interior from the outside viewing aisle. The transfer cart enters the north end of the facility through a shield door. Filled and sealed canisters are unloaded from the cart into the storage racks with a 14.5 Mg (16 ton) crane with a grapple. A total of 11 storage racks, each holding 36 canisters, are installed in a two-tiered, interlocking, seismically designed arrangement. An additional rack holds two cell cooling units for controlling ambient air temperature.

2.11.3 Canister Load-in Facility

The Load-in Facility is adjacent to the west wall of the EDR. It is used as the access for moving empty canisters as well as large components into the VF (via the EDR). The facility provides for truck receiving and unloading capabilities, overhead crane coverage, empty canister handling provisions, a shielded canister port into the EDR for inserting canisters, and an area for staging chemicals to be used in the CCS.

Canisters are moved horizontally from shipping containers into the EDR through a canister port. The port is normally blocked with a movable shield plug. An upending device uprights the canisters once they reach the EDR, where they are loaded onto the transfer cart. An additional shield door exists between the Load-in Facility and the EDR to provide a means to bring miscellaneous equipment into the EDR.

3.0 OPERATIONAL EXPERIENCES AND LESSONS LEARNED

3.1 Waste Tank Farm

As described earlier, prior to the start of the vitrification campaign, the PUREX waste in Tank 8D-2 was pretreated by processing the supernatant through ion-exchange columns (used to trap the radioactive cesium-137). The remaining waste sludge was washed to remove interstitial salts. Next, the acidic THOREX process waste solution from stainless steel Tank 8D-4 was transferred into Tank 8D-2 and combined with the basic PUREX waste, while adding sodium hydroxide to neutralize the acidic waste and protect the carbon steel tank from corrosion. The mixture was again washed to remove the sodium added during the neutralization process. Finally, cesium-loaded zeolite, from the ion-exchange columns in Tank 8D-1, was transferred into Tank 8D-2 and mixed with the existing wastes to form a homogeneous waste stream for the vitrification process.

3.1.1 Waste Mobilization and Transfers

The curie content of the initial waste transfers to the VF were lower than predicted (i.e., less than 100,000 curies per transfer). The cause was evaluated to be twofold.

First, mobilization of the sludge inside Tank 8D-2 was not complete. There appeared to be a low flow area in the tank where sludge was accumulating. A sludge mobilization pump was removed from Tank 8D-1 and installed into an existing tank riser near this low flow area. Subsequent performance of the mobilization pumps (e.g., number of curies per liter in the associated HLW transfer) was tracked while changing operational parameters such as pump rotational directions, speeds, and operating times. This information led to the devel-opment of specific operating schedules for the mobilization pumps to optimize the solids transfer to the VF.

A second contributor to the low curie concentration was the leakage of seal water from the mobilization pumps into the tank during pump operation. As described previously, the mobilization pump shafts are filled with water to lubricate the shaft bearings and seal the shaft from the tank contents. Leakage of seal water into the tank from one of the mobilization pumps added significant amounts of water to Tank 8D-2 whenever the pump was operated. By minimizing the operating time of this pump, in accordance with the operating schedule mentioned above, and periodically decanting the accumulated liquid back to Tank 8D-1, the concentration of solids in the VF transfers was optimized.

Subsequent to the installation of the additional mobilization pump, waste transfers typically exceeded 200,000 curies.

Roughly 18 months after the initial waste transfer, the pump that transfers waste slurry from Tank 8D-2 to the VF failed, effectively idling the vitrification process. Replacement of the highly contaminated, 50-foot pump proved to be quite a complex task. Prior to removal of the failed pump, the pump and riser in which it was located were sprayed down with high-pressure water in order to lower the radiation levels near the work area. Radiation levels near the top of the riser were higher than initially expected. This was presumably due to the process fluid, which is used to lubricate the pump shaft bearings, spraying the inner wall of the riser as it exits the bearing interface. Subsequently, the replacement pump was modified to direct this fluid flow back to the tank without spraying the riser walls. The replacement pump was also designed with side-intake suction ports instead of the previously used bottom-intake port to more efficiently transfer the suspended solids in the waste slurry.

3.2 Melter Feed Preparation

Melter feed preparation consists of accepting and mixing dilute waste and SBS solution streams in the CFMT, concentrating the dilute waste in the CFMT through evaporation, adding nonradioactive, glass-forming chemicals, obtaining samples of the contents of the CFMT, and transferring the acceptable melter feed slurry into the MFHT. Through the completion of Phase I, 53 HLW feed batches had been prepared.

The typical batch preparation process starts by transferring approximately 4,000 liters of solution from the SBS into the CFMT, where it mixes with the residual heel from the prior feed batch. Dilute waste from Tank 8D-2, roughly 15,000 liters, is then added to the CFMT. Samples are drawn and the contents of the CFMT are heated with steam jackets to evaporate excess water and concentrate the slurry. The amount of glass-forming chemicals to be added is determined by analyzing the waste composition and predicting the volume of waste to be processed - one slurry batch produces just over three canisters of waste glass. Once the contents of the CFMT have been concentrated sufficiently to provide room in the tank for the glass-formers, the nonradioactive chemicals are transferred from the cold chemical facility into the CFMT. The resulting mix is again sampled to ensure that the feed composition will result in target glass characteristics. Prior to transferring the accepted feed slurry into the MFHT, a sugar solution is added to the feed. Sucrose is used as a reducing agent which aids in processing the feed in the melter by preventing foaming reactions that disrupt glass production.

3.2.1 Batch Cycle Time

Since the start of radioactive operations, batch cycle time associated with sample analysis and chemical mixing has been reduced. Due to the relative consistency of the waste stream, slurry acceptance engineers are able to generate chemical premix recipes well in advance of the final (post waste analysis) recipe. The glass-former slurry is made from up to 14 separate chemical constituents, tailored to each individual batch. This allowed the bulk of the chemical mixing (in the cold chemical facility) to be accomplished while still awaiting waste sample results.

The Vitrification Cell in-line slurry sampling units were modified, based upon operator input, to improve the ease of remote operation. Typical sampling time was reduced from more than eight hours per batch to roughly one hour per batch.

The turnaround times for chemical analyses (in support of feed batch preparation) experienced dramatic improvement relative to initial predictions. Typically, more than 20 elements are analyzed, although 15 are required for the composition control of the resultant glass. These 15 elements (Al, B, Ca, Fe, K, Li, Mg, Mn, Na, P, Si, Th, Ti, U, and Zr) normally account for more than 98% of the glass composition. Early analytical cell mockup training, combined with experience gained by lab technicians, has reduced the time required for the various feed batch analyses by more than 50% thereby saving 66 hours from the total batch cycle time.

As the curie content in Tank 8D-2 diminished over time, the HLW waste stream became more dilute. This eventually required increased waste volumes involving multiple waste transfers and corresponding evaporation cycles to complete a single feed batch (see figure 3-1). As a result of the added time (as much as two extra days per transfer), there are now periods when the melter must be idled while awaiting the completion of the next feed batch. Cell maintenance activities are now scheduled concurrent with these idle periods in order to reduce the impact of maintenance on process operating efficiency.

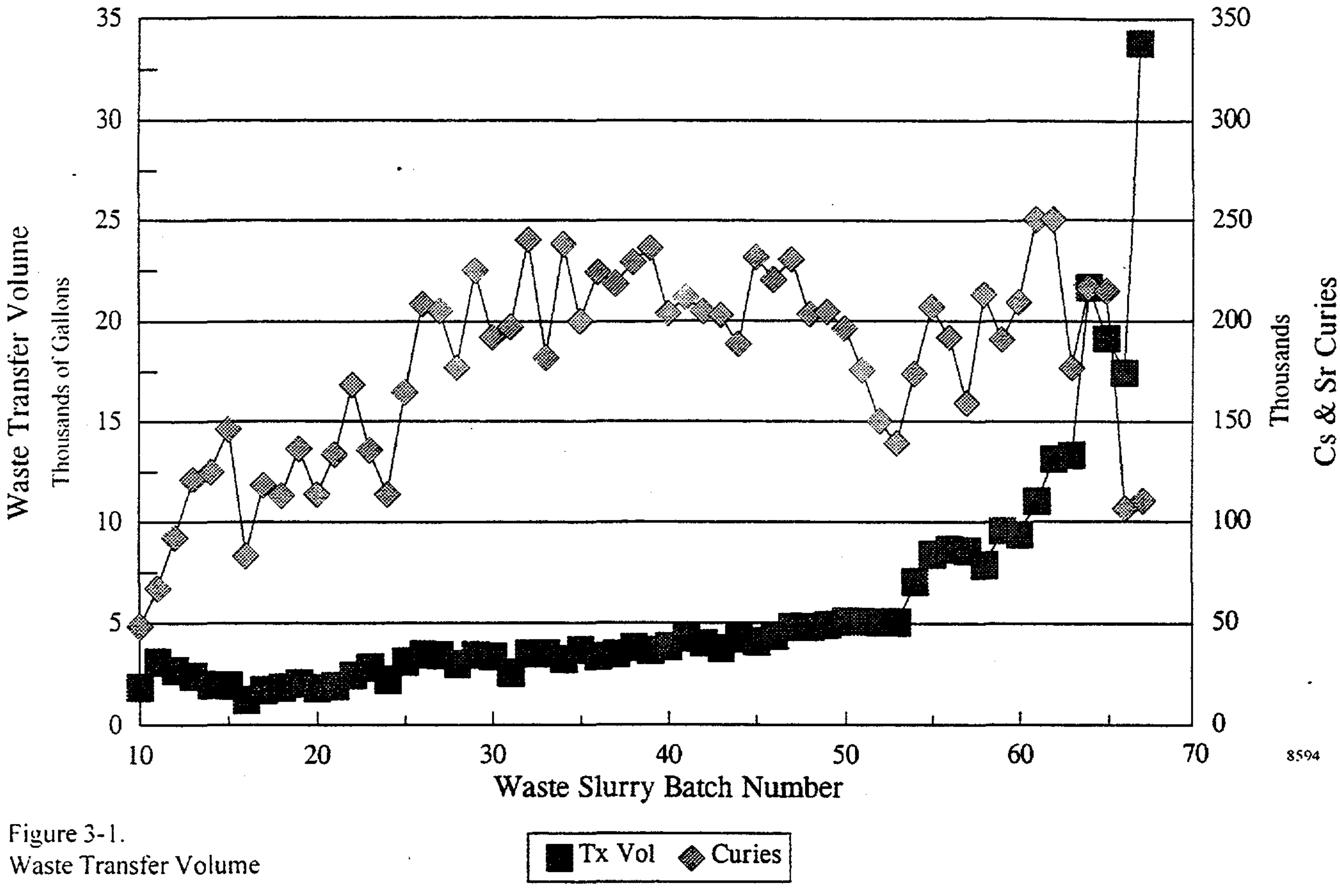


Figure 3-1.
Waste Transfer Volume

Also, a wider range of glass compositions have been studied to expand the range of acceptable glass recipes. These compositions include glasses with little or no uranium or thorium, which have become relatively more depleted from the waste as Tank 8D-2 empties. With a broader range of acceptable compositions, the necessity for small adjustments in the feed will be virtually eliminated.

3.2.2 NO_x Generation During Glass-former Addition

One phenomenon observed during feed preparation was the generation of NO_x gases during the addition of glass-forming chemicals. As the acidic chemicals were mixed with the concentrated, basic, HLW slurry, NO_x gases were produced at rates that exceeded the system's ability to abate the gases. On more than one occasion, this resulted in visual emissions from the exhaust stack. The problem was controlled in two ways. First, an air sweep was established on the CFMT, during chemical addition, to dilute the gases as they are being generated. Second, prior to the chemical addition, dilute nitric acid is slowly added to concentrated HLW. Whereas the glass-former chemical slurry must be transferred at a flow rate of roughly 230 liters per minute (60 gpm) to prevent solids from setting within the piping, dilute nitric acid can be added at a significantly lower flow rate of 35–40 liters per minute (9–10 gpm). The combination of a lower acid addition rate, and hence a lower gas generation rate, and an air sweep to dilute the NO_x gases have brought the NO_x concentrations down to a level where the off-gas system can effectively abate the NO_x gases prior to reaching the exhaust stack and therefore prevent visual emissions.

3.2.3 Bubbler Assemblies

Vessel level, density, and pressure indications within the Vitrification Cell are provided by bubbler assemblies (see figure 3-2). The CFMT and MFHT both have three independent bubbler assemblies. A control scheme that includes automatic, periodic blow-downs with pressurized air has maintained these bubblers relatively free from plugging. Modifications to the automatic blow-down cycles have incorporated a small (~100 milliliters) injection of water into the bubbler probes at the start of the cycle. This provides some scouring action within the bubbler probes and is proving to be effective in maintaining clear bubbler probes. To date, none of the bubbler assemblies located in the Vitrification Cell, except the melter bubbler assembly which is routinely replaced due to accelerated corrosion, have been replaced.

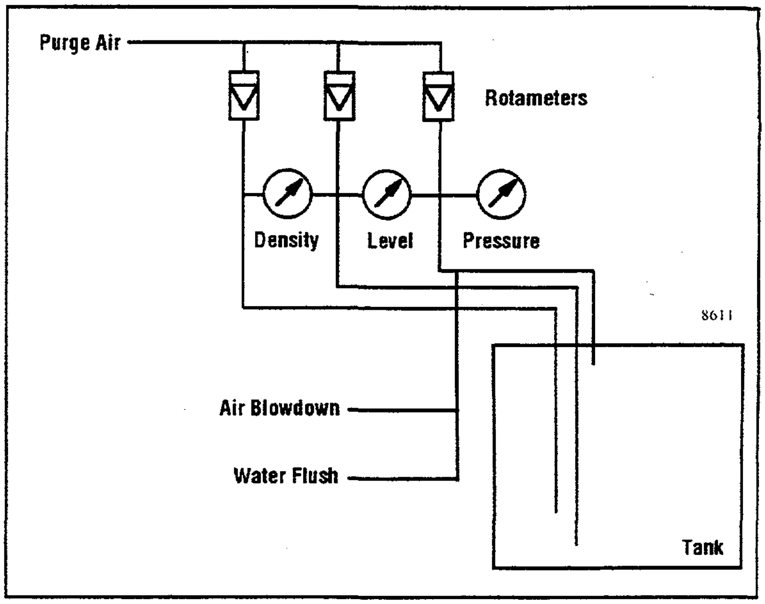


Figure 3-2. Bubbler Assembly

3.2.4 CFMT Sampler

Sampling the CFMT contents is accomplished using an ADS pump similar to the melter feed pump. The sample pump recirculates slurry from the CFMT to the slurry sampling station and back. At the slurry sampling station, an in-line sampler is used to draw samples from the recirculating stream. Provisions are included in the system to flush the sample lines with flush water originating from the pump (forward flush) or from the sample station (back flush). On one occasion, a back flushing operation resulted in HLW slurry being directed into a water line located outside the shielded cell. Subsequent evaluation revealed that while the valve line-up associated with the evolution was established to ensure proper containment of the slurry, the performance of the evolution was outside normal operating procedure. During the flush, an air-operated, three-way valve located in the cell failed to position, thus providing a path for slurry to enter a water line and backup into the operating aisle. Although the event created instantaneously high radiation levels (the affected piping was immediately flushed toward the cell to reduce radiation levels), there were no personnel in the immediate vicinity to receive radiation exposure. Subsequent modifications to the piping system provided an automatic solenoid valve in the affected water line, in addition to the pre-existing check valves. This valve is interlocked such that it will open only when the sample pump is in the normal operating mode, preventing the potential for slurry to backup during flushing.

3.3 Melter Operation and Glass Production

The slurry-fed ceramic melter (SFCM) is the key component in the vitrification process. The function of the SFCM is to dry and melt the slurry feed, converting it to glass. The ceramic-lined melter has three Inconel™ 690 electrodes to pass electric current. The electrodes are in continual contact with the glass pool. The resistivity of the glass pool generates the heat necessary to maintain an operating temperature range of 1,100 to 1,200° C—an effect referred to as joule-heating. The nominal volume of the glass pool is 680 liters.

As melter feed is added to the melter, water in the feed is evaporated and carried off with the melter off-gases. The remaining solids accumulate on the surface of the glass pool to form a crust of dried and calcined wastes, referred to as the cold cap. The size of the cold cap, ideally 70% to 90% coverage of the glass pool, is reflected in the temperature of the air space above the glass pool (plenum) and is maintained by controlling the rate of melter feed addition. Feed rate is manually adjusted periodically to maintain melter plenum temperature between 400 and 600° C.

The molten glass exits the melt cavity via a discharge passage through the refractory, originating near the floor of the melter. The molten glass is air-lifted up through the passage to a trough located in a discharge chamber. The glass flows off the trough and falls through a heated discharge chamber into a stainless steel canister positioned below the melter. Molten glass is batch-poured every four to six hours to maintain the melter glass level within a two-centimeter band. Air is bubbled into the overflow passage via a platinum tube in order to lift the glass up to the trough.

During an air lift, the pour stream is visually monitored by a infrared camera and periscope assembly. The glass level within the canister is visually monitored by the infrared level detection system (ILDS). A shielded infrared camera scans the canister and detects increases in surface temperature as thermally hot glass accumulates within the canister. The average operating glass production rate during Phase I was in excess of 35 kilograms per hour, resulting in an average canister fill time of 58 hours. System availability—actual feeding time vs. total time—for Phase I was impressive at over 71%.

3.3.1 Melter Feed Pump

As previously described, the SFCM is pulse-fed from the MFHT with an ADS pump. The pump is basically a submerged chamber with a double-seated poppet (see figure 3-3) and can deliver slurry feed to the melter at a controlled rate of between 20 and 150 liters per hour. Controlled by a timed, programmed, cycle, the pump chamber is first filled with slurry and then the slurry is displaced to the melter with pressurized air. The throughput capability of the melter dictates a relatively low average feed rate (60 to 80 liters per hour during normal operation). The pulsing design of the ADS pump has provided a low average feed rate while generating high slurry velocity and high back pressure. These characteristics have resulted in essentially none of the plugging problems normally encountered with slurry transport. The ADS pump has also proven to be reliable. The original pump was still operating in June 1998, after more than 2 years and nearly a million operating cycles. However, the few times that the pump (or its associated jumpers) has required remote maintenance attention it has proven to be very challenging and time-consuming. These remote operations will be discussed later in this report.

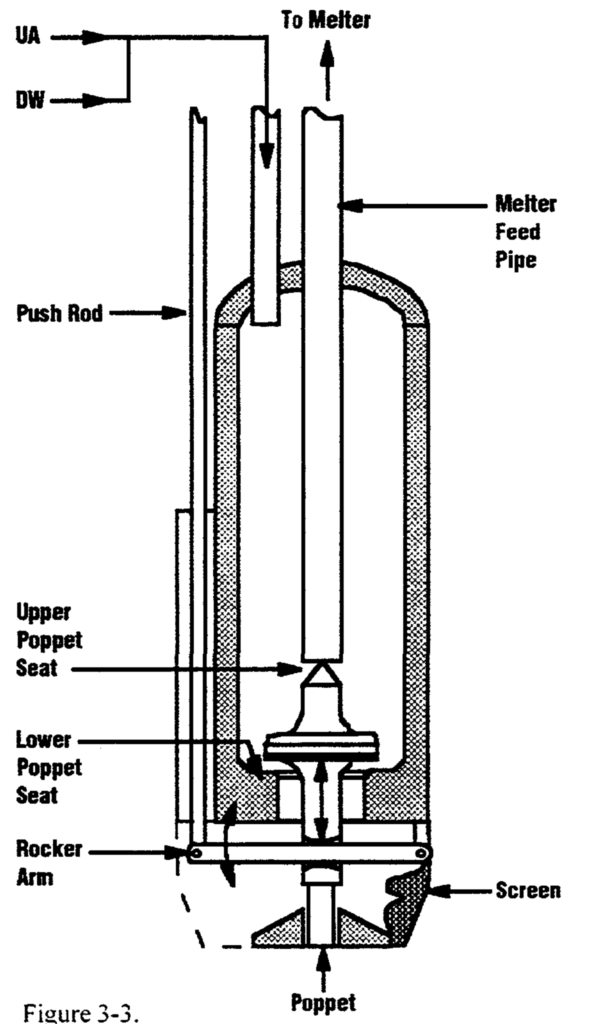


Figure 3-3.
Melter Feed ADS Pump

3.3.2 Melter Pressure Control

The off-gas system blowers provide the motive force to maintain all Vitrification Cell vessels under vacuum. The melter also uses a local pressure control loop that modulates the flow of pressurized air into the front end of the off-gas jumper to control melter pressure at -12.7 cm (-5.0 in.) H_2O.

Melter pressure control has been a challenge from the start of melter operations. Irregular off-gas flow characteristics attributable to the SBS, combined with the pulsing action of the ADS feed pump, create a dynamic environment for pressure control within the melter. The control system was modified by installing a high-speed data acquisition system and a quick-acting control valve. An adaptive gain feature was also incorporated into the control scheme. These modifications made melter pressure more manageable, however melter pressure still fluctuates somewhat. Typically, melter pressure still fluctuates as much as 7.6 cm (3 in.) H_2O from its nominal setpoint. Consequently, melter glass level is always maintained at least 2.5 cm (1 in.) below the overflow point to preclude excessive dripping of glass into a canister between glass pours.

Shortly following the start of radioactive operations, a significant restriction developed in the off-gas jumper connecting the melter and the SBS (see figure 3-4). The differential pressure across the jumper increased from a nominal 5 cm (2 in.) H_2O to as much as 50 cm (20 in.) H_2O. Remotely obtained radiation readings showed the buildup to be occurring at an acute (45 degree) elbow located just a few feet from the melter. The restriction was suspected to be caused by the collection of dried melter feed material, which was being swept into the jumper by the flow of the off-gas stream. A flow-restricting orifice was installed in the air line supplying motive force air to the ADS feed pump. Reduction in the air flow rate minimized the atomization of the feed slurry as it is pulsed into the melter plenum, reducing the amount of feed material entrained in the off-gas stream. Also, a water flush line was added to the air injection (pressure control air) line. A 100 liter-per-hour, 15 minute flush of the off-gas jumper is now performed on a per shift basis. These changes have not only eliminated the restriction, but have proven effective at preventing subsequent blockages.

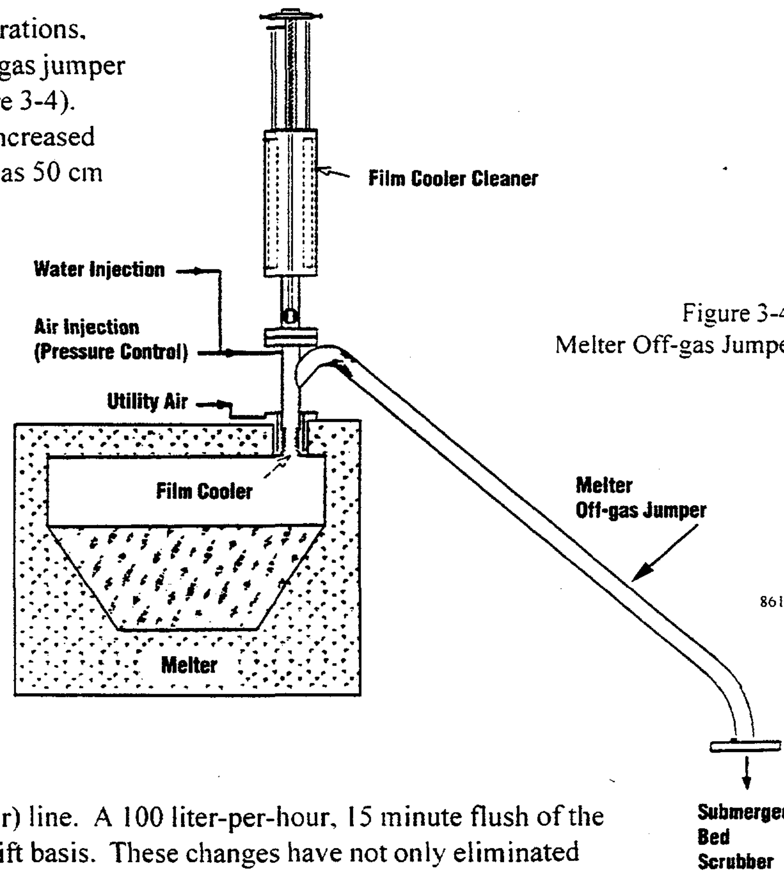


Figure 3-4. Melter Off-gas Jumper

Another operational change, regarding melter pressure control, involves the initiation of melter feed and cold cap formation. The original method of feed initiation called for operating the feed pump at maximum flow (~ 150 liters per hour) until the cold cap was formed. This method led to significant pressure fluctuations within the melter during cold cap formation. The new method establishes a continuous, slow (less than 2.5 liters per minute) addition of water to 'freeze' the surface of the glass pool and reduce plenum temperature prior to feeding slurry to the melter. Since the water addition is continuous, as compared to the pulsing action of the pump, the pressure control system can better react to the pressure changes in the plenum. Cold cap formation time is also reduced, minimizing the periods of high slurry flow rate.

3.3.3 Glass Migration

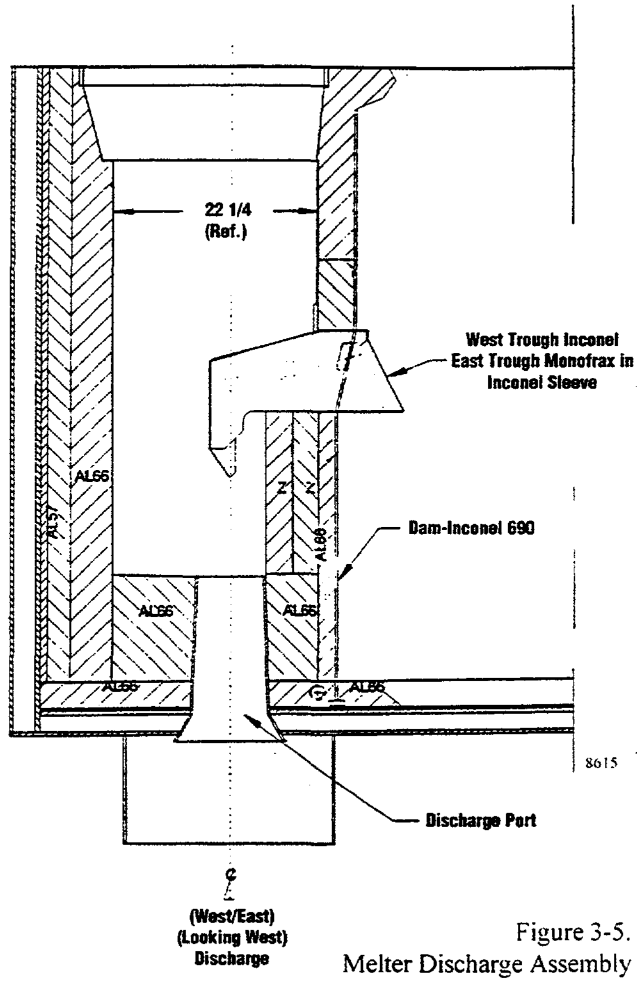


Figure 3-5.
Melter Discharge Assembly

During the course of startup testing with nonradioactive glass, the WVDP melter experienced chronic blockages in the glass pour stream. At one point, the melter discharge port was completely blocked and was cleared with manual tools. In November 1995, visual examination of the discharge chamber revealed that glass was migrating through the refractory wall that separates the main melt cavity from the west discharge chamber. The melter has two discharge chambers: the west chamber, used for production; and the east chamber, an installed spare. Embedded within the refractory wall are air-cooled Inconel™ plates, called dams, to prevent glass migration (see figure 3-5).

Examination of the west chamber revealed the following: the trough was slightly displaced outward and rotated downward roughly two degrees, seal welds joining the trough to the dam had failed, and the dam had bowed outward. Inspection of the east chamber showed no trough distortion, weld failure, or dam distortion. Analyses of all critical data confirmed that trough displacement, weld failure, and dam distortion in the west chamber had been caused by a combination of factors: high temperature, thermal expansion at large temperature differentials, a restraint that prevented expansion, a lack of proper trough-to-dam reinforcement, and the presence of residual weld stresses due to the melter and chamber heatup rate.

A repair plan was developed that both corrected the problem and improved the design of the discharge chambers. Weld repair included increasing weld size, adding a weld to the bottom of each trough, and using a weld procedure specifically developed to reduce distortion and stress during the welding process. The trough-to-dam interfaces were reinforced by adding gussets to both troughs. An expansion joint, made of fiberboard layers, was added to the top of the dam to allow expansion of the dam and reduce stress. Refractory modifications included using six keystone-shaped bricks placed on top of a rectangular-shaped brick to provide greater structural support for the trough.

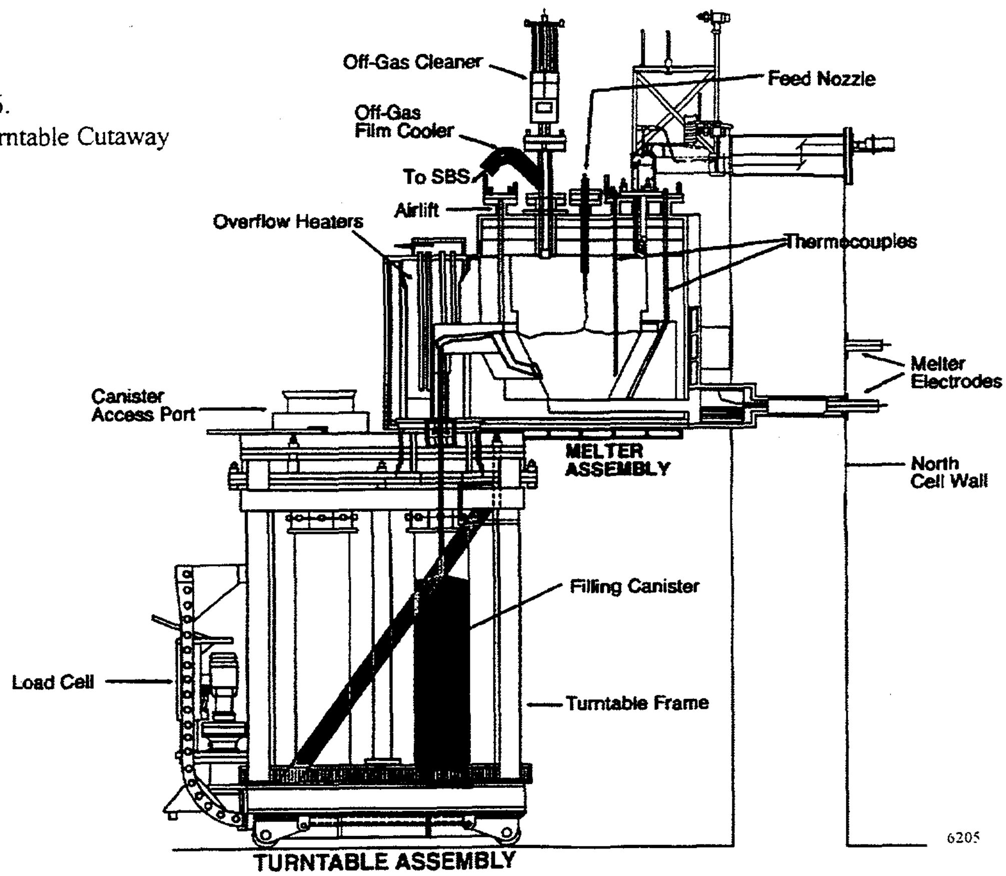
A series of thermal and stress analyses were done at the Westinghouse Science and Technology Center in Pittsburgh, PA to confirm the repair plan. Calculations were made to confirm that sufficient expansion space was provided and that time must be allowed for thermal stress relief during heatup of the dam. Based upon these evaluations, adjustments were made to the melter heatup curve to allow time for creep and stress relief in the melter dam to occur.

Melter restart activities started in February 1996. Melter startup heaters—radiant heaters temporarily placed in the melter plenum—were used to heat the melter glass pool to the point were joule heating could be reestablished. This demonstrated the ability to restart a melter filled with cold, solidified, glass.

3.3.4 Melter Nozzle Liners

Some of the melter nozzles (penetrations through the melter lid) on the original FACTS melter had suffered significant sulfidation corrosion. Replaceable, highly corrosion- resistant alumina liners were designed and built into the production melter to protect the melter nozzles from corrosion. Thermal stresses, possibly from melter heatup, and mechanical stresses, due to removal and reinstallation of melter inserts during melter reconfiguration following initial startup, led to cracking and spalling of the alumina liners during startup testing. The alumina liners were replaced with Inconel™ 690 liners, shown in figure 3-6.

Figure 3-6.
Melter/Turntable Cutaway



Nozzle liners provide protection between the nozzle walls and the melter inserts (i.e., thermowells, plugs, film cooler, etc.). If the liners corrode, vapors can pass through to the melter lid interface and condense. Sulfidation of the melter lid could occur over time if the lid or nozzle temperatures are between 600 and 900° C. Temperatures within this range are feasible as the nominal operating temperature of the plenum ranges from 400 to 1,100° C. The new liner design provides for slight controlled air leakage into the melter around the liners to purge the vapors and provide some cooling action. A heat transfer analysis was done for the melter nozzles and liners to predict expected nozzle temperatures. The predicted temperature ranged between 170 and 420° C. To verify the analysis, thermocouple measurements were taken at several points on the melter during nonradioactive testing. The temperatures observed were well below those predicted by the analysis.

Three separate nozzle liners were removed and inspected after nearly two years of radioactive operation. The liners were in excellent condition, showing no signs of corrosion.

3.3.5 Discharge Heater Performance

The melter discharge chamber is heated with three groups of silicon-carbide radiant heaters to maintain a molten pour stream until the canister is reached. The heaters are integral to the replaceable discharge chamber lid. Originally, the useful life of the heaters was forecasted to be roughly 9 months. Replacement of the heaters requires idling the melter for almost three weeks—a significant production outage.

The first set of heaters lasted approximately 12 months before replacement was necessary. The extended life was attributed to changes in operational strategy. The heaters are controlled by a control loop using the discharge chamber temperature as the process variable. Originally, the thermocouple chosen to drive the control loop was located near the discharge port at the bottom of the chamber. Observations showed that this thermocouple was influenced by the heat given off from the pour stream whenever glass was poured into a canister. Even relatively small changes in the temperature sensed by this thermocouple led to cycling the heaters. By simply using a thermocouple located higher in the chamber, away from the influence of the pour stream, heater output was stabilized and heater bar life was prolonged.

The following additional modifications were made to further extend the life of the heaters. The heaters use maximum length for heating, thereby lowering the watt density per square inch of surface area. The original heaters did not heat the full length of the bar in the chamber. Each of the three heater groups has a separate power supply. The power to each group of heaters is distributed to maintain roughly the same watt density on each heater bar. Finally, standby power was supplied to the heaters to avoid thermal cycling of the chamber and heaters due to power outages. As a result of these changes, the presently installed heaters are predicted to last almost two years before requiring replacement.

3.3.6 Glass Pour Stream Irregularities

The glass pour stream must fall a distance of over 1.5 meters (5 feet) from the end of the trough before entering the canister (see figure 3-7). Lateral movement of the pour stream can (and does) occur due to: melter pressure fluctuations, especially those caused by the pulsing action of the ADS feed pump; small variations in the air lift flow rate, and air in-leakage to the turntable that creates air flow from the turntable, up through the discharge port, through the discharge chamber to the melter plenum, via a cross-over jumper connecting the discharge chamber to the melter plenum. The large canister opening of the WVDP canisters (0.42 meters) has proven to be an effective design feature to accommodate pour stream deflections.

Another consequence of air flow through the discharge chamber is the generation of very thin glass fibers, also called angel hair, and the accumulation of these fibers within and below the discharge port. Just prior to radioactive operations, the generation/accumulation of angel hair was great enough to block the pour stream and require manual cleaning. An orifice was installed into the cross-over jumper to limit the air flow through the discharge chamber. This proved successful in reducing angel hair generation to an acceptable level. Angel hair formation and accumulation, however, has not been nor will it ever be completely eliminated. Periodic accumulation of angel hair in the melter discharge port has been successfully cleared by temporarily removing and blanking the cross-over jumper to eliminate air flow through the chamber, and increasing chamber temperature to redistribute the heat toward the discharge port to slowly melt away the angel hair.

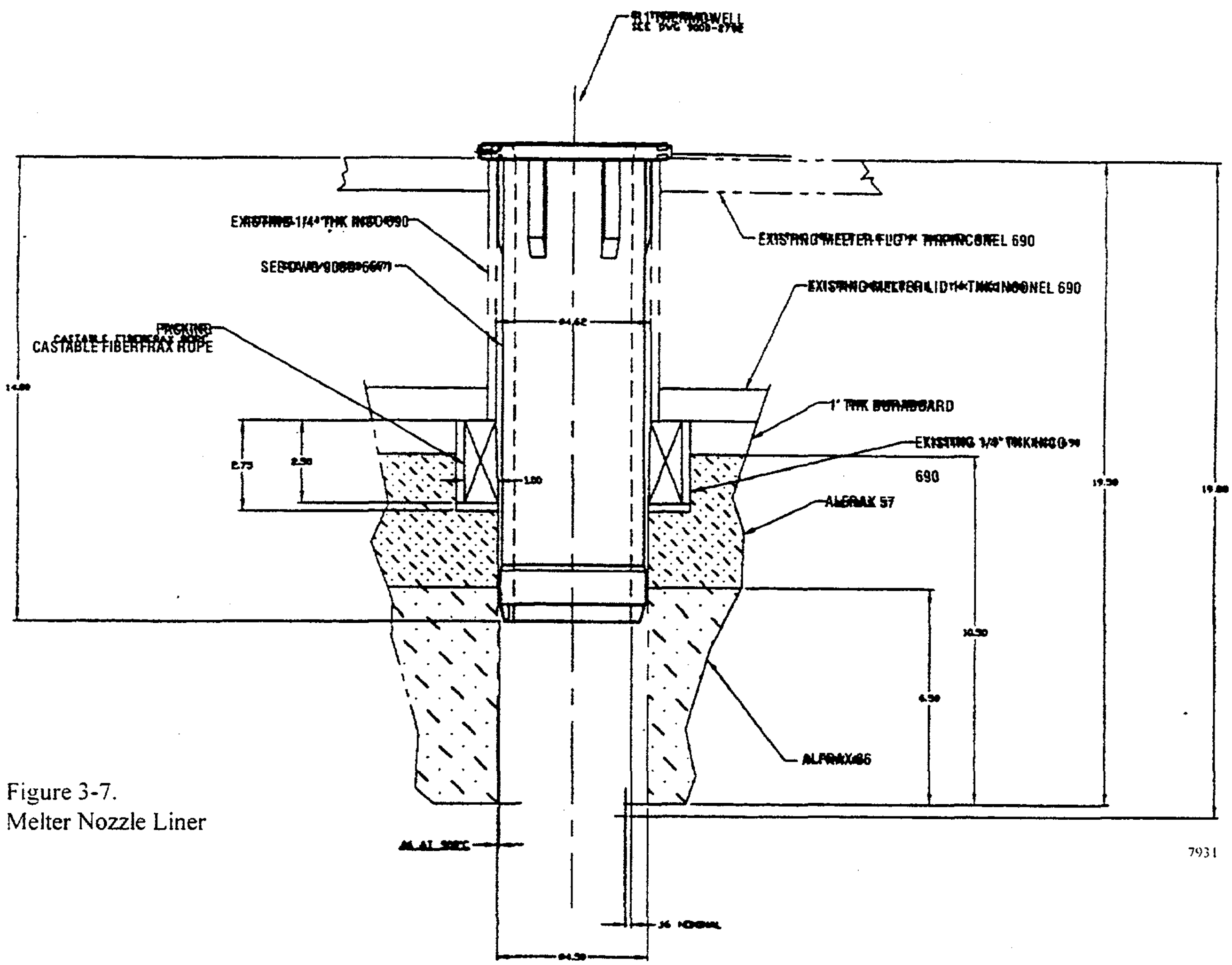


Figure 3-7.
Melter Nozzle Liner

3.3.7 Infrared Level Detection System

The actual recorded glass level, for record-keeping, is obtained by measuring the distance from the top of the canister to the glass surface. This measurement is obtained after the filled, cooled, canister has been moved to the weld station. The infrared level detection system (ILDS) is used to monitor the glass level within the canister during the filling process.

At the beginning of the campaign, canister filling was targeted for the 85% level. Operators used the ILDS, mass balance calculations, and canister weight changes to track glass inventory in the canister. After gaining experience with the video imaging capabilities of the ILDS, operators were able to safely fill each canister higher based upon ILDS information alone. The average fill height of the canisters now exceeds 90%. The variation between the canister fill level provided by direct measurement and that determined with the ILDS is usually within 1%. The expected lifetime of an ILDS camera is 12 months. The camera has been replaced twice in roughly two years, consistent with its expected life.

3.3.8 Noble Metals Accumulation

As melter operation progressed through the first phase of HLW processing, the electrical resistance of the molten glass pool decreased significantly. The electrical resistance values associated with each of the three electrode circuits are presently less than one third of the values observed at the start of radioactive operations. This phenomenon has been attributed to an accumulation of electrically conductive deposits: consisting mainly of ruthenium, rhodium, and palladium; within the melter.

As these noble metals accumulate and settle on the floor of the melter, preferential current paths are established between the electrodes. As relatively more current passes through these deposits, a lower percentage of the total electrode current is available to maintain the molten glass temperature, leading to higher total current demands. This phenomenon was anticipated during the design of the WVDP melter, resulting in the use of three electrodes. The shape of the melter is essentially an inverted, truncated, pyramid. The sides and ends are sloped toward the bottom electrode to direct any metal deposition to the bottom electrode. This way, any metal accumulation will simply act as an extension of the bottom electrode. However, it is believed that the metals are also accumulating in the dihedral corners of the melter, extending toward the corners of the side electrodes. Experience with spinel deposits observed in the FACTS melter, after five years of operation, supports this assumption.

A mathematical model was developed, based upon the assumption of preferential accumulation in these corners, to predict the future trend of melter resistance. The model predicts, as shown in figure 3-8, that the rate of decrease in melter electrical resistance will slow considerably over time. The actual observed resistances correlate extremely well with the predicted values to date and the capability of the melter to complete the WVDP vitrification campaign is not in question at this time.

Designs have been initiated to make a tool to help to characterize the noble metal deposits within the melter. By obtaining and analyzing samples of the deposits, the WVDP hopes to add to the relatively small collection of information regarding noble metals in joule-heated melters.

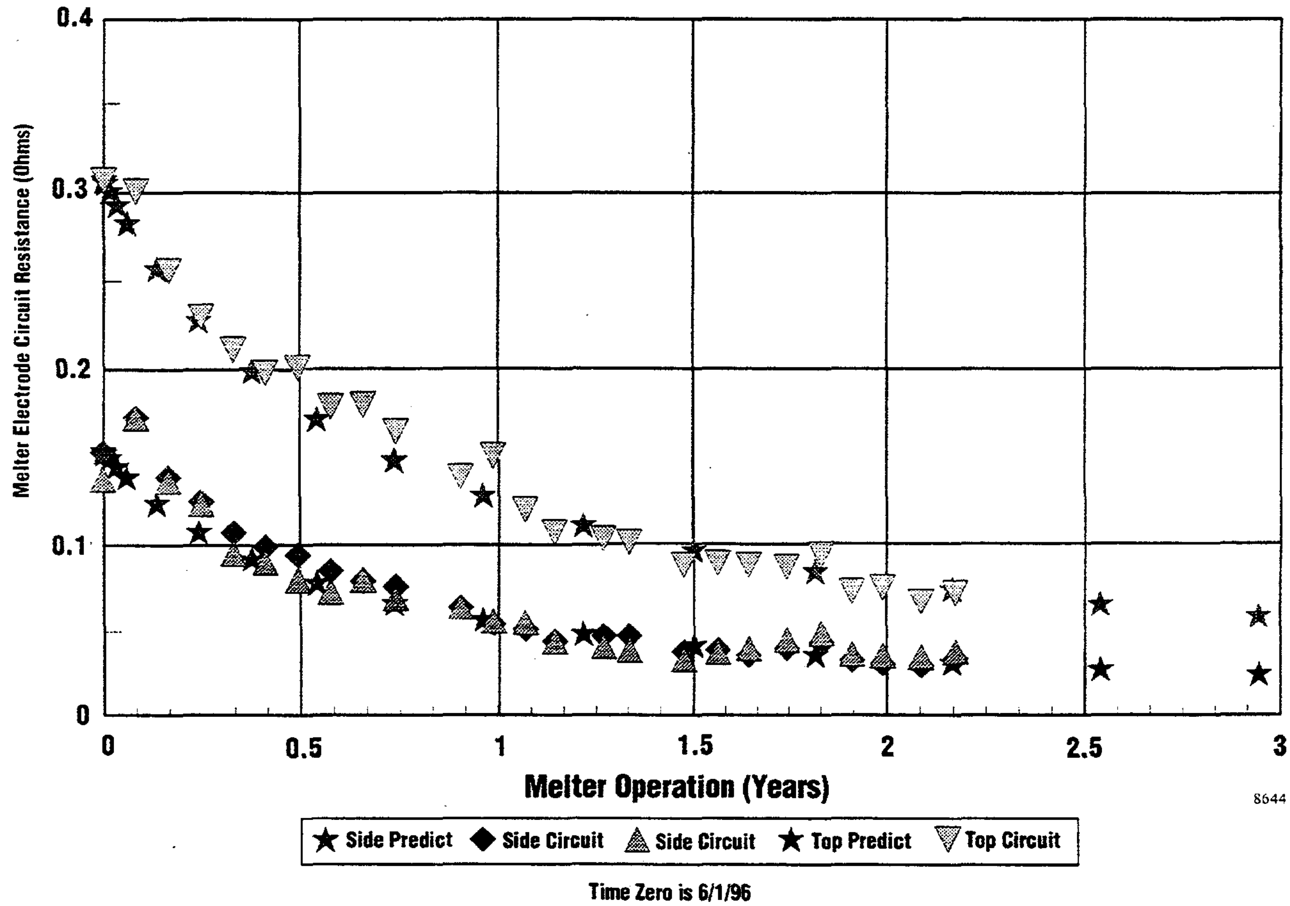


Figure 3-8. Melter Corner Model - Noble Metals Accumulation

3.3.9 Melter Level and Temperature Indicators

The melter level is measured with a bubbler assembly. Two Inconel™ probes are immersed in the glass pool and a third terminates in the plenum, just below the lid. The bubbler assembly insert is routinely replaced approximately every 24 weeks. The immersed probes typically corrode roughly four centimeters (1.5 in.) during this time period. The accuracy of the level measurement is checked by periodically allowing the molten glass to reach the overflow point and noting the indicated level. The glass is airlifted periodically to maintain glass level within an 1.8 cm (0.7 in.) operating band, with the maximum operating level at 2.5 cm (1 in.) below the overflow level. This control scheme results in an airlift roughly every four hours.

Due to the relatively small operating band, even slight perturbations in the level indication are troublesome. At one point, errors in level indication were being caused by feed material and glass accumulating around the reference probe opening. To alleviate this problem, the location of the reference tap was moved to an alternate nozzle, at a point actually above the melter lid, where the opening was not susceptible to clogging.

Two thermowells, each of which contain 9, type N thermocouples, are located in the main melter cavity to provide vertical temperature gradients for the melter glass pool and plenum. The thermocouples are replaced on a 12-week cycle while the thermowells are replaced on a 24-week cycle. Melter temperature indication has proven reliable to date.

Each of the three air-cooled electrodes has three, type N thermocouples to measure electrode temperatures. Originally, three separate thermocouple sheaths were installed for each electrode. Due to some binding observed upon routine replacement, the thermocouples were redesigned so that a single sheath, containing three thermocouples, is used for each electrode.

3.4 Canister Closure and Storage

3.4.1 Canister Lid Welding

After the final fill height measurement is made and shard samples are drawn, a lid is remotely welded onto the canister using a pulsed-gas, tungsten-arc process. The weld process is controlled and monitored by software. A successful weld is ensured by confirming that the desired weld parameters (e.g., current, voltage, speed) are within acceptance ranges and performing a satisfactory visual inspection using a remote camera.

Welds performed with parameters that are outside acceptable ranges are corrected by simply reperforming the automatic weld. Less than 9% of all canister welds to-date fell outside acceptable parameters and required a second weld. These welds were mainly attributable to foreign material at the lid-canister flange interface.

One significant challenge was offered when it was determined that, after 177 canisters had been welded, the current readings associated with the closure welds were inaccurate. An unmonitored ground loop present in the welder control console resulted in unmeasured current being delivered to the weld electrode. Through subsequent testing and evaluation, the magnitude of the previously unmonitored current was determined to be less than 10% of the total current. Additional test closure welds were made and evaluated (visual inspections, leak tests, burst tests, and metallograghic examinations) to ensure that the previous actual weld currents provided acceptable closure welds.

The most significant lesson learned from this experience is that the parameters initially established for lid closure welding were unnecessarily restrictive. Successful, robust welds can be made outside the narrow acceptance range. The more narrow, conservative acceptance range was initially chosen with the belief that the welder control system could easily maintain control within this narrow range.

3.4.2 Canister Decontamination

Decontamination of the stainless steel canisters involves electrochemical dissolution of a thin layer of metal from the canister surface using the ceric ion (Ce^{+4}) in a nitric acid solution. The decontamination reaction is achieved by soaking the canister in the decontamination solution at 65° C for six hours while agitating the solution using an air sparge. The thickness of the metal removed is limited to about 10 micrometers (0.00039 in.) and is controlled by the amount of reactant available, temperature of the solution, and residence time in the solution. The agitation removes the spent cerium (Ce^{+3}) from the surface, allowing fresh cerium (Ce^{+4}) to come in contact with the canister wall.

The canister decontamination operations shortly became routine. There were only a couple of canisters that experienced inadequate decontamination. These were due to operational inconsistencies such as lack of adequate agitation or failure to properly rinse the canister following decontamination. Early difficulties with tank temperature control and cooling coil pressurization were corrected with minor piping modifications and control loop tuning.

The process generates considerable amounts of neutralized decontamination solution and rinse solutions. These solutions are transferred into the SBS and effectively managed by reintroducing them into the melter feed batch makeup cycle.

3.4.3 Canister Storage

Filled, welded, and decontaminated HLW canisters are moved to the HLWISF using the transfer cart and placed in racks for interim storage. The HLWISF provides interim storage for up to 396 HLW canisters, archival shard samples, and radioactively contaminated process equipment. The facility also provides a means for dissipating the decay heat from the HLW canisters to maintain the storage area ambient temperature below 38° C (100° F).

The air flow across the top of the canister storage area, provided by the existing facility ventilation system, is the primary method for heat removal. A fan cooler heat removal system, mounted on the storage rack, will be activated if the ventilation air flow fails to sufficiently cool the storage area. This system consists of in-cell fan coolers and an ex-cell chilled water supply system. This system is manually activated prior to the ambient air temperature exceeding 100° F.

Storage cell air temperature follows the seasonal outside air temperature cycle. It also has slowly trended higher as more canisters are stored in the facility, but is yet to reach 100° F. In the spring of 1998, roofing repairs to the facility resulted in lower ventilation air flow from reduced ambient air in-leakage, and a relatively sharp increase in facility air temperature. This increase was alleviated by simply installing timers on the lights of the facility crane to automatically turn them off after 12 hours (instead of running them continuously). A longer term modification in progress is to provide ducting for 2,000 to 3,000 additional cubic feet per minute of supply air into the storage facility. This modification should ensure sufficient cooling for the storage area through the completion of the campaign.

As vitrification system operating time grows, storage of used process equipment also grows. Roughly 15% of the floor space in the HLWISF is available for the storage of used process equipment (i.e., thermowells, bubbler assemblies, used jumpers, melter discharge lid, etc.). Size reduction of selected jumpers is now being accomplished in the HLWISF using a remotely operated chop saw to better utilize the available storage space.

3.5 Vessel Ventilation and Off-gas Treatment

3.5.1 Vessel Ventilation

The vessel ventilation system maintains a slight vacuum on the CFMT, MFHT, waste header, and canister decontamination station by drawing gases and vapors from these process components and directing them into the off-gas system via the vessel ventilation condenser. The system also condenses steam during CFMT boiling evolutions, returning the condensate to the WTF.

The pressure in the vessel vent header is controlled by an air-operated butterfly valve that separates the vent header from the off-gas system. During startup testing the pressure control valve was unresponsive and stiff, leading to undesirable pressure transients. The addition of a volume booster improved performance by doubling the amount of control air delivered to the valve positioner; pressure response was improved. Since the start of radioactive operations, the performance of the vessel ventilation system has been consistent and steady.

3.5.2 Submerged Bed Scrubber

Off-gases leaving the melter are first quenched and scrubbed of entrained particulate by the SBS. The SBS also serves as a holding vessel for canister decontamination solutions prior to their reintroduction into the feed makeup cycle. The SBS temperature is controlled using two cooling coils, one located in the receiver vessel and another located in the interior scrubber vessel. By optimizing SBS temperature to maximize the amount of water vapor leaving in the off-gas stream, water inventory is effectively managed within the Vitrification Cell. Canister decontamination operations are rarely impacted by the ability to handle decontamination solutions.

The present design of the SBS is the result of lessons learned from FACTS operations. The FACTS SBS experienced considerable accumulation of solids in both the receiver section as well as the scrubber section. The present design, employing a dished receiver bottom and a solids suspension pump to draw liquid from the receiver and discharge it back to the scrubber and receiver, works to keep the majority of the solids in suspension so that they are transferred over to the CFMT during the feed batch makeup cycle. Some evidence of the accumulation of solids has been observed in the present SBS (e.g., increase in density, changes in differential pressure across the scrubber bed, etc.). These symptoms have been mitigated so far by occasionally filling the SBS with water and subsequently jetting the contents to the CFMT in an effort to flush out solids.

Just prior to the start of radioactive operations, the SBS demister was modified. Entrained moisture that is separated from the off-gas stream in the demister originally drained back to the SBS through the same nozzle from which the off-gas exited the tank. This resulted in insufficient drainage and the accumulation of liquid within the demister, causing undesirable off-gas flow characteristics. The demister return line was modified in place, adding a flexible drain line to an alternate SBS nozzle, correcting the problem.

The solids suspension pump for the SBS is a self-priming, centrifugal pump that continuously recirculates the SBS liquid. Early in the campaign, the pump mechanical seal failed, apparently from inadequate prime. It was surmised that the priming chamber was slowly accumulating solids, reducing the volume available for priming fluid. A replacement pump was modified to accept a flexible, remotely installed priming line. Pump operation has been acceptable since the modification.

3.5.3 NO_x Abatement

The NO_x abatement system has performed well, without the need to switch catalytic converters, since the start of radioactive operations. The NO_x destruction efficiency, nominally 95% has not decreased noticeably since the start of operations.

The NO_x and ammonia analyzers continue to provide satisfactory reliability, but not without continuing maintenance and attention. The analyzers appear to be particularly vulnerable to process upsets. It has been observed that within 48 hours of a high NO_x transient, one or more of the sampling/analyzer units must be taken out of service (for maintenance) due to salt buildup in the sensing lines and residue on the analyzer lenses. Additionally, the system does not handle excessive moisture well. As the number of boildowns per batch increase, the off-gas stream runs at a higher moisture content more often. Early in the campaign, drying and chilling units were installed in the off-gas sampling lines to condense and extract moisture prior to reaching the analyzers. However, significant maintenance is still required to mitigate the increased moisture accumulation.

3.6 Remote Operations

Routine remote operations consist mainly of canister movements within the cell and sampling evolutions. Routine remote maintenance operations are limited mainly to periodic replacement of melter inserts (thermocouples, thermowells, bubbler assemblies). Generally, these routine operations have been uneventful. On occasion, remote replacement or repair is necessary due to failed equipment. Most of the downtime associated with the WVDP vitrification campaign can be attributed to this type of remote maintenance.

3.6.1 Melter Feed Pump Maintenance

After more than seven months of processing with very little maintenance-related downtime, a series of challenges with the melter feed pump jumpers resulted in the first significant maintenance outage lasting nearly two months. First, the drive rods on the pump actuator unit became misaligned with the pump rocker arm assembly, rendering the pump inoperative. A spare actuator and spare air supply jumper were both modified by adding structural support and remotely installed.

Subsequent operation of the pump revealed that the three-way ball valve on the air supply jumper was not properly cycling. This resulted in inadequate venting of the pump chamber, preventing the chamber from filling during operation. The jumper was moved to the weld station where valve repair was accomplished using the weld station manipulators to loosen the valve packing. However, attempts to reinstall the jumper were unsuccessful. Damage to the support structure of the jumper (torn weld) was noted and a third air supply jumper was fabricated and placed into the Vitrification Cell.

The third air supply jumper was found to have an oversized kick-plate associated with the actuator nozzle. The nozzle kick-plate was modified by cutting and grinding that was performed remotely at the weld station. Subsequent attempts to install this jumper revealed that a threaded connector on one of the remote connectors had loosened, preventing proper jumper seating. The jumper was decontaminated, using a high-pressure spray wand, and moved to the EDR where the connector was successfully repaired using hands-on maintenance. This was the first opportunity to perform hands-on maintenance of any equipment that had been in the Vitrification Cell during radioactive operations. The jumper was reinstalled and melter feed was successfully reinitiated.

This series of challenges exemplifies the difficulty in maintaining a remote facility. However, the process downtime during this maintenance was utilized to perform another complex and time-consuming remote maintenance item—the replacement of the melter discharge lid.

3.6.2 Melter Discharge Lid Replacement

The melter discharge lid must be replaced to replace the discharge heaters. The discharge section cooling and reheating is performed in a controlled manner to prevent excessive thermal stresses in the melter dam. Lid replacement is also accompanied by removal and replacement of numerous mechanical and electrical jumpers. The complete lid replacement evolution was successfully accomplished in roughly 3 weeks, in parallel with feed pump maintenance.

While disengaging the free nuts on the lid with the impact wrench, one of the 12 nuts apparently galled and became stuck on the threaded stud. Repeated attempts to remove the nut were initially unsuccessful. A variable frequency drive was then (temporarily) installed at the power supply to the impact wrench. The higher frequency provided sufficient torque to forcibly remove the seized nut.

Improvements to hardware and operational methods, as mentioned previously in this report, have significantly extended the expected life of the discharge heaters thereby reducing the impact on vitrification processing time and potentially reducing the volume of radioactively contaminated used equipment.

3.6.3 Jumper Modifications

The installation and fit of the rigid in-cell jumpers requires close tolerances associated with jumper design and fabrication. WVDP experience with remote jumper replacement has led to some design changes that provide flexibility in the jumpers.

For some applications, it was acceptable to use flexible steel tubing with no structural dunnage to provide rigidity. Since these "flex" jumpers require two crane hooks and, sometimes, remote manipulator operation to successfully install, their application is limited. However, by providing a spring-loaded support plate to connect the PUREX connector to the rigid jumper's support structure, the connector can float as much as 19 mm (0.75 in.) in a direction perpendicular to the cell wall. This provides some margin of error in meeting the close tolerances for proper installation, while maintaining the necessary rigidity of the jumper to provide acceptable remote-handling characteristics. This is especially important when considering that spare jumpers cannot normally be test-fitted prior to placing them inside the radioactively contaminated Vitrification Cell.

3.6.4 Visual Access

Proper visual access to components within the Vitrification Cell is paramount to smooth remote maintenance and operation. Visual access is provided through six shield windows; six, fixed, closed-circuit television cameras (CCTV); one movable CCTV; and three fixed CCTVs mounted on the process crane. These CCTVs have pan/tilt and zoom capabilities and, in most cases, have provided excellent detailed imagery of equipment in the cell. But even with this array of cameras and windows, good visual access for remote maintenance is not always available. In cases where visual access is limited, operator experience has proven to be invaluable for performing successful maintenance operations. One particular lesson learned is that where there are components with moving parts (in the cell), a line of sight should be specifically provided to those moving parts.

4.0 SUMMARY

4.1 Production Summary

On 19 June 1996 the Secretary of the Department of Energy approved the initiation of radioactive operations at the WVDP. On 5 July 1996 the first HLW canister was filled. As of 10 June 1998 the WVDP VF had operated at an overall availability (actual melter feeding time versus total time) of approximately 71%, producing 211 canisters of HLW glass. Over 9.46 million curies of Cs-137 and Sr-90 had been removed from underground storage tanks. This accomplishment represents just over 85% of the total activity to be processed and signifies successful completion of the first phase of HLW processing at the WVDP.

4.2 Conclusions

The vitrification process has been performing as designed since initiating radioactive operations. Exhaustive functional and integrated testing, both FACTS and startup testing, contributed greatly to the success of the process. The experience gained through this testing provided insight into the vitrification process and confidence in system performance and operational methods used in radioactive operation. Oversight by engineering and operational personnel during radioactive operations has led to effective use of experiences and lessons learned to optimize facility performance. Strong problem-solving skills and efficient use of unscheduled process downtime has contributed greatly to the impressive system availability and success of the vitrification campaign.

5.0 REFERENCES

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ACRONYMS

ADS	Air Displacement Slurry
CCS	Cold Chemical System
CFMT	Concentrator Feed Makeup Tank
CMR	Crane Maintenance Room
CPC	Chemical Process Cell
Cs-137	Cesium 137
DOE	Department of Energy
EDR	Equipment Decontamination Room
FACTS	Functional and Checkout Testing of Systems
HEME	High-efficiency Mist Eliminator
HEPA	High-efficiency Particulate Air
HLW	High-level Radioactive Waste
HLWISF	High-level Waste Interim Storage Facility
HVAC	Heating, Ventilation, and Air Conditioning
ILDS	Infrared Level Detection System
MFHT	Melter Feed Hold Tank
NO_x	Acidic Oxides of Nitrogen
PUREX	Plutonium Uranium Extraction
SBS	Submerged Bed Scrubber
SFCM	Slurry-fed Ceramic Melter
SMTS	Sludge Mobilization and High-level Waste Transfer System
Sr-90	Strontium 90
SSS	Slurry Sampling Station
THOREX	Thorium Extraction
TT	Canister Turntable
VF	Vitrification Facility
WTF	Waste Tank Farm
WVDP	West Valley Demonstration Project

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at the West Valley Demonstration Project