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Pilot-Scale System Need Report**

**M. F. Morrissey
L. D. Whitney**

March 1996

**Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest National Laboratory
Richland, Washington, 99352**

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Summary

This report examines the need for pilot-scale testing in support of the low-level vitrification facility at Hanford. In addition, the report examines the availability of on-site facilities to contain a pilot-plant.

It is recommended that a non-radioactive pilot-plant be operated for extended periods. In addition, it is recommended that two small-scale systems, one processing radioactive waste feed and one processing a simulated waste feed be used for validation of waste simulants. The actual scale of the pilot-plant will be determined from the technologies included in conceptual design of the plant. However, for the purposes of this review, a plant of 5 to 10 metric ton/day of glass production was assumed. It is recommended that a detailed data needs package and integrated flowsheet be developed in FY95 to clearly identify data requirements and identify relationships with other TWRS elements.

A pilot-plant will contribute to the reduction of uncertainty in the design and initial operation of the vitrification facility to an acceptable level. Prior to pilot-scale testing, the components will not have been operated as an integrated system and will not have been tested for extended operating periods. Testing for extended periods at pilot-scale will allow verification of the flowsheet including the effects of recycle streams. In addition, extended testing will allow evaluation of wear, corrosion and mechanical reliability of individual components, potential accumulations within the components, and the sensitivity of the process to operating conditions. Also, the pilot facility will provide evidence that the facility will meet radioactive and non-radioactive environmental release limits, and increase the confidence in scale-up. The pilot-scale testing data and resulting improvements in the vitrification facility design will reduce the time required for cold chemical testing in the vitrification facility. In addition, confirmation that the glass is of similar quality to smaller scale tests and that the glass can be processed into an acceptable waste form will contribute to reducing the risk to an acceptable level.

The LLW Pilot Plant will act as one segment in developing Hanford's LLW Vitrification Facility. Achieving acceptable certainty that the full-scale facility can achieve its mission requires demonstrating the process with actual radioactive waste. While simulants prove valuable, they require validation. A small scale radioactive facility could validate simulant behavior for all segments of the process. Simulant validation will also require a nonradioactive facility identical to the small scale radioactive facility. The small scale nonradioactive facility would operate with the pilot plant to assist in scaling to full scale operation.

The current schedule indicates that the construction of the pilot-scale facility and advanced conceptual design would be completed (11/96). This will allow the pilot-plant to support and verify definitive design which is scheduled to be completed by 11/98. On-site facilities available to house a pilot-plant are limited. However, possible facilities include buildings 306W, 314, 338, and 427. In addition a facility could be constructed south-west of the 300 area. Vendor protest of the Phase 1 contract award prohibited contacting vendors to evaluate their facilities as possible locations for the pilot plant. It is recommended that potential off-site locations for the pilot-plant be evaluated in FY95.

The conclusions in this report were made based on discussions with vitrification experts at PNL, WHC, WSRC, and WVNS, and on discussions with commercial vitrification vendors. In addition, results of similar studies for HWVP were reviewed as well as other pertinent literature.

Acronyms

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DSSF	Double Shell Slurry Feed
DST	Double-Shell Tank
DWMP	Defense Waste Management Plan
DWPF	Defense Waste Processing Facility
Ecology	Washington State Department of Ecology
EMSL	Environmental Molecular Science Laboratory
FY	Fiscal Year
HLW	High-Level Waste
HVAC	heating, ventilation, and air conditioning
HWVP	Hanford Waste Vitrification Plant
IDMS	Integrated DWPF Melter System
LFCM	Liquid Fed Ceramic Melter
LLW	Low-Level Waste
NPDES	National Pollutant Discharge Effluent System
PSLLWVP	Pilot Scale LLW Vitrification Plant
VTD	PNL Vitrification Technology Development (Project)
RFP	Request for Proposal
SAR	Safety Analysis Review
SCFM	Standard Cubic Feet per Minute
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SSHTM	Small Scale High Temperature Melter
SST	Single-Shell Tank
TOC	Total Organic Carbon
TPA	Tri-Party Agreement
WAC	Washington Administrative Code
WDOH	Washington State Department of Health
WHC	Westinghouse Hanford Company

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1.0 Introduction

In January, 1994, the State of Washington, the U. S. Environmental Protection Agency and the U. S. Department of Energy signed a revised Hanford Federal Facility Agreement and Consent Order (Ecology et al. 1992) (also known as the Tri-Party Agreement or simply the TPA). This revised agreement commits the Department of Energy to retrieve waste from all of the Hanford waste storage tanks. The revised TPA also defines the technologies that are to be used in the treatment and disposal of recovered tank wastes. Insoluble solids retrieved from the waste tanks are to be washed with water and/or mild caustic and vitrified for future disposal as high level waste. The wash liquid will be combined with supernatant liquids from the tank waste. These liquids will undergo chemical pretreatment to remove approximately 99 % of the cesium. The pretreated liquid waste is to be vitrified for disposal as low-level waste glass. Approximately 210,000 m³ of LLW glass will be produced for disposal. The LLW Vitrification Facility must process between 100 and 200 tons/d to achieve its mission.

Westinghouse Hanford Company is implementing the LLW vitrification strategy through the Low-level waste immobilization program. Pacific Northwest Laboratory (PNL) is providing technical support to the program through the PNL Vitrification Technology Development (PVT-D) Project. The objective of this PVT-D report is to evaluate the needs for a pilot-scale vitrification system and identify potential facilities for the pilot plant.

Hanford has evaluated radioactive pilot plant needs for Joule-heated, liquid-fed ceramic melters (LFCM) (Sevigny 1991, May 1992, and Kupfer 1994), for a lower capacity high-level waste vitrification facility. WHC is conducting a two-phase effort to demonstrate and evaluate commercially available melter technologies for LLW. Phase 1 testing will examine a variety of melter technologies. Technologies that appear promising will receive further evaluation in Phase 2. After Phase 2 testing WHC will identify a reference melter technology system and at least one alternative melter technology system. WHC defines a melter system technology as a melter, feed preparation and melter feeding system, and off gas and waste treatment equipment unique to the melter and feed systems (Wilson 1994). Phase 1 testing will determine if a melter technology can produce glass of consistent quality from a LLW simulant. Phase 1 testing will require vendors to describe testing strategy, general operating behavior including perturbations and operating concerns, volume processed, processing rates, mass and energy balances, off gas characteristics, melt characteristics including phase separations, and product composition, consistency, and uniformity (Wilson 1994). Melter technologies that prove successful in Phase 1 will undergo Phase 2 testing. Phase 2 testing will ensure that melter technologies provide a technical basis for selecting reference and first alternative LLW vitrification technologies. For Phase 2 testing, WHC will modify equipment and procedures based on experience gained in Phase 1.

The TPA requires WHC to begin Phase 1 testing by September 1994, and complete melter feasibility and operability tests, select a melter(s), and establish reference LLW glass composition by June 1996. Because melter vendor testing is in its early stages, this report does not have the benefit of knowing the reference or alternative melter system technology. This report presents needs for a pilot

plant. But without a reference melter technology, the report cannot present needs of a specific technology.

2.0 Recommendations

Testing for extended durations in a pilot-plant using non-radioactive simulants is recommended. This recommendation is based on the need for reliability data, flowsheet verification including recycle streams, and a number of other issues to support design, permitting and operations as described in section 4.0. In addition to a non-radioactive pilot-plant, it is recommended that two small scale systems, one radioactive and one not, be utilized. These small scale systems would process actual waste and waste simulant respectively for validation of the simulant. Large-scale radioactive testing is not recommended.

Because the technologies to be included in the LLW vitrification facility have not been selected, it is not possible to identify the required scale for testing. Therefore, this report has used a working assumption of a scale of 5 to 10 metric ton/day glass production to evaluate potential facilities. Several on-site facilities were identified as possible sites for the pilot-plant. These include buildings 306W, 314, 338, and 427. In addition a facility could be constructed south-west of the 300 area. Vendor protest of the Phase 1 contract award prohibited contacting vendors to evaluate their facilities as possible locations for the pilot plant. It is recommended that potential off-site locations for the pilot-plant be studied in FY95.

3.0 Testing

This section discusses the issues to be resolved through pilot-scale testing to support design, permitting and operations.

3.1 Primary Testing Objective

Pilot plant testing is needed to achieve an acceptable level of certainty that Hanford's LLW Vitrification Facility can achieve its mission.

3.2 Testing Strategy

The testing strategy recommended for the LLW Immobilization program includes radioactive and non-radioactive testing at small- and laboratory-scales, non-radioactive testing at a pilot-scale, and final non-radioactive testing in the plant prior to hot operations. The elements of the strategy are shown in Figure 1. The intent is to maximize the information gained from the testing to support the needs of flowsheet and process development, product development, design, and operations while minimizing the costs.

Laboratory-scale (crucible) testing will be used extensively to develop the glass waste form and to characterize physical and chemical properties of materials to be used in the processing and/or disposal facility. Most of the laboratory-scale testing will be conducted with non-radioactive chemical simulants. Simulants spiked with tracers will be used in some instances to understand the behavior of specific radionuclides such as technetium or when analytical techniques favor using radiotracers. Laboratory testing with actual wastes will be necessary on a limited basis primarily to confirm that the work with non-radioactive simulants is valid and to again understand the behavior of specific radionuclides. Laboratory-scale non-radioactive testing is underway now in support of glass formulation development and evaluation of glass melter liner/refractory materials. Testing with actual wastes on a laboratory scale is not anticipated until reference waste composition(s), reference process flowsheet, and reference glass formulations are developed/selected and radioactive confirmation is required.

Process development, equipment adaptation/development, design data generation, integrated system testing, and product quality verification testing will be conducted at small and pilot-scales. The actual sizes of these small- and pilot-scale facilities will be determined after the melter vendor competition has provided sufficient insights to select the technologies to be used. To minimize cost and provide the needed flexibility, most of the testing will be non-radioactive. The pilot-scale facility will be used to provide the scale-up information needed for the vitrification facility design. Because of the limited availability of wastes and the high costs of operation, the radioactive testing with actual wastes will be conducted on a small-scale. Radioactive testing is needed for simulant validation, to determine impacts of minor waste components and to determine the behavior of specific radionuclides in the processing

equipment. A similar size/design non-radioactive melter is then needed to provide validation of the simulants. The melter vendor testing represents the first steps in the non-radioactive testing. The non-radioactive small- and pilot-scale facilities will follow immediately from the vendor testing and may include the selected vendor's facilities. The radioactive small-scale facility will be used later in the program to validate the simulants being used in testing. These small- and pilot-scale facilities will be needed at least through the startup and initial production campaigns of the vitrification plant. They will be used for assessing the processability of wastes and glass formulations as they may vary according to tank retrieval and pretreatment strategies and for process optimization and problem resolution.

The final piece of the recommended testing strategy is the non-radioactive checkout of the vitrification plant. This may include water testing to check plant hydraulics and non-radioactive testing with simulants for final process and equipment verification prior to starting hot operations.

The needs for pilot-scale testing data within this strategy are described in the remainder of this report.

Figure 1. Recommended Testing Scales and Relationships

3.3 Testing Issues

Pilot plant testing must address a variety of issues for testing to meet its primary objective. A summary of issues and their applicabilities appears in Table 3.1. More detailed discussions of issues appear in the following sections.

3.3.1 Final Melter Selection

After Phase 1 and 2 testing, WHC will choose a reference melter, and at least one alternative melter, to fulfill TPA Milestone M-60-02. Reference melter performance during extensive pilot plant operations will determine that the reference melter will meet the plant requirements. A decision can also be made whether Hanford needs to operate an alternative melter at pilot scale. Operating an alternate melter would allow evaluation of unresolved issues with both melters to confirm the reference melter as the definitive design.

3.3.2 Flowsheet Verification

During Phase 1 and 2 testing, vendors will not have tested equipment that operates upstream or downstream of the melter. For example, in the final flowsheet, one vendor's melter may operate with another vendor's feed preparation system. The pilot plant offers large scale, continuous and extended operation, recycle stream interaction, cycling capability, multiple run potential, and operational coupling. All these features are necessary to verify integrated process flowsheet acceptability. Consequently, the integrated process flowsheet must be verified at pilot scale to support or confirm the LLW Vitrification Facility's design. The pilot plant will allow verification of mass balances, energy balances, and energy requirements for preparing feed and vitrifying waste. The pilot plant can verify predictions of the agitation and pumping required to

Table 3.1. LLW Pilot Plant Testing Issues.

Issue	Design Verification	Equipment Selection	Operation	Maintenance
Final Melter Selection	Maybe	Yes	Yes	Yes
Flowsheet Verification	Yes	Yes	Yes	Yes
Integrated System Testing	Yes.	Yes	Yes	Yes
Waste Form Performance	Yes	Yes	Yes	N. A.
Regulations & Permitting	Yes	Yes	Yes	N. A.
Equipment Reliability & Materials Selection	Yes.	Yes	Yes	Yes
Constituent Accumulation	Yes	Yes	Yes	Yes
Process Sensitivity to Operating Conditions	N. A.	Yes	Yes	N. A.
Control Scheme Development	N. A.	Yes	Yes	Yes
Process Hazards Review	Yes	Yes	Yes	N. A.
Radioactive Operation	N. A.	Yes	Yes	Yes
Remote Operation	Yes	Yes	Yes	Yes

provide sufficient feed uniformity. The pilot plant will also provide an opportunity to verify glass and off gas compositions. Furthermore, the pilot plant will allow verification that off gas equipment, feed delivery, and glass discharge equipment perform as expected. The pilot plant will also permit identifying factors that perturb the process, minimizing the potential for perturbations and developing strategies for recovering from process perturbations. Agreement between Phase 1 and 2 testing, small scale radioactive testing, small scale nonradioactive testing, and pilot scale testing will provide guidance in scaling to full scale. Furthermore, operators can use the pilot plant to adjust process variables and thus optimize the flowsheet.

Phase 1 and 2 testing will examine two LLW compositions. Descriptions of these compositions appear in Appendix A. As waste characterization proceeds, new reference glass formulations may prove necessary. If this occurs, the pilot plant can verify the revised flow sheet based on the new reference stream.

3.3.3 Integrated System Testing

Before pilot plant operation, components will not have operated as an integrated system to vitrify LLW. Integrated system testing will identify issues that would not appear by testing components individually. It is necessary to operate as a complete system for extended periods to determine steady state operations performance. The long term operating characteristics and possible degradation of

performance is required to be known. Demonstration of the plant time cycle and handling and processing of waste recycle streams are also necessary.

The Savannah River Site (SRS) constructed the Integrated DWPF Melter System (IDMS) facility as a pilot plant for DWPF. While operating IDMS, nitrite interference with precipitate hydrolysis became evident. Adding hydroxyl amine nitrate decreased nitrite's interference, but extended pilot plant operation determined that adding hydroxyl amine nitrate caused ammonium nitrate to accumulate in the vessel vent system (Phillips 1992). Given ammonium nitrate's explosion potential (Sykes 1963), Savannah River abandoned adding hydroxyl amine nitrate and installed the Late Wash Process to remove nitrite upstream of DWPF. This example makes clear the importance of integrated system testing. The SRS would have never identified this crucial safety issue by testing components individually.

3.3.4 Waste Form Performance

During Phase 1 and 2 testing, vendors will produce glass that will be characterized for its durability. The WHC has not established durability requirements for LLW glasses, but preliminary assessment suggests a need for highly durable glass (Wilson 1994). Until WHC defines minimum acceptable LLW durability, proposed glass compositions should demonstrate a normalized Na^+ leach rate of no more than $1 \text{ g/m}^2/\text{d}$ for the Product Consistency Test Method at 90°C (Jantzen 1992). When vendor testing ends in 9/95, waste form performance specifications will remain under development. The pilot plant will allow determination of the effects of process and flowsheet variations on waste form performance. Some of the effects that require investigation include the potential for glass cracking and/or devitrification during cooling. The pilot plant will also allow evaluation of how the surface area to volume ratio of the waste form affects waste form performance.

3.3.5 Regulatory and Permitting Issues

Pilot scale testing must occur in accordance with all applicable federal and state regulations. Details of permitting requirements will be investigated later. All liquid discharges from the pilot plant must remain within National Pollutant Discharge Effluent System (NPDES) permit limits. If Hanford elects to place the pilot plant in the 300 Area, the process water will discharge to the 300 Area Waste Treatment Facility. This facility is under design at this time, but when it begins operation, the facility will place restrictions on influent quality that will probably relate to pH, solids loading, organic loading, and hazardous constituents.

The pilot plant will allow prediction of off gas, aqueous and particulate emissions for the full-scale facility. Gaining permission to operate the LLW Vitrification Facility will require estimates of radionuclide releases; ^{99}Tc , ^{129}I , ^{14}C , and ^3H all present the potential for release from the full scale facility. The pilot plant will provide data required to support permitting activities. The pilot plant proves to be important in predicting the emissions, because emissions generally vary with scale (Powell 1994). As discussed later, a small-scale radioactive facility would be used to confirm the radionuclide behavior as shown through simulant testing.

3.3.6 Equipment Reliability & Materials Selection

Phase 1 and 2 testing requires vendors to operate for only short periods of time (Wilson 1994). Long term degradation of melter, feed, and off gas components should not occur to any measurable degree during this abbreviated operation. Evaluating long term degradation requires long term operation. Feed systems will be prone to erosion, caking and plugging. Vitrification systems will be prone to erosion, corrosion and attack by the glass salts and the off-gas. Off-gas system will be prone to plugging and corrosion.

The pilot plant will allow identification of components that have substantial operability or maintenance requirements. Pilot plant operation would allow identification of process modifications that would minimize corrosion and erosion potentials. Besides corrosives, off gas will contain particulates that present a potential for plugging film coolers, packed columns, and filters. The pilot plant will allow evaluation of plugging potential over an extended duration, and permit process modification to minimize plugging. In addition, developing the LLW Vitrification Facility will require demonstrating feed processing and glass delivery and handling systems over an extended duration at plant cycle times.

The pilot plant also provides an opportunity for identifying components that cannot demonstrate sufficient reliability for a nuclear facility that might require remote operation. The pilot plant offers large scale, continuous and extended operation, recycle stream interaction, cycling capability, multiple run potential, and operational coupling. All these features contribute to simulating conditions that might occur in the actual facility. Demonstrating component reliability in a pilot plant will provide greater assurance that the full scale facility can meet its objective. It will also identify components that require redundancy. The pilot plant will allow preliminary development of strategies for remote maintenance, but the pilot plant will not prove sufficiently similar to the full scale facility to prove useful in fully developing these techniques. Full scale mock ups will probably prove essential for this task.

3.3.7 Constituent Accumulation

During extended operation constituents may accumulate in piping, filters, vessels, film coolers, packed towers, and other components. Small scale tests of minimal duration cannot evaluate accumulation potentials. A pilot plant that can operate for extended durations proves essential for evaluating constituent accumulation. The pilot plant offers large scale, continuous operation, recycle stream interaction, cycling capability, multiple run potential, and operational coupling. All these features may contribute to constituent accumulation. The pilot plant will also allow minimizing hazardous constituent accumulation through process modification. In components such as filters, accumulation proves inevitable. In these components, the pilot plant can provide data that will allow dose rate prediction and establish maintenance frequency. The pilot plant will also allow preliminary development of strategies to remove accumulations. The pilot plant will not prove sufficiently similar to the full scale facility to prove useful in developing remote techniques for removing accumulations. Full scale mock ups will probably prove essential for this task.

3.3.8 Process Sensitivity to Operating Conditions

Pilot plant testing can determine process sensitivity to operating parameters and provide envelopes for parameters such as glass temperature, feed constituent concentrations, feed rate, and off gas control. Determining these ranges on a pilot facility would prove faster, cheaper, and safer than determining these ranges during cold runs of the full scale facility. A period of testing will be necessary in the full scale facility. However, identifying the operating envelope before cold runs will minimize cold testing duration and cost.

3.3.9 Control Scheme Development

A process as complex as LLW vitrification will present many challenges to process control. A pilot plant would allow development of a control scheme before cold runs in the full scale facility. Defining the control scheme before cold runs would minimize the cost and time requirements of control scheme development. Developing a control scheme would involve establishing interlocks, feed batching sequences, and subsystem controls.

3.3.10 Process Hazard Review

The pilot plant will provide extensive experience in operating the LLW Vitrification Process. This experience will allow identification of potential process hazards and support preparation of facility and system operating procedures and safety analysis documentation. A pilot plant's usefulness in identifying process hazards became evident during SRS's experience with the IDMS facility (Schwallie 1993).

3.3.11 Radioactive Operation

A pilot plant that could process actual radioactive waste and accurately predict performance of a full scale facility would prove to be valuable. While such a facility would allow examination of the subtleties associated with processing actual waste, and eliminate the need for simulant verification, a radioactive pilot plant would negate many advantages normally associated with a pilot plant.

Pilot plants generally present fewer regulatory and permitting challenges, because they operate with simulants rather than actual waste. Resolving additional regulatory and permitting concerns would significantly increase the time required to build the facility and the total project cost. Furthermore, operating a pilot plant with actual radioactive waste would require delaying operation until waste can be retrieved from the tanks and perform pretreatment. If pilot plant operation relies on tank waste retrieval and pretreatment, the pilot plant cannot begin operating much before the full scale facility, and thus pilot plant operation could not contribute significantly to Definitive Design. Given the parallel nature of pilot plant and full scale facility development, delays in obtaining pilot scale data decrease the usefulness of the data obtained.

Pilot plants generally prove their worth; they provide rapid and inexpensive process information. A nonradioactive pilot plant allows researchers to dismantle, examine and modify equipment. A

radioactive pilot plant limits these practices and restricts observation techniques. Radioactive operation drastically increases the cost of inspection and decreases the quality of information obtained. The ability to resolve process concerns by physically handling the equipment has proven to be crucial.

A nonradioactive pilot plant also allows contact maintenance. A radioactive pilot plant might also allow contact maintenance, but some maintenance would require substantially more engineering and procedural control. A nonradioactive pilot plant would present fewer safety concerns and process hazards. A radioactive pilot plant offers little reduction in safety concerns or process hazards compared to the full scale facility, except for the quantity of material handled. Conducting the Process Hazard Reviews and Safety Analysis Reviews (SARs) associated with operating a radioactive facility could prove to be expensive and time consuming.

The LLW Pilot Plant will act as one segment in developing Hanford's LLW Vitrification Facility. Achieving acceptable certainty that the full scale facility can achieve its mission requires demonstrating the process with actual radioactive waste. While simulants are valuable, they require validation. A small scale radioactive facility could validate simulant behavior for all segments of the process. Simulant validation will require a nonradioactive facility identical to the small scale radioactive facility. This will assure a translation of data between the actual and simulated flowsheets. The small scale nonradioactive facility would operate with the pilot plant to assist in scaling from small scale radioactive operation to full scale radioactive operation. Validating simulant behavior with actual waste on a small scale and then using simulants on the pilot scale will prove more cost effective than operating a radioactive pilot plant. This also minimizes the quantity of actual pretreated waste required. Savannah River has used simulants extensively in designing DWPF, and found simulant behavior has correlated well with that of actual waste (Schwallie 1993).

4.0 Facility Survey

Preliminary assessment has identified 5-10 tons/d as a possible scale for the LLW pilot plant, but final scale will depend on the technology chosen. In the event Hanford elects to use 5 tons/d as a scale, the pilot plant will require the services presented in Table 4.1. All numbers that appear below are preliminary estimates for a 5 tons/d pilot plant. The basis for these estimates appears in Appendices B-D.

Facilities Administration has surveyed Hanford to identify space for the LLW pilot plant; space appears to be limited. The 100, 200 East, and 200 West Areas do not appear to contain a facility that might prove sufficient for a pilot plant of substantial size. Space in these areas seems unlikely to become available in the future. Space does appear to be available in the 306W and 314 facilities, but these facilities have fixed contamination in some spots, and operate under radiological controls. The 338 facility currently houses a Kaiser fabrication shop, but Facilities Administration expects Kaiser to relinquish the facility within 12 months. Space on the west side of the 300 Area, just south of Cypress, remains available, but using this space would probably require erecting a small structure and running utilities to the structure.

The 400 Area contains the 427 facility. This facility has more than 30,000 ft² of floor space, high bay, crane, heating, ventilation, and air conditioning (HVAC), fire protection, and electrical power. The crane requires certification. WHC can provide this space for approximately \$36/ft²/year. While this facility remains available at this time, it may not remain available indefinitely. While space at Hanford appears limited at this time, new space may become available in the future. PVTD will need to reevaluate facility availability before beginning pilot plant construction.

Vendor protest of the contract award for Phase 1 and 2 testing prohibited contacting vendors and determining the availability of off site locations. The PVTD recommends surveying off site locations in 1995.

Table 4.1. Preliminary Estimates of Pilot Plant Facility Requirements.

Requirement	Joule Heated Melter	Combustion Melter ^(a)	Vortec Melter ^(b)	Babcock & Wilcox Melter ^(b)
Power	1200 kW	600 kW	600 kW	600 kW
Process Water	5 gpm	5 gpm	5 gpm	5 gpm
Cooling Water	200 gpm	100 gpm	100 gpm	100 gpm
Combustion Air	Not applicable	530 scfm	530 scfm	530 scfm
Compressed Air	500 scfm	500 scfm	500 scfm	500 scfm
Fuel	Not applicable	2750 ft ³ /hr	20.78 gal/hr	68.9 gal/hr
Space	5000 ft ²	5000 ft ²	5000 ft ²	5000 ft ²

-
- (a) The combustion melter burns natural gas.
 - (b) The Vortec and Babcock and Wilcox melters burn kerosene.

While PNL cannot determine the exact requirements of a pilot plant until the PVTD identifies the reference and alternate melter technologies, many issues deserve mention.

4.1 Schedule

Hanford expects to install the LLW pilot plant by 11/96. Since Hanford expects to complete Advanced Conceptual Design by 11/96, the pilot plant will not contribute to Advanced Conceptual Design unless Advanced Conceptual Design experiences significant schedule delays. The pilot plant can validate Definitive Design bases and assumptions; and support all development that follows. The pilot plant will support plant start-up and process optimization. Because the full scale facility will not go into service until at least 2003, the pilot plant should remain in service until at least that time. Hanford may wish to maintain pilot plant availability throughout the full scale plant life to provide an opportunity for testing the process with different feeds, optimizing the process, and training operators. Since the LLW pilot plant may remain in service for the life of the LLW vitrification project, the pilot plant will require a site for which no future demands exist or one that is satisfying a lower priority function.

4.2 Power Requirements

A pilot plant that uses a Joule heated melter would require approximately 1200 kW of electrical power. While supplying a facility at Hanford with power sufficient for a Joule heated melter should not be difficult, supplying one with natural gas for a combustion melter may prove to be more challenging. The 300 Area does not have a natural gas line. The Environmental Molecular Science Laboratory (EMSL) had planned to run natural gas to the 300 Area, but since this facility has moved to the 3000 Area, no plans currently call for running natural gas to the 300 Area. If the pilot plant consumed sufficient gas, the local gas supplier might install a line to the 300 Area. If the pilot plant locates in the 400 Area, the pilot plant would require a substantially longer gas line. A pilot plant in either of the 200 Areas would require a gas line of approximately 16 miles. Running this line would be costly. If the pilot plant used a combustion melter that burned kerosene or another liquid fuel, operating the melter would require transporting fuel and storing it at the pilot plant. Permitting a kerosene tank requires permission of the Department of Ecology.

4.3 Waste Stream

A pilot plant of 5 tons/d would generate approximately 5 gpm of scrubber effluent. Following pilot plant recycle operations this stream will require treatment before it could enter the environment. The 400 Area does not have access to waste water treatment facilities. The 300 Area has access, but the 300 Area process sewer cannot, at this time, tolerate substantial increases in waste water flow rates. Pilot plant designers should consider an evaporator to reduce effluent volume. In the future the 300 Area Waste Treatment Facility will begin operation. This facility could treat pilot plant effluent, but

effluent would have to meet the treatment facility's influent restrictions and facility has limited capacity.

5.0 Scale Up

Phase 1 and 2 testing will test commercially available vitrification technologies to identify the most suitable technique for LLW vitrification. After identifying a process, TWRS will determine the need for, and size of a pilot plant. Hanford anticipates the full scale facility will produce at least 100 metric tons of glass/d.

This preliminary assessment has assumed 5-10 tons/d as the scale for the pilot plant. The need for the pilot plant and its size will depend on the vitrification technology chosen, processes upstream and downstream of vitrification, and the waste stream. If a thorough understanding exists of the processes and the waste stream and the vendor has a strong technical basis for scale up, ultimate scale up can be minimized. On the other hand, if a thorough understanding of either does not exist, designing the full scale facility will probably require a pilot plant of substantial scale. The need for the plant and the plant's size increases as the understanding of the process and the process stream decreases. In designing the DWPF, Savannah River tested most of the complex process equipment with full scale prototypes (Schwallie 1993). Savannah River recommends this practice for complex processes that require the highest degree of certainty.

Designing a facility requires an understanding of the streams upon which the facility may operate. The LLW Vitrification Facility will operate on a salt solution that will contain less than 1 wt% undissolved solids (Wilson 1994). Dewatering this salt solution could increase the undissolved solids loading to 10-30 wt%. LLW will have a pH of approximately 14, Na^+ concentration of approximately 6 M, high $[\text{NO}_3^-]$, and limited radionuclide concentrations. Given LLW's highly complex composition, potential for compositional variation, and the need for certainty that the full scale facility can complete its mission, using small scale models and classical fluid dynamic relationships to predict behavior in a full scale facility seems unlikely.

This preliminary assessment has determined that because LLW will exist as a slurry, classical fluid dynamic relationships alone cannot accurately predict the behavior of LLW. On the other hand, using classical fluid dynamic relationships with dimensionally similar physical models can predict LLW behavior with some certainty.

Before pilot plant operation, vendors will have tested their melters at the scale available at their facilities. These facilities may prove much smaller than the proposed pilot plant scale of 5-10 metric tons of glass/d. These facilities may prove too small to achieve similarity with the full scale facility. The pilot plant's actual scale will depend on the melter chosen and the required degree of certainty that the pilot plant will predict performance of the full scale facility. Melter technologies that prove more difficult to model will probably require larger pilot plants to predict performance of the full scale facility. Maintaining similarity may place limits on the minimum possible pilot plant scale. Savannah River recommends testing complex equipment, such as a melter or an off gas system with a full, or as large a scale as possible (Schwallie 1993).

6.0 References

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Appendix A

LLW and Simulant Characteristics

Appendix A

LLW and Simulant Characteristics

Several processes generated Hanford's tank waste; thus, waste varies in composition. Older single-shell tanks (SSTs) contain mostly precipitated sludges and saltcake, and newer double-shell tanks (DSTs) contain mostly liquid wastes. In the reference process, operators will wash sludges (low solubility) and saltcake (high solubility) to produce a large volume liquid waste and a small volume of washed solids that contains most of the radionuclides. Ion exchange will remove most of the ^{137}Cs in the liquid waste to produce LLW for the LLW Vitrification Facility. Cesium will combine with HLW.

Hanford will retrieve waste from DSTs before SSTs, because these tanks have different generation histories. LLW from DSTs will differ from LLW from SSTs. Although operators will blend wastes as much as possible to minimize variability, LLW will fall into two categories: double shell slurry feed (DSSF) and "remaining inventory," which includes SSTs and wastes from pretreated DSTs. LLW will probably contain between 4 and 6 M Na^+ , and less than 1 volume % undissolved solids (Wilson 1994). The process may require concentrating this feed to 10 or 15 M Na^+ , to reduce water content before vitrification. Concentrating LLW may cause salts to crystallize and increase solids loading to 10 to 30 volume %.

For Phase 1 testing WHC has chosen a DSSF simulant composition based on actual DST characterizations. DSSF simulant composition and compounds needed to prepare the simulant appear in Table A.1. For the remaining inventory of non DSSF, DST, and SST LLW, a preliminary composition, and compounds needed to achieve the composition appear Table A.2. Calcined solids compositions that assume no halide or metal oxide volatility, and the relative quantities of volatile components for the two LLW simulants appear in Table A.3.

A weighted average of six DSTs provides a basis for the Phase 1 DSSF simulant composition. Many minor constituents, mostly those contributing less than 0.02 wt%, do not appear in the Phase 1 DSSF simulant. The simulant includes all major constituents in DSSF and spike concentrations of constituents that may volatilize during vitrification, such as Cs, I, Cl, and Mo. Mo is a simulant for ^{99}Tc . The simulant also contains constituents that may exceed their solubility in silicate glasses, such as PO_4 , SO_4 , Cl, and F. The simulant includes Sr, because ^{90}Sr will have the highest activity of any radionuclide in LLW. The simulant will include 0.01 M Cs, Sr, I, and Mo to provide sufficient concentrations of these elements to allow mass balance verification. Additional LLW simulants for Phase 2 testing will probably include minor components omitted from the simulants described in Tables A.1-A.3. Additional simulants may also include higher concentrations of PO_4 , SO_4 , NO_3 , F, Cl, OH, and Cr to allow identification of melter technologies that provide the most flexibility for processing these constituents.

Table A.1. LLW Simulant for DSSF Tanks Normalized to 6.0 M Na⁺ (Wilson 1994).

Component	Target concentration <i>M</i>	Compound	Molecular weight (g/mol)	M required
Al ³⁺	0.61	Al (NO ₃) ₃ *9H ₂ O	375.14	0.61
Ca ²⁺	0.00063	Ca (NO ₃) ₂ *4H ₂ O	236.16	0.00063
Ca ²⁺	0.0052	Cr (NO ₃) ₃ *9H ₂ O	400.17	0.0052
Fe ³⁺	0.00046	Fe (NO ₃) ₃ *9H ₂ O	404.01	0.00046
K ⁺	0.30	KOH	56.10	0.30
Mg ²⁺	0.00062	Mg (NO ₃) ₂ *6H ₂ O	256.41	0.00062
Mn ²⁺	0.00025	Mn (NO ₃) ₂	178.94	0.00025
Mo ⁺⁶ (a)	0.010	Na ₂ MoO ₄ *H ₂ O	241.95	0.010
Na ⁺	6.0	—	—	—
Sr ⁺² (a)	0.010	SrCl ₂	158.52	0.010
Cs ⁺ (a)	0.010	CsNO ₃	194.91	0.010
PO ₄ ⁻³	0.026	NaH ₂ PO ₄ *H ₂ O	138.00	0.026
IO ₃ ⁻ (a)	0.010	NaIO ₃	197.89	0.010
CO ₃ ⁻²	0.16	Na ₂ CO ₃	106.0	0.16
Cl ⁻	0.096	NaCl	58.45	0.076
F ⁻	0.15	NaF	42.00	0.15
SO ₄ ⁻²	0.026	Na ₂ SO ₄	142.06	0.026
NO ₃	1.9	—	—	—
NO ₂ ⁻	1.0	NaNO ₂	69.00	1.0
OH ⁻ (b)	2.3	NaOH	40.00	4.0
TOC	0.81 (9.7 g/L)	Na ₄ EDTA, (C ₁₀)	416.20	0.081

(a) Spiked with 0.01 M Cs, Sr, I, and Mo to allow mass balance verification.

(b) Contains an excess of 1.4 moles of NaOH To neutralize hydrolyzable metal salts of Al, Ca, Cr, Fe, Mg, Mn & Sr.

TOC = Total organic carbon.

Table A.2. LLW Simulant for the Remaining Inventories (Less DSSF) Normalized to 6.0 M Na⁺ (Wilson 1994).

Component	Target Molarity M	Compound	Molecular weight (g/mol)	Required Molarity M
Al ³⁺	0.16	Al(NO ₃) ₃ *9H ₂ O	375.14	0.16
Ca ²⁺	0.00040	Ca(NO ₃) ₂ *4H ₂ O	236.16	0.00040
Cr ³⁺	0.0042	Cr(NO ₃) ₃ *9H ₂ O	400.17	0.0042
Fe ³⁺	0.00024	Fe(NO ₃) ₃ *9H ₂ O	404.01	0.00024
K ⁺	0.0058	KOH	56.10	0.0058
Mg ²⁺	1.1 E-06	Mg(NO ₃) ₂ *6H ₂ O	256.41	1.1E-06
Mn ²⁺	0.0010	Mn(NO ₃) ₂	178.94	0.0010
Mo ⁶⁺ (a)	0.010	Na ₂ MoO ₄ *H ₂ O	241.95	0.010
Na ⁺	6.0	—	—	—
Sr ²⁺ (a)	0.010	Sr(NO ₃) ₂	149.63	0.010
Cs ⁺ (a)	0.010	CsNO ₃	194.91	0.010
PO ₄ ³⁻	0.11	NaH ₂ PO ₄ *H ₂ O	138.00	0.11
IO ₃ ⁻ (a)	0.010	NaIO ₃	197.89	0.010
CO ₃ ²⁻	0.050	Na ₂ CO ₃	106.00	0.050
Cl ⁻	0.0092	NaCl	58.45	0.0092
F ⁻	0.13	NaF	42.00	0.13
SO ₄ ²⁻	0.038	Na ₂ SO ₄	142.06	0.038
NO ₃ ⁻	3.6	NaNO ₃	85.00	3.0
NO ₂ ⁻	0.26	NaNO ₂	69.00	0.26
OH ⁻ (b)	1.4	NaOH	40.00	2.2
TOC	0.11 (1.3 g/L)	Na ₄ EDTA, (C ₁₀)	416.20	0.011

(a) Spiked with 0.01 M Cs, Se, I, and Mo to allow a mass balance verification.

(b) Contains an excess of 0.8 moles of NaOH to neutralize acidic hydrolyzable salts of Al, Ca, Cr, Fe, Mg, Mn & Sr.

TOC = Total organic carbon

Table A.3. DSSF and Remaining Inventory Compositions on Calcined Solids Weight Basis (Wilson 1994).

LLW Simulant on Calcined Solids Weight % Basis		
Component	DSSF	Remaining Inventory
Na ₂ O	72.67	85.36
K ₂ O	5.77	0.13
Al ₂ O ₃	12.70	3.84
CaO	0.01	0.01
Cr ₂ O ₃	0.16	0.15
Cs ₂ O	0.58	0.66
Fe ₂ O ₃	0.01	0.01
MgO	0.01	0.00
MnO ₂	0.01	0.04
MoO ₃	0.59	0.68
SrO	0.42	0.49
P ₂ O ₅	0.75	3.68
SO ₃	0.85	1.43
NaCl	2.29	0.25
NaF	2.57	2.57
NaI	0.61	0.71
Total solids as g/L @ 6.0 M Na ⁺	245.05	212.49
Volatiles as g/100g calcined solids		
H ₂ O (estimated)	330	380
NO ₃ ⁻	48.07	105.04
NO ₂ ⁻	18.77	5.63
OH ⁻	15.96	11.20
CO ₃ ⁻	3.92	1.41
Organic carbon	3.96	0.61

Appendix B

Calculations to Determine Joule Heated Melter Facility

Appendix B

Calculations to Determine Joule Heated Melter Facility

Assumptions

Glass production = 5 metric tons/d
Oxide loading = 500 g/L
(melter is liquid-fed)
cooling H_2O ΔT = 20 °C (36 °F)
Off gas flow (dry) ~ 500 scfm
(cold plant assumed)

Feed Prep

Feed rate = x L/d

0.5 kg oxide/L (x) L/d = 5,000 kg oxide/d

x = 10,000 L/d = 2642 gal/d = 1.8 gpm

Assume 2 10,000 gallon tanks needed
Approximate size - 12 feet high
12 feet diameter

Assume process H_2O needed $\approx$ feed rate in order to make up feed.
Process H_2O $\approx$ 2 gpm

Melter

For LFCM in EVC-102,
capacity = 0.5 - 1 ton/d
surface area = 1.05 m².

Scaling linearly:
1.05 m² * 5 ton/0.5 ton = 10.5 m² needed for pilot plant
for a square melt surface, each side = 3.2 m = 10.6 ft

Power Requirements

For LFCM in EDL-102,

power = 100 kW

Scaling linearly:

100 kW 5 ton/0.5 ton = 1000 kW

Cooling H₂O Requirements

For LFCM, Cooling water $\approx$ 25 gpm

Scaling-up is not expected to be linear.

Instead, assume a factor of 4.

25 gpm * 4 = 100 gpm

Off Gas Quenching

Assuming steam flow from melter:

0.75 gal H₂O/gal feed * 2,642 gal feed/d = 1,982 gal H₂O/d (as steam)

Approximate cooling requirements to condense steam:

$Q = 1982 \text{ gal H}_2\text{O/d} * 971 \text{ Btu/lb m} * 8.331 \text{ lb m/gal} * 1/1440 \text{ d/min} = 11,131 \text{ Btu/min}$

Using cooling H₂O with $\Delta T = 36^\circ\text{F}$

$Q = mC_p\Delta T$

$m = 11131 \text{ Btu/min} / 1 \text{ Btu/lb m}^\circ\text{F} * 36^\circ\text{F} = 309.2 \text{ lb/min} * 1/8.331 \text{ gal/lb} = 37$

Air requirements for cooling, control assumed $\sim$ 400 scfm.

Other Filtration

Assume other filtration requires minimal power or H₂O.

Glass Discharge

Assuming a H₂O quench, approximate cooling requirements are:

$Q = mC_p\Delta T$

$m = 5,000 \text{ kg glass/d}$

$C_p, \text{ glass} \sim 0.2 \text{ Btu/lb }^\circ\text{F}$

$\Delta T \sim 1800^\circ\text{F}$

$Q = 5000 \text{ kg glass/d} * 0.2 \text{ Btu/lb }^\circ\text{F} * 1,800^\circ\text{F} * 2.2 \text{ lb/kg}$
 $= 3.96 * 10^6 \text{ Btu/d}$

Using cooling H₂O with $\Delta T = 36^\circ\text{F}$

$Q = mC_p\Delta T$

$m = 3.96 * 10^6 \text{ Btu/d} * 1/1440 \text{ d/min} / (1 \text{ Btu/lb }^\circ\text{F} * 36^\circ\text{F} * 8.331 \text{ lb/gal}) = 9.2 \text{ gpm}$

Less significant power and H₂O requirements will come from instrumentation, feed nozzle/electrode cooling, filter flushing, pumping, etc. The approximate values shown that follow can be used to approximate pilot plant requirements.

LFCM Pilot Plant Requirements (LLW):

Power = 1200 kw

Process H₂O = 5 gpm

Cooling H₂O = 200 gpm

Space > 5000 ft²

Air = 500 scfm

Other = Crane for equipment movement, etc.

Appendix C

Calculations to Determine Generic Natural Gas Combustion Melter Facility Requirements

Appendix C

Calculations to Determine Generic Natural Gas Combustion Melter Facility Requirements

Assumptions

Glass production = 5 metric tons/d
 Oxide loading = 500 g/L
 (feed will be dried)
 Cooling H_2O $\Delta T = 20^\circ C = 36^\circ F$
 (cold plant assumed)

Feed Prep

Utilities required to make up feed assumed will equal that for an LFCM system (see LLW-PS-1)
 Process $H_2O \approx 2$ gpm

Evaporation/Drying

Assume that feed/glass former mixture will be fully dried before feeding.

Assume energy needed $\sim 2x$ that to evaporate all H_2O , and that feed is 25% H_2O by volume.

Power = $2 * 0.750 * 2,642 \text{ gal/d} * 8.331 \text{ lb/gal} * 971.2 \text{ Btu/lb m} * 1/24 \text{ d/hr} = 1/34 * 10^6 \text{ Btu/hr} = 391 \text{ kW}$

Melter

Assume 6,000 Btu/lb glass necessary overall in melter. Approximate value estimated from various sources in *Combustion Melting in the Glass Industry*.

Assume fuel is natural gas w/1000 Btu/ft³ value.

Fuel required = $5,000 \text{ kg glass/d} * 2.2 \text{ lb/kg} * 6,000 \text{ Btu/lb glass} * 1/24 \text{ d/hrs} * 1/1000 \text{ ft}^3/\text{Btu} = 2,750 \text{ ft}^3 \text{ natural gas/hr}$

From spreadsheet FFM-LLW.XLS, air required = 530 scfm

Glass Quenching

Assume cooling requirements for glass quenching equals that of for LFCM System (see LLW-PS-1).

Cooling H₂O = 9.2 gpm

Off Gas Quenching

Approximate flowrate of exhaust gases from melter = 570 scfm (from spreadsheet FFM-LLW.XLS).

Assume $\approx$ 400 scfm air for gas cooling and control

Total off gas $\approx$ 1,000 ft³/min * 1/360 lb mol/ft³ * 30 lb/lb mol = 83.3 lb/min

Cooling H₂O required to cool gases from 700 °F to 100 °F.

$$Q = mC_p\Delta T$$

$$Q = 83.3 \text{ lb/min} * 0.25 \text{ Btu/lb } ^\circ\text{F} * 600 ^\circ\text{F} = 12,495 \text{ Btu/min}$$

H₂O needed:

$$Q = mC_p\Delta T$$

$$m = Q/mC_p\Delta T = 12495 \text{ Btu/min} / (1 \text{ Btu/Lb } ^\circ\text{F} * 36 ^\circ\text{F} * 8.331 \text{ lb/gal})$$

$$\text{Cooling H}_2\text{O} = 42 \text{ gpm}$$

Filtration

Assume passive filtration with minimal utility requirements.

Other requirements for power, H₂O, and air consumption will come from instrumentation, blowers, pumps, etc. Approximate values on the next page can be used to approximate pilot plant requirements.

Combustion Melter Pilot Plant Requirements

Power = 600 kw

Process H₂O = 5 gpm

Cooling H₂O = 100 gpm

Combustion Air = 530 scfm

Compressed Air = 500 scfm

Fuel (natural gas) = 2,750 ft³/hr

Space > 5000 ft²

Other = Crane

Appendix D

Calculations to Determine Generic Kerosene Combustion Melter Facility Requirements

Appendix D

Calculations to Determine Generic Kerosene Combustion Melter Facility Requirements

Purpose

Estimated required fuel storage tank capacity for the conceptual design of the Pilot Scale LLW Vitrification Plant (PSLLWVP).

Case I

Based on fuel consumption published in "Phase 1 Test Results" by Vortec Corporation.

Assumptions

Glass production rate = 6.1 tpd as depicted in the Phase 1 Testing report. A glass production rate of 5 tpd is sought for the PSLLWVP. Therefore, no scaling is required.

Vortec used natural gas. The conceptual design will use kerosene. Mark's Standard Handbook for Mechanical Engineers gives a heating value of 19,750 Btu/lb of kerosene.

Assume natural gas has a higher heat value than methane. This was taken from Table 30.6 of EIT Reference Manual, 8th ed.

Vortec test 63 #1 fuel flow rate = 172.84 lb of natural gas/hr

Assume equal efficiency for natural gas and kerosene.

Calculations

$$\begin{aligned} m_{\text{kerosene}} / \text{HHV}_{\text{kerosene}} &= m_{\text{CH}_4} / \text{HHV}_{\text{CH}_4} \\ m_{\text{kerosene}} &= m_{\text{CH}_4} / \text{HHV}_{\text{CH}_4} * \text{HHV}_{\text{kerosene}} \\ m_{\text{kerosene}} &= 172.84 \text{ lb/hr} / (23,879 \text{ Btu/lb} * 19,750 \text{ Btu/lb}) \\ m_{\text{kerosene}} &= 142.95 \text{ lb/hr} \end{aligned}$$

$$\begin{aligned} \text{Volume flowrate} &= \nabla = m/\rho = 142.95 \text{ lb/hr} / 6.879 \text{ lb/gal} \\ \nabla &= 20.78 \text{ gal/hr} \end{aligned}$$

$$\text{On a per-week basis: } \nabla = 24 \text{ hr/d} * 7 \text{ d/wk} * 20.78 \text{ gal/hr}$$

$$\nabla = 3491 \text{ gal/wk}$$

Case II

Kerosene Flowrate - Based on Babcock & Wilcox Cyclone Melter:

$q = 15,000 \text{ Btu/lb soil (includes moisture)}$ Reported on conservative soil flowrate = 300 lb/hr (80% solids)

$$\text{GPR} = \text{glass production rate} = 300 \text{ lb/hr} * 0.0108862 * 0.80$$

$$\text{GPR} = 2.56 \text{ tpd}$$

$$\text{LHV}_{\text{kerosene}} = 127,300 \text{ Btu/gal}$$

$$\text{GPR conversion factor, } c = 5 \text{ tpd}/2.56 \text{ tpd} = 1.95$$

Kerosene Fuel Requirement

$$\nabla = 15,000 \text{ Btu/lb}_{\text{soil}} * 300 \text{ lb}_{\text{soil}}/\text{hr}/127,300 \text{ Btu/gal} * 1.95$$

$$\nabla = 68.9 \text{ gal/hr}$$

per week

$$\nabla = 68.9 \text{ gal/L} * 24 \text{ hr/d} * 7 \text{ d/wk}$$

$$\nabla = 11,580 \text{ gal/wk}$$

Kerosene Tank Capacity

Assume

Storage capacity = 7 days

Furnace thermal capacity = 6 MM Btu/hr

$\text{LHV}_{\text{KPTD}} = 127,300 \text{ Btu/gal}$ (Mark's Standard Handbook 9th ed, p.7-14)

Melter throughput = 2.56 tpd

Burner efficiency = 1

Fuel flowrate

$$\nabla = 6,000,000 \text{ Btu/hr} / 127,300 \text{ Btu/gal} = 47.13 \text{ gal/hr}$$

Tank Volume

$$V_{\text{Tank}} = 47.13 \text{ gal/hr} * 24 * 7 \text{ hr} = 7,928 \text{ gal}$$

$$V_{\text{Tank}} = 8000 \text{ gal}$$

$$\nabla = 47 \text{ gal/hr}$$

If throughput increases twofold, the fuel flowrate will probably not double as well. Assume it will increase by a preliminary factor of 1.5.

Adjusted Fuel Flowrate

$$V_{5\text{tpd}} = 1.5 * 47 \text{ gal/hr} = 70.5 \text{ gal/hr}^*$$

$$V_{5\text{tpd}} = 1.5 * 8000 \text{ gal} = 12,000 \text{ gal}^*$$

*This figure is off by a factor related to the actual furnace efficiency, which is unknown at this time. It is advisable to use the previous values of 70 gal/hr and 12,000 gal/wk as a conservative approximation.

Electrical Power

Based on HWVP Pilot Scale Ceramic Melter Test 23, Feb, 1990

Ref: PNL-7142/VC-721

Assumptions

Direct scale up + 1.5 conservative factor

Glass production rate = 4.6 lb/hr-ft²

Area = 8.2 ft²

Mean electrode power = 61.35 kW

Mean glass discharge trough heater power = 3.65 kW

Mean glass discharge face heater power = 6.54 kW

Estimated plenum heater power = 61.35 kW

Calculations

Glass production rate = 4.6 lb/hr-ft² * 8.2 ft² * 24 h/d)

0.00045359 t/lb = .4106 tpd

Scale factor (linear), k = 5 tpd/.4106 tpd = 12.2

Total Power

P = 12.2 (2* 61.35 kW + 3.65 kW + 6.54 kW) * 1.5

P = 2,431 kW