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7. Abstract

Some innovative approaches have recently been proposed that may have significant schedule, cost, or environmental advantages which could improve the current HLW program strategy. Three general categories of alternative concepts are now under consideration: (1) process/product alternatives, (2) facility layout options, and (3) contracting strategies. This report compares the alternate approaches to the current program baseline to illustrate their potential significance and to identify the risks associated with each approach.

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December 1994

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EXECUTIVE SUMMARY

Some innovative approaches recently proposed may have significant schedule, cost, or environmental advantages that could improve the current high-level waste (HLW) program strategy. Three general categories of alternative concepts are now under consideration: (1) process/product alternatives, (2) facility layout options, and (3) contracting strategies. This report compares the alternate approaches to the current program baseline to illustrate their potential significance and to identify the risks associated with each approach.

Process/Product Alternatives. The most significant alternatives now being evaluated include the following:

- Waste feed preparation processes to minimize the volume of HLW that must be processed into glass thereby reducing the repository disposal costs

- Waste blending strategies to minimize the volume of glass produced

- Melter technologies to minimize capital and operating costs associated with the vitrification facility and to minimize the total volume of glass

- Glass formulations that increase the amount of HLW that can be incorporated within the glass waste form thereby decreasing the total volume of glass produced

- Process control strategies that minimize cost and uncertainty of product quality verification.

The upper limit for the volume of waste feed to the vitrification process is based on a process where tank sludge is washed with water to dissolve soluble components. An enhanced sludge washing process is now under development. The process would dissolve an additional 40 percent of sludge by adding sodium hydroxide to the wash water. The process could save the HLW program over $2 billion in vitrification and repository costs.

The reference waste feed for HLW vitrification is a blended material made from the waste from each of the HLW tanks. Some tanks contain chemical components that limit the amount of waste that can be incorporated within the glass waste form. This is a significant risk to the HLW program in that failure to blend wastes with high and low concentrations of these chemicals could increase glass volumes by as much as 30 percent over the reference case. This would cost the HLW program over $2 billion in vitrification and repository costs.

The reference vitrification process uses a low-temperature (1150° C), electrically powered melter. Options now under evaluation and development include a higher temperature melter with potential to increase the amount of waste that can be incorporated within the glass; induction melting to eliminate the need to use electrodes that typically require frequent replacement in a high temperature melter; and stirring equipment to increase the melting rate, thus reducing the size or the number of melters needed to meet throughput requirements.

The reference product for the vitrification process is a borosilicate glass. Adding boric oxide to the formulation (to create borosilicate glass) enhances the processability, thermal stability, and chemical durability of the glass product. Sodium alumina silicate glasses are also being evaluated for a high-temperature melter. An increase in waste oxide loading from 25 percent to 45 percent would save the HLW program over $2 billion in vitrification and repository costs.

One process control strategy is a feed-forward scheme where the melter feed is verified with extensive analyses in the laboratory before a batch of waste is fed to the melter. The analyses are required to ensure that the waste feed meets prescribed specifications for the process. Tight controls on the process are necessary to create a near certainty that the glass product will meet prescribed standards. As an alternate process control strategy, the HLW program will investigate a feedback method where minimal work is done to preverify the product. Under this strategy, samples of glass are taken and evaluated against prescribed standards. Material that does not meet standards will be recycled through the process.

The reference configuration for the HLW vitrification product is an unshielded stainless steel canister that is filled with molten glass, decontaminated, and placed into a vault covered by a metal building. The glass is stored in the vault as an interim measure before it is shipped to the deep geologic repository. The use of a large container to overpack several small canisters will reduce costs by reducing the total number of pieces that have to be handled for interim storage, shipment, and disposal at the repository. An overpack also reduces the requirements for the extensive

decontamination of inner canisters and reduces requirements and expenses for welding with remotely operated equipment.

The preferred canister/overpack configuration has the potential to reduce the total estimated cost of the waste form by as much as $40 million. The savings, however, could be partially, if not totally, offset by other costs (e.g., the operating costs of the storage building).

Facility Layout Options. The reference facility is a canyon building with all of the necessary support structures. The most significant alternatives now being evaluated include the following:

- A detached facility that is part of a complex of buildings consisting of pretreatment facilities, a low-level waste (LLW) vitrification facility, an HLW vitrification facility, and buildings supporting all three processes

- A common facility that houses parallel LLW and HLW vitrification lines

- A facility with dual vitrification lines that processes LLW until the need for a high LLW throughput diminishes to the extent that one of the lines can be converted to HLW processing.

The detached facility as part of a complex has the potential to save hundreds of millions of dollars in capital and operating costs over the

reference case. The savings are due, primarily, to the sharing of common support structures such as laboratories and effluent processing systems.

The use of a common facility that houses both an LLW and an HLW vitrification line has the potential to save an additional $500 million in capital costs alone. The savings are due, primarily, to the sharing of common support systems such as offgas, liquid effluent treatment, utilities, and remote maintenance cells.

Finally, a facility with an LLW vitrification line converted to an HLW vitrification line will be investigated sometime within fiscal year 1995. It is anticipated that some savings can be identified by using even more equipment for both LLW and HLW vitrification.

Contracting Strategy. The reference contracting strategy is competitive bid, government financed, design and construction with operations provided by the site operating contractor. Alternatives that are now being evaluated include the following:

- A commercialization strategy where a single contract is awarded for design and construction of a turn-key facility. The site operating contractor would operate the facility.

- A privatization strategy where the capital needed for design and construction comes from the private sector. The private investors are paid by the quantity of material processed by their facilities.

In general, commercialization and privatization strategies are designed to shift ownership from the government to the contractors who are performing and/or financing the work. The shift in ownership is designed to take advantage of the relative efficiencies associated with private industry. The down side of these approaches is that the HLW program would be less flexible for changes that are often demanded by interests outside of the vitrification project. The 20-year duration of the program makes it particularly vulnerable to changes.

The traditional approaches are better suited for a changing regulatory environment. In such approaches, project ownership is diffused and input from all interests is readily accommodated throughout the duration of the program. The down side of this approach is that the program becomes vulnerable to cost overruns and schedule slippages.

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LIST OF TERMS

A-E	Architect-Engineer
CM	Construction management
CCM	Cold crucible melter
CPFF	Cost plus fixed fee
CPIF	Cost plus incentive fee
CSTR	Continuous stirred tank reactor
CVS	Composition Variability Study
DF	Decontamination factor
DN	Dilute noncomplexed
DOE	U.S. Department of Energy
DQO	Data Quality Objective
DRE	Destruction and removal efficiency
DSSF	Double-shell slurry feed
DST	Double-shell tank
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESW	Enhanced sludge washing
FTE	Fulltime Equivalent
FY	Fiscal Year
GCC	General Construction Contractor
HLW	High-level waste
HTCM	High-temperature ceramic melter
HTM	High-temperature melter
HVAC	Heating, ventilating, and air conditioning
HWVP	Hanford Waste Vitrification Project
LFCM	Liquid-fed ceramic melter
LLW	Low-level waste
MOG	Melter Offgas
NCRW	Neutralized Cladding Removal Waste
NOI	Notice of Intent
OCB	Operations Control Building
OCRWM	Office of Civilian Radioactive Waste Management
OSB	Operations Support Building
PCT	Product Consistency Test
PFP	Plutonium Finishing Plant
PNL	Pacific Northwest Laboratory
PSCM	Pilot-Scale Ceramic Melter
PVV	Process vessel ventilation
PUREX	Plutonium-uranium extraction
REB	Regulated Entrance Building
RFQ	Request For Qualification
SEIS	Supplemental Environmental Impact Statement
SM	Stirred melter
SST	Single-shell tank
TOE	Total On-Line Efficiency
TRU	Transuranic

LIST OF TERMS (CONTINUED)

TWRS	Tank Waste Remediation System
VOG	Vessel Offgas
WESF	Waste Encapsulation and Storage Facility
WHC	Westinghouse Hanford Company
WIPP	Waste Isolation Pilot Plant
WVNS	West Valley Nuclear Services

ALTERNATIVE CONCEPTS FOR TREATMENT AND DISPOSAL OF HANFORD SITE HIGH-LEVEL WASTES IN TANKS

1.0 INTRODUCTION

This evaluation report is prepared in response to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1994) Milestone M-51-01 which states:

> "Provide report to Ecology and EPA on evaluation of alternative concepts for treatment and disposal of high-level Hanford tank wastes.
>
> Some innovative approaches, such as privatization of the high-level waste vitrification facility, have recently been proposed which may have significant schedule, cost, or environmental advantages which could improve the new program strategy.
>
> Options may be identified which have the potential to significantly improve the tank waste disposal strategy. A systems engineering approach will be used to define and evaluate the options. This evaluation is not intended to provide options which marginally improve the reference strategy. Options which maintain or enhance environmental conditions and 1) significantly improve reference case schedules or 2) substantially reduce cost while maintaining or improving reference case schedules will be proposed through the approved change control process."

Based on recent discussions with the Washington State Department of Ecology (Ecology) regarding the interpretation of the milestone wording, the following assumptions have been made:

- Alternative concepts that are considered should focus primarily on high-level waste (HLW) vitrification. Considerations of the other disposal program elements (e.g., pretreatment) should be included only as they pertain to, or potentially impact, the HLW vitrification function.
- Three general categories of alternative concepts should be considered for possible evaluation:
  - Process/product alternatives
  - Facility layout options (capital/operating)
  - Acquisition strategies.
- Alternative concepts that are selected for systems engineering evaluation should have a major impact on one or more of the following:

- Cost (>$0.5 billion in capital and/or operating cost savings)
- Schedule (>3 to 5 year acceleration in start and/or completion of the mission)
- Environmental concerns/performance assessment.

• Qualitative risk assessment on selected alternative concepts should provide relative ranking of risk to the HLW program.

2.0 BACKGROUND

This chapter provides background information on the evolution of the current HLW vitrification program. Chapter 2.0 also discusses the baseline adopted for the program and the associated baseline assumptions. Chapters 4.0 through 7.0 discuss the status of work needed to validate the assumptions.

2.1 HANFORD DEFENSE WASTE ENVIRONMENTAL IMPACT STATEMENT

The U.S. Department of Energy (DOE) addressed disposition of tank waste (and other radioactive waste at the Hanford Site) in a series of documents that culminated with the *Final Environmental Impact Statement for the Disposal of Hanford Defense, High-Level, Transuranic, and Tank Wastes, Hanford Site, Richland, Washington; (HDW-EIS) Record of Decision* (53 FR 12449). The record of decision, substantiating results of many previous engineering studies, directed the following for the HLW program:

- Retrieve and separate all existing and future double-shell tank (DST) wastes into high-activity and low-activity fractions.
- Process the radioactive HLW fraction into a borosilicate glass in the Hanford Waste Vitrification Plant (HWVP) and dispose in a geologic repository.
- Dispose of overpacked capsules containing ^{137}Cs and ^{90}Sr in a geologic repository.

The final HDW-EIS record of decision committed to the preparation of a supplemental environmental impact statement (SEIS) for the single-shell tank (SST) waste. The SEIS has been replaced by the Tank Waste Remediation System (TWRS) Environmental Impact Statement (EIS) (FR 6450-01-P).

2.2 TANK WASTE REMEDIATION SYSTEM ENVIRONMENTAL IMPACT STATEMENT

Although not formally accepted in writing by the DOE, plans are for the TWRS EIS to evaluate and present five different alternatives for public review:

1. **No Action Alternative.** The No Action Alternative leaves the waste in tank storage. The tanks will be monitored until loss of institutional control, which is assumed to occur in 100 years.
2. **Tri-Party Agreement (Preferred Alternative).** The Tri-Party Agreement (Preferred Alternative) separates SST and DST wastes into an HLW and low-level waste (LLW) fraction. The respective fractions would be vitrified into a glass form suitable for final disposition.
3. **Extensive Pretreatment Alternative.** The Extensive Pretreatment Alternative involves the use of sophisticated processes to separate SST and DST wastes into HLW and LLW fractions.

4. **No Pretreatment Alternative.** The No Pretreatment Alternative vitrifies all waste without any pretreatment.

5. **In-Place Stabilization and Disposal Alternative.** The In-Place Stabilization and Disposal Alternative uses three processes: (1) in situ chemical stabilization, (2) in situ radio frequency drying, and (3) in situ vitrification.

A Notice of Intent (NOI) to file the TWRS EIS was issued in mid-1994. A subcontractor, Jacobs Engineering Company, has been employed to write the Statement. Nine technical data packages will be compiled as input to Jacobs Engineering by mid-1995. A Record of Decision is due November 1996.

2.3 TANK WASTE DISPOSAL PROGRAM REDEFINITION

As part of the TWRS rebaselining effort during fiscal year 1993, a New Technical Strategy was defined based on the application of systems engineering to identify the best technical options for disposal of tank wastes. The DOE decided that the new baseline would include the retrieval of all underground storage tanks, including the SSTs.

Two bounding waste separations strategies were identified as part of the New Technical Strategy.

1. **Minimum Pretreatment Strategy**

   - Wash sludges to remove water-soluble species from insoluble.
   - Separate radioactive cesium from other water-soluble species to produce a low-activity feed stream that is suitable for immobilization and onsite disposal.
   - Use proven processes and minimize equipment and facility costs for pretreatment.

     This was considered minimum pretreatment because it required minimal facilities to implement (DSTs for decantation and sludge washing and a facility for the ion exchange process) and the degree of waste separations needed (i.e., radionuclides from inert constituents) was the least.

2. **Extensive Separations Strategy**

   - Maximum removal of radionuclides from the HLW to produce a low-activity feed stream suitable for grouting and onsite disposal
   - Minimum HLW volume
     - Early pretreatment of supernatant and salt cake to produce LLW
     - Later pretreatment of sludges to produce a concentrated HLW

- Requires a substantial investment in technology to develop numerous chemical separations processes and more equipment and facilities to implement.

  The objective of this extensive separations approach was to minimize the inventory of radionuclides left at the Hanford Site in near-surface disposal and to minimize the volume of the HLW to be sent to the repository.

2.4 RESULTS OF THE TRI-PARTY AGREEMENT NEGOTIATIONS

In March 1993 the DOE proposed the New Technical Strategy to Ecology and the U.S. Environmental Protection Agency (EPA) during the renegotiation of the Tri-Party Agreement, in the form of a request to modify the original agreement. The negotiations involved input from stakeholders (e.g., regulators, public interest groups, Indian tribes).

As a result of the negotiations, pretreating the LLW for further radionuclide removal and then processing the LLW stream into a vitrified waste form was selected as the preferred approach. Enhanced (caustic) sludge washing (ESW) was chosen over the standard (water) wash as the primary pretreatment process for the waste going to the HLW vitrification facility. The ESW process further reduces the volume of HLW to 60 percent of that from a standard wash. However, the HLW processing rate is still much larger than what was originally envisioned for the HWVP. Since it was no longer large enough to complete the entire TWRS mission of vitrifying the HLW fraction of all tank wastes in the prescribed timeframe, construction of the HWVP was halted.

This strategy enables early progress in immobilization of waste using existing technology and allows improved pretreatment capability to be incorporated later, if necessary. Details of the baseline approach for vitrifying the HLW consistent with the Tri-Party Agreement are presented in the following sections.

2.5 HIGH-LEVEL WASTE PROGRAM BASELINE

The primary objective of the TWRS HLW program is to immobilize the HLW fraction of the tank waste and seal it in containers that can be temporarily stored at the Hanford Site until shipment to a geologic repository for final disposal. The technical strategy for achieving this objective is to vitrify the waste in a glass matrix that is sealed in stainless steel canisters. To achieve this objective, processes and equipment are being identified, designed, tested, and evaluated and technologies are being developed that would lead to the design, construction and operation of a government-owned and operated vitrification facility. As an alternative to this traditional DOE approach, the DOE also is evaluating the technical and economic advantages and disadvantages of a proposal to privatize the vitrification facility.

Currently the HLW program is performing equipment development activities on both high-temperature and stirred melter concepts. A melter assessment task is also in progress to identify and evaluate other melter technologies that have potential application for vitrifying HLW. Glass formulation and other process development activities that support the melter evaluation (near-term) and conceptual design of the HLW vitrification facility (long-term) are also in progress.

2.6 KEY BASELINE ASSUMPTIONS

Several key assumptions have been used as the basis for the current multi-year program planning (WHC 1994) of HLW vitrification at the Hanford Site:

- The HLW vitrification plant will start up in 2009 and will be a government-designed, constructed, and operated facility. Alternatives to a government-designed, constructed, and operated facility are given in Chapter 7.0, Acquisition Strategies.

- The HLW fraction from all waste storage tanks (both DSTs and SSTs) will be vitrified and placed in sealed canisters. Alternatives to vitrification will be evaluated as discussed in Section 2.2.

- The sealed canisters of vitrified waste will be disposed at a single geologic repository, operated by the Office of Civilian Radioactive Waste Management (OCRWM), starting in 2035 and completed by 2040. Alternatives to this disposal strategy will be evaluated as discussed in Section 2.2.

- The HLW form will be glass contained in a canister that is larger than those currently designed for use at Savannah River and West Valley. A discussion of the effect of canister size is given in Section 5.7.

- Transuranic (TRU) waste will not be vitrified separately from the remainder of the HLW tank wastes unless there is an economic incentive to do so. The disposition of TRU waste is discussed in Section 5.3.

- The HLW vitrification facility will have adequate throughput capacity to complete its vitrification mission by 2028, using a slightly caustic sludge washing pretreatment and assuming a nominal waste oxide loading of 25 percent. Based on this operating scenario, it is estimated that as much as 28,000 m^3 of vitrified HLW will be produced. Feed preparation options are discussed in Sections 5.1 through 5.3.

- The HLW vitrification facility will be a standalone, dual-melter line facility that has a footprint approximately 25 percent larger than that of the HWVP design. Other options for the facility are described in Section 6.0.

- The HLW vitrification facility will use a canyon-type design. Other facility layouts are described in Section 6.5.

- The HLW program will build and operate a canister storage facility sufficient to store the entire volume of glass produced by the vitrification facility for a minimum of 30 years. An alternative to the canister storage facility will be evaluated as discussed in Section 2.2.

- Waste streams sent to the vitrification facility will meet feed specification(s) jointly developed by the Pretreatment, LLW, and HLW program elements. Feed preparation options are discussed in Sections 5.1 through 5.3.

- Overpack of the cesium and strontium capsules will be acceptable to OCRWM as a waste form for disposal and will be performed in the HLW vitrification facility. Before overpacking, these capsules will continue to be stored in the Waste Encapsulation and Storage Facility until the HLW storage facility is built. An alternative to this strategy will be evaluated as discussed in Section 2.2.

- Two vitrification system candidates will be selected for further testing and evaluation. The reference melter system that is carried into conceptual design will be one of these two candidates and a modified or new pilot-scale system will be needed for further testing. A discussion of melter options is given in Section 5.4.

- Approximately 10 basic blended feed stream types will require waste form qualification. A discussion of blending operations is given in Section 5.2.

- The HLW program will include feed lag storage in its scope. The functions and requirements of the HLW Program will be further developed in fiscal year 1995 (see Section 4.1).

- The HLW program will either rework or overpack out-of-specification canistered waste. In the event that neither rework nor overpacking is feasible, a nonconformance waiver would be requested from the repository. A discussion of quality control options is given in Section 5.6.

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3.0 RECOMMENDATIONS

Recommendations for the HLW program are as follows:

- Continue current blending and process control studies to optimize waste loading.
- Preserve cost-effective technical features used for HWVP and other United States vitrification facilities.
- Continue to explore new and innovative methods that would realize significant cost and schedule savings through a combination of technology transfer from industrial and foreign experience and an aggressive technology development program.
- Interface with OCRWM to determine the acceptability of the waste form and packaging alternatives that are being considered.
- Identify and complete trade studies that have the potential to significantly improve the tank waste disposal strategy.
- Perform the functional decomposition of the four HLW program functions (see Section 4.1), using the systems engineering approach, to ensure that the HLW vitrification system is sufficiently defined.
- Continue to test and evaluate the two most promising vitrification systems through Fiscal Year (FY) 1997 and recommend one to carry forward as the primary system for the remainder of the conceptual design phase; maintain the second vitrification system concept as a backup until the start of definitive design in December 1998.
- Perform glass formulation, composition variability studies, and waste form qualification testing that support the melter system evaluation and selection activities.
- Perform the majority of the melter testing using small-scale melters; use limited pilot-scale testing to confirm anticipated scale-up performance.
- Develop representative waste simulants for nonradioactive melter testing and evaluation studies.
- Perform limited melter testing using pretreated radioactive waste to the extent required to confirm the results of testing performed with simulants.
- Complete the evaluation of the technical and programmatic advantages and disadvantages of privatization and modify the HLW program strategy and program plan to accommodate this approach, if it is selected.

- The *Tank Waste Remediation System Multi-Year Work Plan* (WHC 1994) was based on a planning assumption of two melters while the technical baseline consists of one melter. Existing trade studies did not use a second operating line to achieve a desired operating efficiency because that concept would have doubled many of the estimated costs. A concept that depends on multiple lines to operate while the first line is down for repair will be considered if plant operating efficiency cannot be achieved with a single operating line.

Using the conclusions of trade studies that have been completed so far, the HLW program should begin planning on the following system configuration:

- HLW vitrification will be part of a complex of processes that share a number of common utilities.

- The HLW glass product will have a nominal 45 percent waste oxide loading.

- The 45 percent waste oxide loading will be achieved, in part, by using enhanced sludge washing and blending of waste.

4.0 SUMMARY OF FUNCTIONAL ANALYSIS

Chapter 4.0 discusses how the information in this document fits into the systems engineering process. The following was taken from the *High-Level Waste Vitrification Program Definition and Implementation Strategy* (Powell 1994).

4.1 SYSTEMS ENGINEERING

Systems engineering, which is a structured process used to identify and implement a complete, traceable solution to a mission need for complex programs or projects, is being applied to TWRS. Work is currently underway using this approach to develop a consistent set of functions and requirements that satisfy the mission needs.

Three systems engineering functions comprise the HLW program's contribution to completing the TWRS mission: (1) Immobilize HLW and TRU Waste (Function 4.2.2.5.1), (2) Prepare Cesium/Strontium Capsules for Disposal (Function 4.2.2.5.2), and (3) Interim Store Immobilized Waste (Function 4.2.2.5.3). They involve the vitrification and interim onsite storage of the HLW and TRU waste, as well as the retrieval and packaging of cesium and strontium capsules currently stored in the Waste Encapsulation and Storage Facility. For program planning purposes it has been assumed that HLW and TRU waste can be blended, vitrified, and disposed at the geologic repository.

The Treat HLW/TRU Waste subfunction (4.2.2.5.1.1) is divided into five subfunctions (NOTE--These subfunctions are currently being revised and are subject to change):

1. **Prepare Melter Feed (4.2.2.5.1.1.1).** Combine and condition pretreated HLW/TRU waste and scrap glass with glass frit and/or glass forming additives and chemicals to provide a feed stream suitable for vitrification.

2. **Vitrify HLW and TRU Waste (4.2.2.5.1.1.2).** Vitrify prepared melter feed consisting of pretreated HLW/TRU waste, scrap glass, glass frit, and/or glass forming additives and chemicals.

3. **Encapsulate Immobilized HLW and TRU Waste (4.2.2.5.1.1.3).** Perform all functions required to package the immobilized HLW and immobilized TRU including minimum functions required to seal and decontaminate the packages.

4. **Inspect Immobilized HLW and Immobilized TRU Canisters (4.2.2.5.1.1.4).** Inspect and survey the sealed immobilized HLW and immobilized TRU containers.

5. **Prepare Immobilized Wastes for Transport (4.2.2.5.1.1.5).** Load the immobilized HLW and/or immobilized TRU containers on transport mechanisms for transport to interim storage.

4.2 PROGRAM REQUIREMENTS AND DRIVERS

The requirements to address each of these functions are also being developed through the systems engineering process. A critical requirement for the HLW program and for its supporting technical activities to proceed effectively is to establish product specifications for the pretreated feed streams that will be immobilized as HLW. Preliminary feed specifications are being prepared for use in the TWRS technical baseline. A clear understanding of the tank waste characteristics is also critical to defining the requirements for the process flowsheet. Data Quality Objectives (DQO) for HLW vitrification are being prepared as part of the pretreatment program. Technology evaluation in the laboratory using simulated and actual wastes is another element of developing the process requirements.

One of the key drivers for separating the tank waste into an optimally reduced volume of HLW with the remaining volume as LLW is the anticipated cost of disposing of defense HLW in the national geological repository which is projected to cost significantly more per unit volume than near-surface disposal of LLW at the Hanford Site.

Another driver for the disposal program is an urgency to make progress in cleanup of the Hanford Site, particularly to initiate retrieval, pretreatment, and disposal of the tank waste. Specifically retrieving these wastes from tanks that are leaking or have the potential to leak waste to the groundwater, and transforming those wastes into a more chemically stable form is highly desirable, even if it is necessary to store the canistered HLW at the Hanford Site for several years while a repository is sited and built. This urgency is captured in the aggressive schedule of Tri-Party Agreement milestones agreed to by the DOE, the EPA, and Ecology in January 1994 (Ecology et al. 1994).

5.0 PROCESS/PRODUCT ALTERNATIVES

Chapter 5.0 describes the HLW feed processes that could have a profound effect on the quantity of glass sent to the repository. The status of the melter selection, process control, and then the types of glass that are under consideration also are discussed.

5.1 ENHANCED SLUDGE WASHING

Hanford Site tank sludges contain sizeable quantities of aluminum, chromium, and phosphorus solids, which have a significant impact on the volume of HLW glass produced. Large percentages of these solids can be converted to soluble forms of aluminum, chromium and phosphorus by leaching with caustic solutions (i.e., ESW), thereby reducing the volume of feed to the HLW vitrification facility and the amount of HLW glass produced. Further, caustic leaching can be performed in the existing DSTs rather than building new, expensive facilities for pretreatment.

The following ESW discussion comes from Orme (1994) and Gasper (1994) and is paraphrased in some instances.

5.1.1 Description of Pretreat In-Tank

The ESW process uses leaching washes with 3 M caustic solution to remove selected components (aluminum, chromium, and phosphorus from the tank waste sludges), followed by dilute caustic washes to remove the interstitial dissolved components. The process is based on experience at the Savannah River Site, and preliminary caustic washing results with a limited number of Hanford Site sludge samples. Initial indications from process mass balance calculations are that the HLW oxides remaining after ESW will be about 60 percent of the amount remaining after simple water washing alone.

Implementation of an in-tank pretreatment operation requires that sufficient tank space has been freed to receive retrieved sludges into the 241-AN, -AW, and -AP tank farms. The space is made available by retrieving and evaporating dilute noncomplexed waste (DN), and by processing the double-shell slurry feed (DSSF) wastes through the LLW pretreatment facility, followed by vitrification of the pretreated DSSF. The pretreatment facilities are scheduled to begin operations in December 2004.

Orme (1994) describes operation of an in-tank sludge treatment operation that accomplishes multiple stages of washing (initial wash concurrent with retrieval, followed by a first stage enhanced caustic wash, followed by three dilute caustic washes) and three stages of blending to arrive at treated sludges that are suitable for vitrification; they are summarized below.

5.1.1.1 Initial Wash. The retrieval of waste with dilute caustic solution and accumulation of waste from different tanks constitutes an initial wash and blending. The initial wash effectively occurs during retrieval as salts are dissolved and insoluble solids are mobilized and dispersed through the slurry; blending occurs when slurries from different sources are combined in an accumulation tank.

The output from several simultaneous retrieval operations is accumulated in a 3,800-m^3 (1-Mgal) staging tank. This staging tank may be part of the Waste Staging and Sampling Facility, or another underground tank set aside for that purpose. The development of criteria for the sequencing of retrieval operations is discussed in Section 5.2.

5.1.1.2 Settle and Decant. It is expected that a sludge treatment operation will be used utilizing 18 DSTs to perform the functions of settling, decanting, leaching, washing, accumulating, and staging pretreated waste to subsequent out-of-tank pretreatment operations or to vitrification in the case of pretreated solids. Each washing tank is equipped with a floating suction decant pump, a transfer pump, and two or more mixing pumps. The waste inlet lines extend to near the bottom of the tank to facilitate settling.

5.1.1.3 Dilute Caustic Washing. Dilute caustic is added to the first wash tank, the solids are mobilized and washed, and the mobilized slurry is transferred to the second wash tank. The supernatant solution is decanted. The wash is repeated two more times. Three stages of washing are required because the settled solids layer, being only 20 wt% solids, is mostly interstitial liquor. The washed solids in the fourth wash tank are remobilized with recycled condensate and transferred to an HLW accumulation tank.

5.1.2 High-Level Waste Volume Projections

Results of laboratory tests of sludge caustic leaching (Lumetta 1994) are used indirectly to calculate flowsheet mass balance impacts. The TWRS process flowsheet (Orme 1994) is based on a blending of all tank waste (Total Blend). The flowsheet model has no provisions to account for the leaching efficiency of individual tanks or blends of selected tanks.

In the flowsheet, a set of overall sludge caustic leaching efficiency assumptions is used to calculate the removal of aluminum, chromium, and phosphorus from sludges. Of these three components, only the leaching efficiency of phosphorus has changed from the value assumed at the time of Tri-Party Agreement negotiations at the end of FY 1993 (Ecology 1994). The phosphorus leaching efficiency has been lowered from 80 percent to 70 percent based on the results of laboratory tests reported in the FY 1994 status report (Lummeta 1994). The resulting increase in volume of HLW glass due to the decreased leaching efficiency of phosphorus is not significant.

Table 5.1-1 projects the number of canisters for four waste pretreatment options: sludge washing only (Option 1), ESW (Option 2), extensive separations (Option 3), and no separations (Option 4). The number of canisters is provided for two types of waste canisters: the standard waste form canister (DOE 1993), and the TWRS reference canister (Boomer et al. 1994). The standard waste form canister is identical to the canister described in the DOE *Waste Acceptance System Requirements Document* (DOE 1993). The TWRS reference canister (Boomer et al. 1994) is similar to the West Valley canister design and contains twice as much glass as the standard canister.

Table 5.1-1. Number of Canisters for Hanford Site High-Level Waste Pretreatment Options.

Type of pretreatment	Total HLW glass (Mg)	Number of canisters	
		Standard Waste Form Canister[e] (0.61 m OD x 3.05 m)	TWRS Reference Canister[a] (0.68 m OD x 4.57 m)
Option 1 - Sludge Wash	63,600[a]	38,500	19,000
Option 2 - Enhanced Sludge Wash	22,800[b]	13,800	6,800
Option 3 - Extensive Separations	3,300[c]	2,000	1,000
Option 4 - No Separations	368,000[d]	223,000	110,000
Approximate weight of vitrified waste per canister (kg)	-	1,650	3,350
Approximate total weight of filled canister (kg)	-	2,100	4,100

[a]Boomer et al. 1994
[b]Orme 1994
[c]Johnson 1994
[d]Boomer et al. 1993
[e]DOE 1993.

Sludge washing (Option 1) separates the waste into solid and liquid fractions by settling, decanting, and simple dilution of the interstitial liquids.

ESW (Option 2), which includes sludge washing (Option 1), solublizes large amounts of aluminum, chromium, and phosphorus solids by leaching with caustic solutions. The result is a sizeable reduction in the amount of HLW

glass produced (22,800 Mg versus 63,600 Mg) with ESW (Option 2) when compared to sludge washing (Option 1) as illustrated in Table 5.1-1. The reduction in the volume of HLW glass with ESW can be attributed to (1) the solubilization of aluminum, chromium, and phosphorus that would have otherwise gone to HLW and (2) the higher waste loading in glass (>45 wt% versus 25 wt%) that is achievable when glass limiting constituents (chromium and phosphorus) are leached from the sludge. Glass formulation models based on a uniform blend of all tanks have predicted that glasses with high waste loadings (~50 wt%) probably have acceptable properties (durability, melting point, viscosity, and conductivity). The higher waste loading is a key aspect of the ESW flowsheet that remains to be verified by empirical glass formulation studies using different waste blends. See Section 5.5 for a discussion of glass formulation.

Information on canister projections will be used in the decision process described in *Enhanced Sludge Washing Evaluation Plan* (Jensen 1994) to determine if ESW results in a reasonable quantity of HLW glass. The criteria for a reasonable quantity of glass will consider policy issues, technical information, cost, and stakeholder values.

Option 3 encompasses extensive separations, including the CLEAN process proposed by PNL (Knutson et al. 1994). Extensive separations product estimates typically vary from 2,000 to 1,000 standard canisters, depending on the assumptions and the exact process chosen. The CLEAN process is one of several processes using complex flowsheets with dozens of separation processes intended to minimize the final HLW volume and radiotoxicity of the LLW product. The CLEAN option is the only option in the Knutson et al. (1994) study capable of producing Class A LLW. Generally, the extensive separation options cause greater personnel exposure to radiation than other options. Extensive separation options also tend to require significant technology development and demonstration. In terms of total cost, there is no advantage to extensive separations over the existing baseline pretreatment technologies.

Option 4, the no separations option, does not segregate the retrieved waste into LLW and HLW fractions. All of the retrieved waste is treated for offsite disposal. The offsite disposal processes establishes a cost baseline for evaluating the savings derived from other separations options. The entire waste volume is destined for the HLW and/or TRU waste treatment for offsite disposal. The no separations option results in the largest waste volumes.

These options will be more fully developed in the upcoming EIS (see Section 2.2).

5.1.3 Pretreat Out-of-Tank

Pretreatment out-of-tank includes decanted supernatant and wash solutions. The treatment entails evaporation of dilute retrieved waste to a standard solution, clarification through a glass frit deep bed filter, and ion exchange to remove ^{137}Cs. The need for out-of-tank pretreatment of sludges by extensive separations is being evaluated (i.e., acidic dissolution of sludges and subsequent separation of radionuclides). A decision on extensive separations is scheduled for March 1998.

5.1.4 Sludge Washing Test Plan

The sludge samples tested during FY 1994 and the standard suite of tests to be performed on the sludge samples are identified in *Laboratory Development of Sludge Washing and Alkaline Leaching Processes: Test Plan for FY 1994* (Rapko 1994). Although the test plan only includes work performed in FY 1994, the test approach described in the test plan can be extended to laboratory tests planned for FY 1995 through FY 1997 because the standard suite of sludge washing and alkaline leaching experiments is expected to change very little from year to year. The schedule for collecting core samples to provide waste material and the process development laboratory testing of ESW planned during the period FY 1995 through FY 1997 is provided in WHC-EP-0805, *Enhanced Sludge Washing Evaluation Plan* (Jensen 1994). The plan is to conduct process development laboratory testing on a total of 76 cores; 16 in FY 1995, 30 in FY 1996, and 30 in FY 1997. The tanks from which these 76 cores are to be taken represent approximately 70 percent of the sludge inventory.

5.1.5 Enhanced Sludge Washing Laboratory Tests

Sludge washing and alkaline leaching experiments completed through the third quarter of FY 1994 are reported in *Washing and Alkaline Leaching of Hanford Tank Waste: A Status Report* (Lumetta 1994), PTD 5000 and 5005.

5.1.6 Computer Modeling of Enhanced Sludge Washing Test Results

The progress on modeling sludge washing and alkaline leaching by using calculated activity coefficients is reported in *Computer Simulation of Laboratory Leaching and Washing of Tank Waste Sludges* (Meng 1994). Use of activity coefficients allows simulation of sludge washing and alkaline leaching based on fundamental thermodynamic principles instead of the empirical approach currently used for flowsheet calculations. The computer program selected for this task is the Environmental Simulation Program (ESP) by OLI Systems. OLI Systems has been responsive to requests for improvements and adding new data to the model. Version 4.0 of the program was beta tested at the Hanford Site and is now released.

As this model is improved, it will become a more useful tool for predicting leaching behavior. There are a number of deficiencies in the model that require correction; most appear to be a matter of adding the appropriate data to the data bank.

5.1.7 Summary

The ESW process is expected to separate some soluble problem chemical components from the HLW stream. This will reduce the amount of problem vitrification compounds containing sludge going to HLW and slightly increase the amount of LLW. Current HLW program assumptions are that the HLW vitrification facility will have as much as 28,000 m^3 of vitrified HLW, assuming a nominal waste oxide loading of 25 percent.

Using ESW, the HLW problem components could be removed to allow the waste oxide loading in the glass to increase to 45 percent. This increase in waste loading and the decrease in total mass to the HLW vitrification process will allow only about 11,000 m^3 of vitrified HLW to be produced. Therefore, ESW would significantly reduce the total number of HLW logs produced. Currently ESW is considered to be a probable pretreatment process for HLW. A better estimate of the number of HLW logs saved will be available when characterization of the tanks is more complete (WHC 1994), and laboratory leaching tests using actual tanks wastes are completed (PTD 5000 and -5005, PTL 5010 and -5015) as noted in WHC (1994). Completion of these modeling studies also will help confirm the significant reduction in estimates of HLW produced.

5.2 WASTE FEED BLENDING

The following discussion is taken from Hoza (1994) and is paraphrased in some instances. The Hoza (1994) report is the most recent completed study available on blending of waste to reduce the amount of HLW glass. Studies are continuing at WHC and PNL to determine better blending strategies, improve blending models and enhance process continuity.

5.2.1 Introduction

Many waste feed streams for the high-level and low-level vitrification facilities have components that limit waste loading in the respective waste glasses. Blending of waste feed streams may be a simple but effective method of increasing the waste loading in glass. The basic concept is that a feed high in one component, relative to feed limits, would be mixed with another feed that contains a low level of the same component. The blended wastes could be processed with greater overall waste loading and a lower volume of waste glass produced. Blending waste also would reduce the number of waste forms for repository qualification.

5.2.2 Recent Work Summary

In Hoza (1994) the effect of blend size (number of tanks per blend) on blending benefit were examined, two methods of solving the discrete blending problem were examined, and several blend formulation strategies were evaluated. An approach for using the results of this work to develop and evaluate retrieval sequences was proposed.

The blend size study examined blend performance for 30 randomly generated orderings of 87 tanks. It was found that, for the best ordering, optimal blending performance could be obtained with as few as 10 tanks per blend. For the worst ordering, optimal performance was still not achieved for 45 tanks per blend. Currently the TWRS HLW baseline assumes a perfectly blended (total blend) feed, except for waste form qualification considerations. The maximum improvement expected in production of HLW logs from the no blend case to the total blend case was found to be on the order of 25 percent, or 75 percent of

the glass logs that would be produced from the worst case of no blending (see Figure 5.2-1).

This works out to be about a worst case 33 percent increase in disposal costs from baseline if the blending is not performed. At a cost of $200,000/canister that would be $2.5 billion in repository costs. See Section 5.6.3, Option 1 (sludge washing), for canister basis.

In Hoza (1994) several strategies for generating blending combinations were explored. Formulating blends such that all have the same limiting constraint as the Total Blend of the waste set results in optimal blending performance but may not be possible for small waste sets or blend sizes. Several other strategies were compared.

An approach for developing and evaluating retrieval sequences was proposed. The approach would use methods described in Hoza (1994) to generate retrieval strategies and candidate sequences. The candidate sequences would then be evaluated with tank processing logistics models under development at WHC. One candidate strategy proposed, if it performs as well as expected, could result in optimal blending performance and produce only four distinct HLW feed compositions to be vitrified.

5.2.3 Recent Work Assumptions

Several assumptions and simplifications were made for the work discussed in Hoza (1994). The key assumptions are listed below.

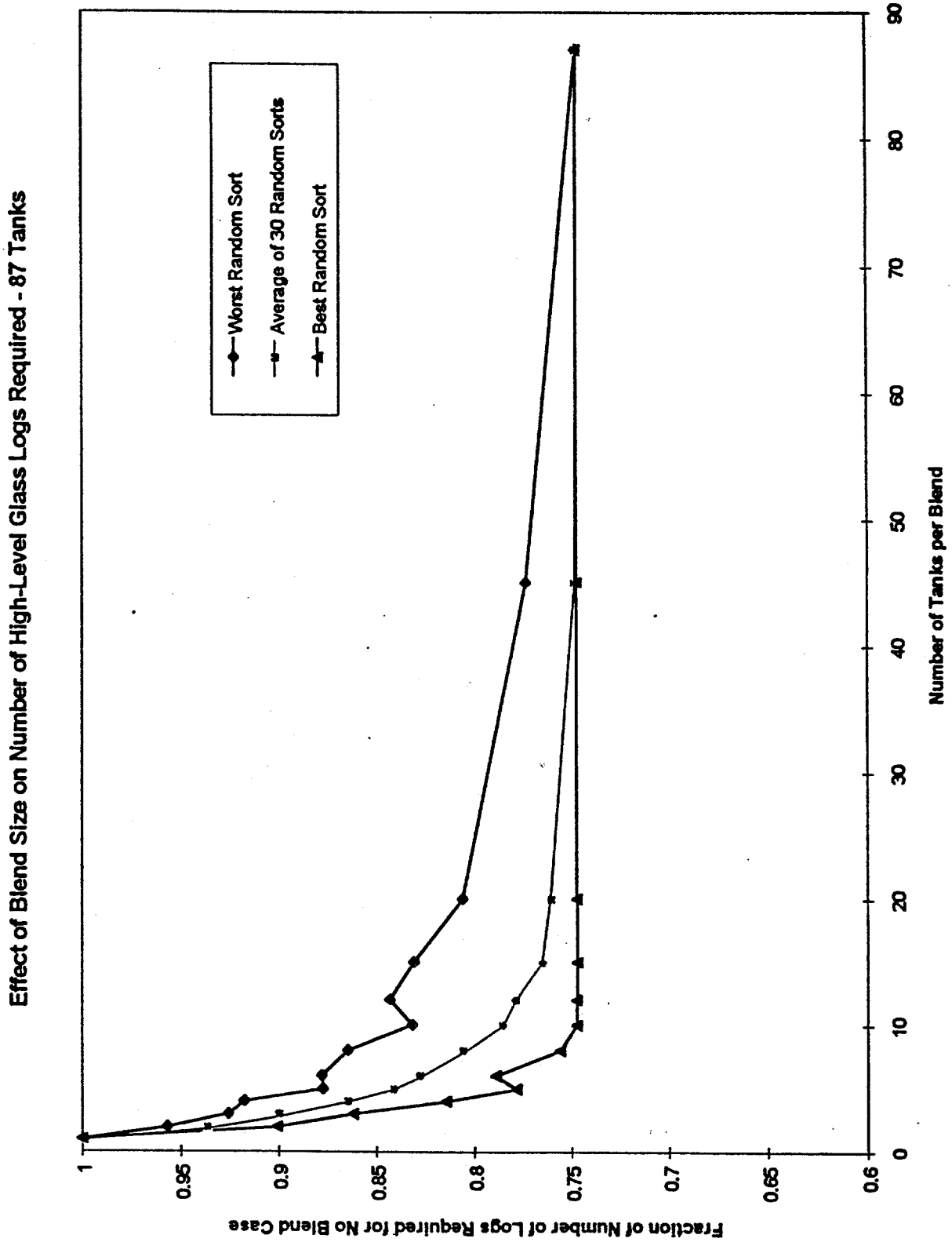
1. The calculated HLW compositions came from the Hoza and Geeting blending study for 87 tanks (Hoza and Geeting 1993). The set consisted of all tanks for which tank inventories were readily available (95 tanks) minus eight tanks (201-C, 202-C, 203-C, 204-C, 105-U, 106-U, 104-TX, 107-TX) for which the reported total oxide mass was less than 100 kg. While not all 177 tanks were used in this study, it was assumed that 87 tanks established a large enough subset for the results of the study to be meaningful.

2. All wastes were subjected to limited simulated pretreatment. It would have been impractical to perform an Aspen-simulated pretreatment for each of the tanks. Data for some of the tanks were received as washed sludge compositions. No additional pretreatment, such as ESW, was assumed.

3. For all blending and glass waste loading calculations performed with the OWL models, the constraint sets used were based on the *Phase II Composition Variability Study* (Hrma and Piepel 1992).

4. Glass logs were assumed to have a mass of 1,650 kg, not including canister.

Figure 5.2-1. Effect of Blend Size on Number of High-Level Glass Logs Required.



5.2.4 Caveats

While specific numerical results for assumed waste loadings and estimated number of glass logs required are presented in Hoza (1994) and this document, emphasis should not be placed on the absolute value of these results, since they are based on waste compositions that are not well known at this time, on a simple sludge wash, and on constraints that are likely to change. The important results are the general behaviors that are identified.

Other applicable caveats include the following:

- These results do not address tank farm logistics, safety issues, or processing schedules.
- All calculations have assumed perfect blending of wastes that are assumed to be uniform in composition.

5.2.5 Discrete Blending Problem and Solution Approaches

Section 5.2.5 describes the discrete blending problem, the model developed to solve it, and some calculated results. This represents a purely mathematical approach to blend formulation.

5.2.5.1 Problem Description. The problem is to form N blends from M tanks (M>N) such that the entire contents of each tank go entirely to a single blend. An added restriction is that each blend contain wastes from an equal number of tanks. An alternate restriction that could be used is that each blend have approximately the same mass. If neither of these restrictions is in place, the trivial solution would be to combine all wastes into one blend (resulting in the Total Blend).

5.2.5.2 Model Description. The discrete blending problem must be formulated such that blends are formed as described in Section 5.2.5.1 and each blend is vitrified such that the total number of glass logs for all blends is minimized. The problem can be stated as follows: minimize total number of glass logs for all blends subject to the following constraints.

- Blend formulation
- Glass mass balance
- Single component
- Multiple component
- Solubility
- Glass properties.

All results are bounded by the No Blend and the Total Blend cases. The No Blend case is the worst case and is certainly not under consideration for tank remediation. Even if it were, the "unintentional" blending obtained during retrieval and processing of waste would make it unachievable. Likewise, the Total Blend and Continuous Blend strategies are unlikely to be applied to the entire Hanford Site tank sets due to the impossibility of simultaneously retrieving all the wastes and then having to store them in one huge tank. It may still be possible, as is discussed in Hoza (1994), to

achieve comparable performance from a combination of tank waste blending strategies.

5.2.6 Blending Conclusions and Recommendations

Random sort strategies are not particularly effective at obtaining near optimal blends for small blend sizes. They are, however, easy ways to obtain some blend benefit, and are much more effective at larger blend sizes.

Blending by tank farm is not a particularly effective method for formulating blends. It can, however, play an important role in an overall retrieval and blending strategy.

Heuristic strategies can be very effective at achieving very good, if not optimal, blends. Better blend formulation models than those developed for this work are likely possible.

Mathematical methods are most effective for assigning tanks to blends to obtain optimal or near-optimal blends.

Blend size clearly plays a critical role. For the 87 tank case, one of 30 randomly generated tank orderings equaled the performance of the Total Blend. This is an OptiBlend, since all blends have the same binding constraint as the Total Blend. For small blend sizes and tank sets, an OptiBlend may not be possible; for larger tank sets and blend sizes, there may be numerous OptiBlend combinations.

5.2.6.1 Summary of Blending Behavior. This section summarizes the accumulated understanding of blending, its role, and its behavior. The information in this section is grouped into several categories.

1. Effect of Constraints

   - Blending is most beneficial when the system is tightly constrained by single component or multi-component crystallinity constraints.

   - Blending offers little reduction in the number of glass logs when all constraints except glass property are removed.

   - Blending wastes with the same binding constraint does not reduce the number of glass logs.

2. Effect of Blend Size

   - The benefit gained from blending increases with the number of wastes in each blend (i.e., for a given waste set, the Total Blend is always best).

3. Bounds on Blending Benefit

- For discrete blending of a waste set, the best blend may be as good as, but not better than, the Total Blend. The worst blend may be as bad as, but not worse than, the No Blend case. There may be a wide range of performance among the different blending combinations.

- Continuous blending of a waste set will equal the performance of the Total Blend.

5.2.6.2 Waste Segregation. Swanson (1994) presented some rough calculations that showed if high PO_4 waste is blended with high calcium waste before sludge washing, the glass volume increases. The calcium phosphate ($Ca_3(PO_4)_2$ precipitates and is not leachable by caustic wash. Therefore, the precipitate is segregated to HLW when it does not wash out of the sludge.

This chemical precipitation effect, and probably similar effects, can not be seen in any of the blending models currently used (ASPEN, ITHINK, OWL, ARENA/SIMON, etc.). The resolution, or level of detail of the models are not sufficient to analyze and detect these chemical interactions. Therefore any real blending evaluation needs to explicitly maintain waste segregation.

5.2.6.3 Criteria for Evaluating Blending Strategies.

- Blending strategies can be compared by comparing the total number of glass logs produced by vitrification of a set of tank wastes.

- Blending strategies must be evaluated in the context of the entire waste set:

  - Can form good blends but leave bad balance of wastes (waste complement)

  - Must consider effect of blend selection on total waste set

  - Determine total number of logs for waste set and its complement.

- Comparisons are only valid if the same glass constraints, feed composition, and pretreatment assumptions are used for all blending strategies compared.

5.2.6.4 Blend Formulation Strategies

1. What to Blend When

   - To gain maximum reduction in glass logs required, blend wastes of very different compositions.

   - Blending of some wastes done before sludge washing (SW) pretreatment ("early") should be of similar wastes to avoid dilution of species to be removed.

- Blend similar wastes before pretreatment and dissimilar wastes (pretreated early blends) after SW pretreatment.

- Waste segregation of certain wastes should be considered to avoid unwanted chemical interactions, such as precipitation, that would be detrimental to the process.

2. Techniques for Formulating Blends

- Based on preliminary results obtained, modeling appears to be a very effective mathematical method for formulating blends.

- Random blending may work satisfactorily with large sets of tanks and large blend sizes, assuming numerous optimal or near-optimal solutions.

- Blending by retrieval annex and tank farm is recommended only for early blending. It does not work well when it is used throughout the simulation. Unavoidable blending of wastes is not necessarily detrimental to the program.

- Alternate formulations of the blending optimization problem may prove useful in formulating blends.

- Formulating blends by distributing masses of limiting components evenly among the blends is a simple strategy that can be performed manually.

- Optimal blends (OptiBlends) can be produced if the binding constraint for each of the blends is the same as for the Total Blend. This may not be possible for small tank sets and blend sizes; but may be very achievable for larger tank sets and blend sizes.

5.2.6.5 Approaches for Increasing Waste Loading and Reducing Volume of Glass. There are several approaches that can be taken to increase the waste loading in the glass and reduce the volume of glass produced.

1. **Blend to Average out Troublesome Species.** Blending can effectively decrease the amount of vitrified waste glass produced, but the extent of the benefit from blending diminishes as constraints are relaxed and troublesome components removed (i.e., by pretreatment).

2. **Relax Constraints.** In the OWL calculations, the waste loading is increased until a constraint prevents it from being increased further. If one or more constraints are relaxed or removed, the waste loading can be increased further. Experimental studies may be able to show that some of the more restrictive constraints can be relaxed or removed.

3. **Pretreat to Remove Troublesome Species and Reduce Mass of Waste to Be Vitrified.** For those components whose constraints cannot be relaxed or removed, pretreatment methods may be able to substantially reduce their concentration in the waste such that these components are no longer limiting.

4. **Combination of Above.** All three methods above can provide a benefit. All three should be used in combination to provide the maximum benefit.

5.2.6.6 Future Blending Investigations. One of the ongoing blending efforts at WHC is funded by the pretreatment program and is titled "Select Retrieval Sequence and Blending Strategy" (starting activity number PSW04001).

The objective of this work for FY 95 is to establish a preliminary retrieval sequence and blending strategy that will be incorporated into the TWRS baseline and also provide an indication of the time-varying composition of feed to the HLW and LLW Vitrification Facilities. The intention is to select the preliminary retrieval sequence and blending strategy in May 1995 and to document its basis in September 1995. It is expected that early results of testing a few sequences will be available in January 1995. The work is broken into three main tasks:

1. The first is a decision analysis task that will insure that the retrieval/blending problem is properly framed (identify values, establish metrics that relate to the values, assist with interpretation of results, and document the selected retrieval sequence and blending strategy).

2. The second task involves formulation of candidate retrieval sequences and blending strategies using simple (manual or semiautomatic heuristic) approaches, testing these candidates by modeling with the "TWRS Baseline Simulation Model" (ARENA/SIMON) and an abbreviated version of the "TWRS Process Flowsheet" (ASPEN), and evaluation of the results in terms of the metrics. The blending architecture considered will probably be limited to (1) the unavoidable blending that occurs during retrieval, ESW, and lag storage and (2) unavoidable blending with a stage of rule-based intentional blending for waste entering the HLW Vitrification feed storage tanks.

3. The third task is to review alternative approaches to solving the fully constrained (logistics, etc.) retrieval sequence and blending strategy problem. This review will consider approaches used at the Hanford Site and other sites in addition to more advanced methods (AI, fuzzy logic, neural nets, etc.).

The objective of this work for FY 96 is to update the TWRS Baseline Retrieval Sequence and Blending Strategy for inclusion in SST retrieval sequence Tri-Party Agreement milestone M-45-02A (9/30/96) "Submit initial SST retrieval sequence document for Ecology Approval." The retrieval program is responsible for this milestone, which will also document the planned retrieval

methods for each tank. M-45-02A is the first of a series of milestones that require submittal of an annual update of the SST Retrieval Sequence.

5.3 DISPOSITION OF TRANSURANIC TANK WASTE

The following information was taken from the *Tank Waste Remediation System Decisions and Risk Assessment* (Johnson 1994).

Tank waste types potentially designated as TRU waste are the Plutonium Finishing Plant (PFP) waste derived from the second cycle purification of plutonium solutions and neutralized cladding removal waste (NCRW) derived from the dissolution of cladding on spent nuclear fuels. This assumption needs to be confirmed due to complicating issues associated with the handling and disposition of TRU tank waste.

Assuming that TRU tank waste is determined to exist, three options have been identified as alternates for the disposition of TRU tank waste:

- **Dispose in the HLW Repository.** Dispose of the TRU tank waste in the HLW repository along with HLW tank waste. This disposition could result in blending schemes (see Section 5.2 of this report) such that the TRU tank waste would not be an identifiable, segregated waste type, separate from other tank waste. This waste would be immobilized and sent to the spent nuclear fuel/HLW geological repository for disposal.

- **Dispose in the Waste Isolation Pilot Plant (WIPP).** The TRU tank waste is processed in a manner to produce an immobilized waste form which is in discrete containers that are separate from the remainder of the tank waste. This segregated, immobilized waste in then disposed in the WIPP TRU repository, while the remainder of immobilized HLW is disposed in the spent nuclear fuel / HLW repository.

- **Disposition Unacceptable in Either the WIPP or HLW Repositories.** The TRU tank waste disposition, based on current repository scopes, is found to be unacceptable for receipt in either the WIPP or HLW repositories. This situation could occur under a number of scenarios, such as, the TRU tank waste is found to be unacceptable for disposition in the HLW repository due to legal definition constraints and unacceptable for disposition in the WIPP due to lack of space and priority based on current repository scope.

Presently known characteristics of NCRW, PFP waste and other tank waste are documented in *Radionuclide and Chemical Inventories for Double-Shell Tanks* (WHC 1993a), and *Radionuclide and Chemical Inventories for Single-Shell Tanks* (WHC 1993b). Historical tank usage and transfers of waste types are documented in *A History of the 200 Area Tank Farms* (WHC 1990). This information may be useful in establishing whether or not certain types of tank waste are classified as transuranic tank waste.

The selection of a specific disposition for TRU waste will potentially influence the selection of a process for immobilizing TRU tank waste. Waste acceptance criteria at the WIPP may be significantly different than the criteria at the HLW repository. In that case, two immobilized tank waste forms may have to be developed and manufactured. Two waste forms also may be desirable for the Hanford Site to minimize manufacturing costs.

In addition to potentially impacting the waste form selection, the disposition of TRU tank waste could impact the number of processes that have to be built or it could impact the sequencing of operations in the pretreatment and immobilization facilities. If the TWRS is required to segregate TRU tank waste from HLW, then the TRU would have to be processed as a separate block of waste in campaigns or in separate process systems. The segregation of TRU tank waste could potentially lengthen the duration of tank waste processing and increase total costs for the TWRS program.

Fortunately, the conceptual design of the tank waste immobilization facility is not scheduled to be completed until March 1998. This decision can be resolved in the intervening three years to reduce the program risk to an acceptably low level. Discussion with personnel at the HLW and WIPP repositories will be conducted during FY 1995 to resolve this issue. If resolution can not be achieved before commencing definitive design of the HLW immobilization process, segregation of potential TRU tank waste will have to be maintained throughout retrieval, pretreatment, and immobilization to distinguish this waste from the remainder of tank waste.

The HLW program identifies the following activity numbers for resolution of this issue:

SDW5000 Identify TRU Waste Tanks

SDW5100 Evaluate WiPP as Alternative to HLW Repository

SDW5150 Obtain DOE review and concurrence on WHC recommended disposition of TRU tank wastes.

A follow on activity for development of a strategy for segregation of TRU tank waste is also identified (activity number SDW5300) and would be implemented if a decision is reached to send the TRU tank wastes to WIPP. The HLW program includes activity SDW7473; A/E Trade Study Close Out, which will provide information that addresses technical issues associated with the processing of TRU and HLW in the same facility.

5.4 MELTER SYSTEM ALTERNATIVES ASSESSMENT

Unless otherwise stated, the information in this section is extracted from the *Feed Processability Study* (Lambert 1994).

The purpose of the vitrification process is to convert Hanford Site HLW into a stable and durable (nonleachable) glass which is acceptable for disposal in a geological repository. The Tri-Party Agreement specifies that a viable melter system must be available by September 1998. Candidate melter

systems were evaluated during fiscal year (FY) 1994 to select a limited number of vitrification systems for in-depth development. Certain feasibility studies of selected melter technologies will be performed to establish the basis for design of the HLW plant melter system and plant facilities by the start of definitive design. The HLW vitrification plant definitive design is currently scheduled to start in December 1998.

5.4.1 Impact of Vitrification to Feed Processability

The design and operating characteristics of the melter are expected to have a significant effect on the processability of Hanford Site waste. Important design considerations include the normal operating temperature of the melter, materials of construction, energy source, use of mechanical or natural convection, cold cap coverage, potential volatility effects imparted to the melt, characteristics of the feed system and type of pour system employed. These features will generally have a pronounced effect on the operating characteristics of the melter, properties of the glass and glass production rates obtained. Certain glass properties such as viscosity, electrical conductivity and density are directly affected by composition and temperature of the molten glass. Other properties such as waste oxide loading and solubility of glass limiting components in the melt are also expected to be affected by temperature and composition of the glass. The volatility of ruthenium and cesium oxides, mercury and cadmium oxide are affected by temperature, cold cap coverage and agitation. All of these aspects must be taken into consideration when formulating the optimum glass composition (see Section 5.5) and assessing the processability of Hanford Site waste.

5.4.1.1 Minimum Performance Requirements for Candidate Melters. Each candidate melter is expected to satisfy certain minimum requirements that have been established for the HLW program at the Hanford Site. These requirements are as follows:

1. Vitrify the entire HLW fraction of SST and DST waste into borosilicate glass or a glass of equivalent durability within 19-years. Equivalent glass is interpreted to be a glass with equivalent durability as compared to Environmental Assessment (EA) glass. It is essential to process the required Site HLW feed volume during the plant's lifetime (December 2028) established in the Tri-Party Agreement Milestone No. M-51-00. For comparison purposes, estimates will be made of the melter technology's waste processing rate (function of glass production rate and waste oxide loading) to ensure that the minimum production rate capabilities are achieved.

2. Provide a reasonable cost basis for the construction, operation and decommissioning of the plant and disposal of the glass in comparison to other viable melter system alternatives. A determination of potential impacts on plant design, plant operations, and processing flexibility will be made, with the understanding that those technologies with excessive initial plant construction cost and/or plant operating cost impacts will be eliminated from consideration.

3. Be compatible with existing or potential TWRS flowsheets/processes for pretreatment and LLW vitrification. A standardized Site HLW blend composition, representative of the all tank blend, will be used to evaluate the ability of candidate systems to produce an acceptable glass waste form. See Section 5.2 for a discussion of the all tank blend. In addition, the nominal feed and feed variability will be used as the basis to establish each system's ability to accommodate high waste oxide loading and maximum amount of limiting components in glass (phosphorus, chromium, iron, etc.).

4. Meet the Tri-party agreement milestones by demonstrating that the selected melter is compatible with the pretreatment technology to be deployed by September 1998 and will support initiation of conceptual design by April 1997.

5. Minimize the HLW glass volume to the extent possible (repository cost consideration).

5.4.1.2 Melter Selection Criteria. Certain criteria have been developed for the comparative evaluation and selection of candidate melters for the HLW program. These criteria are as follows:

1. **Melter Feed**

   Flexibility to process the expected glass compositions within the operating envelop of the melter, considering:

   - Operating temperature (1050 to 1400 °C)
   - Range of wastes (glass composition and properties, slurry feeds, feed viscosity, particle size, glass formers etc.)
   - Incorporation of semi-volatiles in glass
   - Ability to handle fissile material (accumulation effects)
   - Waste loading (maximum achievable waste loading at melter operating temperature).

2. **Product/Process Control**

   Ability to produce a consistent product with a controlled composition, considering:

   - Product quality (durability, phase separation, crystallinity, homogeneity)
   - Waste homogenization (undissolved solids and gases in glass matrix)

3. **State of Technology Development**

Maturity of the technology, taking into consideration:

- Ability to meet Tri-Party Agreement milestones
- Demonstrated scale of operation (kgs. of glass per hour) - Availability of evaluation data
- Additional technical development required
- Probability of technical success.

4. **Facility/System Integration**

Requirements placed on the balance of plant, including:

- Feed preparation requirements (pH, solids content, reductants)
- Offgas system requirements (flow rate, complexity)
- Number of melter trains (melter cell heat load, canister handling)
- Plant service requirements (electrical, steam etc.)
- Melter dimensions, weight (melter disposal and replacement)
- Disposal system requirements
- Environmental requirements (waste streams issuing from plant)
- Special safety requirements (safety class, safety analysis etc.)
- Special maintenance support (melter changeout considerations).

5. **Design Life**

Expected operating life of melter, including:

- Refractory life
- Electrode life/replacement.

6. **Melter System Scale-up**

Demonstrated capacity to achieve the desired processing rate of at least 8.3 MT/d for the low temperature melter (1050 °C) and 7.9 MT/d for the high-temperature melter (1350 °C), assuming a nineteen year plant operating life at 60 percent total operating efficiency.

7. **Product Sampling and Recycle**

   Capability to sample and recycle out of specification glass.

8. **Secondary Waste Streams**

   Secondary waste handling/disposal, considering:

   - Mass and volume of solid and liquid wastes
   - Waste compositions
   - Process flowsheet impacts (recycle streams to HLW/LLW plant etc.)

9. **Operability**

   Design features related to operation and remote maintenance

   - Ease of control
   - Remoteability (special remote operating requirements)
   - Reliability (on-line efficiency)
   - Maintainability (normal maintenance requirements)
   - Estimated lifetime
   - Ability to confine radioactive materials (volatility effects)
   - Potential for radioactive source buildup (refractory cesium absorption)
   - Modular design features
   - Sealing and containment

10. **Factors Affecting Total Cost**

    Life-cycle cost issues, including:

    - Development costs
    - Deployment costs
    - Replacement and repair costs
    - Solid waste disposal costs
    - Product disposal costs (glass volume as a function of waste oxide loading and glass production rate for different melters).

11. **Unusual Safety or Environmental Problems**

Ability to operate safely in a remote environment, considering:

- Plant/worker safety
- Offgas characteristics
- High energy issues (pressurization, explosion, uncontrolled reaction)
- Criticality
- Passive shutdown.

5.4.2 Melter Selection

A major objective of the TWRS Fiscal Year 1994 HLW program scope was assessment of potential HLW melter systems. The assessment process used a Technical Advisory Committee of external (non-Hanford) experts in commercial and HLW glass processing as described in the *High-Level Waste Melter Alternatives Assessment Decision* (Alumkal 1994). A working group was built around this Technical Advisory Committee using experienced WHC staff and other DOE complex and international HLW melter experts. The goal of the assessment process was to recommend technologies and focus program development on areas which have the highest potential to meet HLW program objectives.

Starting with a list of 15 melter system technologies, the evaluation team narrowed the options for detailed consideration by performing an initial screening evaluation. A recommendation on preferred melter technologies and technology development direction was prepared by the Technical Advisory Committee. The *High-Level Waste Melter Alternatives Assessment Decision* (Alumkal 1994) provides a summary description of the melter assessment process, the full text of the technical advisory committee recommendation, and summary of the application of results.

Key elements of the recommendation are as follows:

- All-electric, cold-top melters with nickel-based electrodes represent a solid base technology for vitrification of Hanford Site HLW. Primary emphasis should be placed on developing high temperature capabilities for this technology and variations in features to increase waste processing capacity and improve performance.
- High-frequency induction melting offers significant advantages, including relief from problems of electrode attack, but should be considered a backup technology because of the relative immaturity of these melter systems.
- Several refinements are available to improve the performance of both types of electric melters, and these should be developed further. These are completely compatible with the basic electric melting

technologies, and could be incorporated without fundamental changes. However, reliability of any melter is strongly reduced by complexity, and this consideration reduces the attractiveness of these approaches.

- Agitation by mechanical stirring can greatly increase melting rate, thus reducing the number of melters needed or their size.

- Feed drying or calcining can significantly reduce the power that must be supplied by electrodes or high frequency power supplies, thus reducing the size or number of melters.

- Sloped bottoms may be needed to minimize deposits of noble metals and other insoluble components.

- Other points of the recommendation focus on the need for development and testing of small- and large-scale test systems, cost/benefit considerations of an ample development program, and benefits of developing flexibility in the remote facility design to allow future installation of alternative, improved technologies.

The results of the independent external review panel's assessment have been accepted and implemented for the baseline HLW melter development approach. The short list of melters now includes both the reference (1150 °C) and high-temperature (1350 °C) joule-heated melters, a low-temperature (1050 °C) stirred melter (SM) and the cold-wall crucible melter which is derived from the high frequency induction heated melter. A description of these melters and their development requirements is given in the rest of this section, Section 5.4. Glass formulation requirements corresponding to each of these melters is given in Section 5.5. Process control considerations corresponding to each of these melters is given in Section 5.6.

5.4.3 Reference and High-Temperature Joule-Heated Melters

Joule-heated melters are typically heated by passing alternating electrical current through glass using a submerged set of electrodes. The alternating current is conducted between two or more electrodes by mobile ions, usually sodium or lithium alkali metal ions, in the molten glass. The electrodes in the high-temperature melter (HTM) are arranged in a three-phase system with two side electrodes and one bottom electrode. Reference melter designs vary with most employing a two electrode arrangement while others have a third electrode at the bottom to control the temperature of the bottom glass. The melter surface geometry is normally specified by the required surface area to meet production requirements and the depth required for adequate residence time. Glass residence times are typically determined by offgassing and canister glass density considerations which favor longer residence times for refining of the HLW glass.

5.4.3.1 Melter Design. Joule-heated melters have certain advantages in comparison to other melters, especially the ability to suppress the volatilization of melt constituents and to melt black glasses where radiant heat transfer in limited. This melter is normally limited to a temperature

range determined by the materials of construction for the refractory and electrodes. For the reference melter, this temperature range is usually limited to about 1150 °C because of temperature limits imposed on the system by the submerged Inconel[1] 690 (high chromium nickel alloy) electrodes. The high-temperature joule-heated melter currently relies on two electrode systems, a pair of shielded and water cooled inconel/molybdenum electrodes inserted from the top and a second set of Monofrax[2] E (high chromium oxide) refractory electrodes incorporated into the melter's refractory envelop. Since these electrodes are capable of higher temperature performance, this melter will be typically operated at temperatures of 1350 to 1450 °C.

Most joule-heated melters are ceramic-lined with Monofrax K-3 fused cast refractory or equivalent (chrome alumina-zirconia-silica AZS), although a few such as the stirred melter (SM) are Inconel 600 or 690 metal-lined. The metal melters either operate at a lower temperature (<1200 °C) or are water cooled such that the metal liner is protected by a layer of frozen glass. Because glass is not electrically conductive at room temperature, joule-heated melters must have auxiliary heating for initial startup. This is usually provided by electrical resistance heaters placed in the plenum space above the glass surface.

It is assumed as a baseline condition of the HLW program that the HLW melters will be slurry fed in a similar fashion to the previous HWVP melter. The reference and high-temperature joule-heated melters are designed to accept a slurry feed (although calciner fed and dry fed melters have been evaluated as well). Depending on the size of melter, more than one slurry feed nozzle may be required to assure adequate coverage of the melt surface. Significant work has been done to develop feed nozzles that will not clog. Current feed nozzles are water cooled to avoid plugging. The nozzles can be water flushed whenever the feed is shut off to assure that the feed does not dry in the nozzle.

There are several variations of this melter design (sloped bottom, dry-fed with an evaporator, agitated, etc.). The flat bottom melter is normally considered to be the reference case since most HWVP tests were conducted in flat bottom melters. It is also assumed that the reference melter is equipped with a bottom drain and a differential pressure (vacuum) overflow system for discharging the glass. The bottom drain consists of an inductively heated vertical pipe or udder which is enclosed in a hollow copper tube coil that serves as an induction heater and cooling coil. The drain operates as a freeze valve. When glass is to be poured, the drain pipe is inductively heated to melt the glass plug. The glass pouring rate is essentially controlled by varying the induction power. When enough glass has been poured, the induction power is reduced until glass flow stops. The ability to adequately stop glass flow is determined by certain characteristics of the system, including the level of glass (or differential pressure at the bottom of the melter), the density and viscosity of the glass and the diameter of the pour stream or throat diameter of the pour spout. These characteristics in

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[1]Inconel is a trademark of Inco Alloys International, Incorporated.

[2]Monofrax is a trademark of SOHIO Company, Incorporated.

addition to the basic materials used are considered to be important to the safe and reliable operation of an inductively heated bottom drain.

The ceramic-lined, joule-heated melter has been selected for high-level waste vitrification in the United States (Savannah River, West Valley), Germany, Japan, and Russia. These melters have two or more layers of refractory inside a water cooled containment box. The glass contacting refractory is usually high chromia fusion-cast refractory (K-3). The corrosion rate for K-3 is 10-20 micrometers/day in the most aggressive areas at the melt line, but more typically 4-8 micrometers/day as experienced by PNL in the Pilot-Scale Ceramic Melter (PSCM). The fused cast refractory in the HWVP melter is 30 cm (12 in.) thick. Assuming a maximum corrosion rate of 20 micrometers/day, the expected refractory life would be 42 years. The electrical conductivity of glass contacting refractory is important. If the refractory is too conductive (chromium content too high) short circuits may develop between the electrodes via the refractory. This is only a concern with low conductivity (low alkali content) glasses. Since the fused-cast refractory is not a very good insulator, it is usually backed with layers of better insulating ceramics such as high alumina castable ceramics or ceramic board.

5.4.3.2 Melter Performance Sensitivities. Compounds or elements that require special treatment in the offgas include tritium, mercury, ^{14}C and iodine. These elements will not be incorporated into glass at 1150 °C, except for a minor amount of mercury, and must be captured in the offgas system and sent out as a secondary waste stream. Carbon-14 will probably be released to the atmosphere as long as Clean Air standards are met. Chloride, fluoride, technetium, cesium, cadmium and ruthenium oxide are partially soluble in glass, but require special consideration in the offgas treatment system for recycle.

Noble metals such as rhodium, palladium and ruthenium oxide (RuO_2) are virtually insoluble in borosilicate glass. Previous tests and studies have indicated that accumulation of these metals can cause premature failure of the melter due to electrical short circuiting at concentrations as low as 0.1 wt% in glass. Designs developed by the Germans (Kernforschungszentrum Karlsvuhe GmbH [KfK]) have proven that accumulation of noble metals can be avoided by having a steeply sloped (75 °) bottom that allows the precipitated noble metal particles to be drained out of a bottom drain.

The Japanese have developed a method that limits the deposition of noble metals by cooling the glass near the melter floor (Elliot 1994). The cold, viscous glass near the bottom acts as a barrier and significantly slows the settling rate of noble metal particles. Noble metals therefore remain in the molten glass above the layer of cold glass which is maintained at a temperature of 850 °C to 950 °C. Such glasses can be poured through the bottom drain of the melter when the bottom temperature is raised to 900 ° to 1050 °C to reduce the viscosity of the glass. With this method, The Japanese were able to demonstrate that the retention of RuO_2 could be reduced from 43 percent to 17 percent and PdO from 39 percent to 3 percent, with some tests indicating that less than 1 percent of the noble metals (fed to the melter) remaining in the melter.

It is not clear if noble metals are a concern for the Hanford HLW melter. The all tank blend composition only has 0.07 wt% total noble metals (Ru_2O3, PdO, Rh_2O_3) in the waste. At 50 percent waste oxide loading in the glass, the noble metals concentration would be 0.04 wt%. With this level of noble metals in the glass, it is not clear if this low concentration would result in an accumulation of noble metals in the melter. Even if this were to occur, noble metals may not cause melter failure before other components fail.

Semivolatile elements are only partially soluble in glass. Table 5.4-1 shows the melter decontamination factor (DF) for elements with DFs below 300, except HgO.

Table 5.4-1. Melter Decontamination Factors.

Oxide	Wt% oxide in waste	Melter decontamination factor	Reference
CdO	0.091	7.5	Scott 1985
Cl	0.033	6.6	Goles and Nakaoka 1990
Cs_2O	0.012	8.3	Goles and Nakaoka 1990
F	0.555	9.2	Goles and Nakaoka 1990
HgO	0.0005	2,833.3	Pegg et al. 1994
HgO	0.008	1.3	Chapman 1987
Rb_2O_3	0.007	290.0	Perez 1994
Rh_2O_3	0.013	29.0	Whittington 1993
Ru_2O_3	0.047	10.0	Scott 1985
SO_3	0.341	6.4	Goles and Nakaoka 1990
SeO_2	0.024	58.0	Scott 1985
Tc_2O_7	0.021	2.5	Chapman 1987
TeO_2	0.003	11.0	Scott 1985

The DF is defined as the ratio of the mass flow of an element into the melter divided by the mass flow in the offgas. The DFs shown in Table 5.5-1 were determined for liquid-fed melters operating at 1150 °C. Volatility losses from liquid-fed melters are believed to be affected by certain parameters, for example cold cap coverage, plenum temperature and feed/glass composition. Because of its high specific activity, cesium volatility is of particular interest. Cesium is believed to volatilize as cesium metal, or as Cs_2O, CsOH, or other compounds (Erleback 1960, IAEA 1982). If chloride is present, CsCl is assumed to be the primary volatile species (Burkholder and

Allen 1987). The addition of technetium has been shown to increase volatility as well due to formation of $CsTcO_4$. Upon addition of technetium to a feed, cesium losses increased from 2 to 5 percent to 18 percent (Baumgartner 1984).

Radioactive materials are confined to the melter because the melter plenum and overflow are kept under vacuum to prevent the airborne release of such materials to the melter cell. However, certain deposits (such as cesium oxide) can still accumulate in the offgas line. This can be controlled by using a film cooler to quench and dilute the hot particulate material from the melter or by designing the offgas line so that deposits can be physically removed with a reamer, as was done for the PAMELA melter.

These melters typically have side or bottom entering electrodes constructed of Inconel-690, or for the high-temperature melter, water cooled top entering Inconel/molybdenum electrodes and refractory E-block electrodes. Submerged Inconel 690 electrodes corroded at an average rate of 3 microns/day in the Pilot Scale Melter after three years of operation (Barnes 1981). Inconel materials in the plenum space have shown severe attack due to halides and sulfates in the feed stream (Dierks 1980). Corrosion attack by sulfur and its compounds has been found to be a potentially severe problem. In the PAMELA plant, the baffle plate and the wall opposite the offgas inlet corroded through in less than 150 hours (Chapman 1983). The materials used in this area of the PAMELA were the European equivalent of 304 SS. Inconel 690 does provide some improvement in time to failure, but the performance characteristics of this alloy have not been determined over the projected life of the plant. Most Inconel materials exposed to offgas (thermowells and bubblers) are remotely replaceable.

It is assumed on the basis of past test experience that organics are thermally destroyed in the plenum space of the melter. The plenum temperature is normally about 650 °C when plenum heaters are used. The destruction and removal efficiency (DRE) for formic acid was recently determined for liquid-fed ceramic melters. The destruction of formate was at least 99.8 percent for feeds containing 37 g/L to 46 g/L formate (Perez 1994). Similar tests have been performed at Savannah River to assess DREs for the Defense Waste Processing Facility (DWPF) melter.

Joule-heated melters have been demonstrated with nonradioactive simulants at Savannah River (Scale Glass Melter with 1.2-m^2 surface area and melt rates of 45 kg/h), at West Valley Nuclear Services (WVNS melter of 2.15-m^2 area and melt rates of 45 kg/h) and at the PNL (Liquid-Fed Ceramic Melter of 1.05-m^2 surface area and melt rates of 50 kg/h and the PSCM of 0.76-m^2 surface and rates of 22 kg/h).

Extensive plenum heating is usually required to meet the indicated melt rates. Existing test facilities in addition to those mentioned are the K-6 melter in Germany (0.88 m^2), the advanced B melter in Japan (0.88 m^2), the IDMS melter at Savannah River (0.29 m^2), the 1/10th scale (0.25 m^2) and PSHTM (2 m^2) melters at PNL, and finally the two Duramelters (0.13 and 0.33 m^2) at GTS Duratek. Such melters have demonstrated remote operation in radioactive environments in Russia (Mayak plant), Belgium (PAMELA plant), and the United States (RLFCM at PNL). Similar systems have been designed but not operated in Japan, (Tokai) and the United States (West Valley, HWVP and Savannah River).

The Savannah River production melter (2.5 m^2) is currently being assessed in the cold chemical runs now underway at the DWPF plant.

The reliability of the joule-heated melter is measured by the total on-line efficiency (TOE). This is defined as the total hours that a melter operates divided by the total hours a melter is in place, including the time for melter changeout. A TOE of 60 percent was assumed for the HWVP design. This was arrived at by assuming the melter was on-line 70 percent of the time with a six month changeout every three years. This was considered to be a conservative design basis because efficiencies of greater than 85 percent have been regularly attained with test melters.

The average on-line efficiency of the PAMELA melter was 85 percent, while the efficiency was greater than 98 percent during the recent liquid-fed ceramic melter (LFCM) tests conducted by PNL. In practice, melter efficiencies of less than 70 percent should be expected during the first year of operation for a production plant, with some increase in on-line efficiency as problems are worked out of the process. Since the waste compositions are likely to vary, some uncertainty needs to be assumed in the analysis and control of waste composition through the process and in the control of glass composition. It is reasonable to assume that the HLW vitrification process will produce glasses of about 85 to 90 percent of the theoretical waste oxide loading. For plant design capacity calculations, a TOE of 60 percent should be assumed, while glass volume predictions should be based on 85 percent of the theoretical waste oxide loading.

5.4.3.3 Estimated Melter Design Life. The minimum melter lifetime of the HWVP melter was estimated to be two years and the expected lifetime 3 to 5 years. The IDMS melter at Savannah River has experienced very little refractory wear after 5 years of continuous idling and operation. Monofrax E and K-3 refractories have shown little or no corrosion after 5 years of operation at West Valley (Lamar 1994). If refractory wear is the only consideration, ceramic-lined melters should last for 10 years or more under continuous service conditions (at 1150 °C).

The most likely scenario for early melter failure is apparently the accumulation of noble metals on the melter floor causing short circuiting of the lower set of electrodes. This was determined for NCAW feed which has approximately eight times the noble metals content of the all tank blend.

The potential accumulation of noble metals could be mitigated by one of several control strategies. One strategy is to blend the NCAW feed with other wastes to reduce the likely concentration of noble metals. Another approach developed at Savannah River involves adding water to the glass surface during idling periods to increase convective flow and limit the settling of noble metals. A recent analysis of IDMS data from Savannah River suggests that 70 to 80 percent of the noble metals may have settled from the melt when the melter was idled (Hutson 1994).

Another important aspect relates to the composition and electrical characteristics of the glass found in the bottom of the IDMS melter. This glass apparently contained enough precipitated spinel such that the glass was relatively insulating compared to other melter bottom glasses with similar

concentrations of noble metals. In this case, the electrical characteristics of the bottom glass appear to be control by the composition of the melt. Still another strategy is to design a sloped bottom melter and bottom drain system for sludge forming noble metal wastes, or to devise a control scheme such as the one developed by the Japanese that allows for the efficient purging of noble metals. These are important strategies to consider, not only for noble metal waste but also for sludge forming wastes such as high chromium and zirconium wastes in the SX and C SST farms.

5.4.3.4 Data Needs. Additional information may be required for optimization of the reference or high-temperature joule-heated melters and possible integration of these melters into the HLW vitrification plant. For example, DFs across the melter need to be better established for certain semi-soluble components such as mercury, cadmium, chloride, cesium and technetium, in the concentration and temperature ranges of interest. Mercury DFs are known to be strongly influenced by the concentration of mercury in the feed, based on tests with simulated Fernald waste (Pegg 1994). Given the likely variability of these components in Hanford Site wastes and higher operating temperatures of the HTM melter, better DF estimates are needed to assess the possible impact of these components on the melter offgas (MOG) system and the distribution and concentration of these materials in different areas of the plant. Better estimates of ^{14}C need to be developed from analysis of tank samples for environmental emissions modeling. Also, through glass formulation development, more data needs to be developed on the solubility of chromium, phosphate, uranium, bismuth, chloride, fluoride, technetium and cesium in borosilicate and non-borosilicate glasses, as a function of temperature and glass composition. This information is needed to establish glass composition and waste oxide loading estimates for glass limiting components. Although cesium absorption into the refractory is regarded as a low level waste shielding issue, similar information needs to be developed for HLW melters to close the cesium material balance (if the absorption of cesium is significant), for shielding calculations and for melter decommissioning purposes.

The corrosion of Inconel 690 plenum space and offgas system components needs to be assessed, as a function of halide and sulfate concentration in the feed, to establish better plant materials performance estimates. Particularly for the high-temperature melter, better corrosion estimates are needed for K-3 and E-block refractories for melter life prediction estimates. If lower viscosity glasses are formulated for the purpose of improving melt rate, refractory corrosion rates also need to be assessed for lower viscosity range glasses. Small scale melter tests have demonstrated that melt rates can increased by a factor of 2.3 when temperature is raised from 1050 °C to 1200 °C and viscosity of the glass is reduced from 180 to 40 poise (RSM report, comparing segments 4 and 7, Cooper and Elliot 1993). If mechanical agitation is chosen for melt rate enhancement, agitator materials and the impact on melter refractory life must be evaluated for each melter type. Since melt rates are normally controlled by convective conditions in the melter, large scale tests will probably be required for accurate melt rate and capacity predictions for the production scale melter.

Most HLW glass formulations are being developed for high waste oxide loaded glasses. For high nickel, chromium or iron feeds, spinel precipitation

and sludge formation may occur in the melter. The precipitation and settling characteristics of such materials need to be assessed for different melters. Also, functional and reliable bottom drain systems are needed to prevent noble metals and sludge forming deposits from accumulating in the melter. If reliable systems could be developed, sludge forming wastes such as high chromium wastes in the SX farm could be processed in a special melter campaign without blending or dilution with other wastes.

Tank waste composition estimates need to be improved for the development of better blending and pretreatment strategies for high chromium and phosphate wastes. See Section 5.2 for a discussion of blending. One of the most urgent needs is to increase the rate at which tank core samples are processed through the ESW process. Sludge washing efficiencies in the Aspen model are often based on assumed values which need to be experimentally verified for different wastes.

Glass formulation work also needs to be performed on uranium and actinide containing wastes. Neodymium because of its interaction with phosphate does not appear to be an adequate substitute for uranium. The French have indicated that cerium oxide is highly refractory and quite resistant to vitrification, while the British have noted that cerium tends to form insoluble precipitates with actinides (plutonium and neptunium) in molten glass (Stegen 1994). Obviously, this could have a drastic effect on criticality control of the melter and possible accumulation of such materials in the plant. These issues need to be evaluated in the glass formulation laboratory.

Glass composition and waste oxide loading estimates derived for different tank farm blends need to be experimentally verified. These estimates, which were developed for the reference and high-temperature joule-heated melters, are currently being used as a basis for estimating the volume of glass produced from each waste. Glass volume predictions are expected to have a significant impact on melter sizing, estimates of optimum plant capacity, development of blending and retrieval strategies for different wastes and determination of overall repository costs for Hanford Site waste.

5.4.4 Stirred Melter

The stirred melter operates on the basis of joule heating of the glass combined with a rapid mechanical stirring to induce rapid volumetric melting of the glass. These features effectively reduce the required melt area to only 25 percent of that required for a conventional cold cap melter of equivalent capacity (Richards 1991). The stirring action provides a shearing effect to promote the dissolution of waste oxides in the glass melt. The stirred melter consists of three parts, an agitator/spindle assembly, a primary melter and a superheater for refining the glass. All three modules are specifically designed to be remotely replaceable.

5.4.4.1 Melter Design. The primary melter is an Inconel 690 metal-lined crucible with the metal agitator and crucible wall also serving as functional electrodes. The working temperature of this melter is limited to 1050 °C to 1100 °C by the Inconel 690 materials in the crucible and agitator. There are

two zones of external heaters in the melter pot which are used during startup and for additional temperature control during operation. These heaters are electric plate heaters applied to the outside of the melting pot and are embedded in ceramic.

The agitator assembly includes a variable speed agitator drive, bus bars and the capacity to vary the agitator height in the glass melt pool. Agitator height is an important consideration with respect to separation of bubbles, glass density and achievable melt rates in the stirred melter. Glass densities of 98 percent were obtained under optimum conditions. Observations seem to indicate that the stirred melter has two discrete zones, the upper one consisting of foamy glass with 2 to 3 percent undissolved silica and the lower one having only dense glass with less than 1 percent undissolved silica. The homogenous molten glass at 1050 °C flows by gravity into a refractory-lined superheater that elevates the glass pool temperature to 1300 °C. This is intended to assure complete dissolution of the waste oxides.

The stirred melter can be either dry or liquid slurry fed. The baseline for this technology is to dry feed the waste separately from the dry glass formers; however, either feeding option is equally viable. The melter can be fed by increasing the agitation of the melt pool and introducing slurry directly into the vortex. This method increases the foaming and offgas entrainment characteristics of the melter, but also tends to increase the glass production rate. A different, more conservative way is to slow the rate of agitation and feed slurry to the outside of the melt pool, which produces less foam and offgas entrainment with steadier melter operation.

The superheater utilizes resistance heating over a minimum of 4 hours to achieve the desired refining of the glass. Additional surge capacity is provided in the superheater to allow control of the semi-continuous pouring of glass. A pour spout bellows is employed to seal the canister to the pour nozzle on the superheater to prevent uncontrolled releases of condensable, radioactive materials (cesium vapors) into the melter cell.

The two systems for glass draining include a bottom drain and an overflow system which are both water cooled. The overflow drain is a continuous, gravity controlled system. To initiate glass flow in either drain, the water cooling is shut off to allow a plug of frozen glass at the end of the drain to melt. Auxiliary heaters are also located at the bottom and overflow drains to maintain glass flow.

The primary melter and agitator can be easily replaced, minimizing disposal volume and cost in comparison to the reference joule-heated melter. This compact design combines the most desirable features of the continuous pot melters and slurry-fed ceramic melters. Potential benefits include lower melter cost, ability to repair major components, shorter downtime for melter changeout, usage of a smaller melter of simpler design, easier melter disposal and higher capacity in the same canyon space.

A large scale stirred melter is currently being designed for DWPF. The objective of the testing and development program at DWPF is to assess glass production rates and mechanical features of this melter. Key issues include an assessment of the normal operating conditions, glass pouring system and

drain valve and relation of agitator speed and height to glass production rates and glass properties. Additionally, DWPF plans to demonstrate primary melter, agitator and superheater replacement capabilities, agitator seal design and replacement of gas baffles if a film cooler is required for this design. Small scale stirred melters have been tested at Clemson University (1/4 ft^2) and at Stirred-Melter (1.0 ft^2).

5.4.4.2 Melter Performance Sensitivities. Certain elements and compounds cannot be incorporated into glass at 1050 °C. Such materials include tritium, ^{14}C and iodine. These must be captured in the offgas system and sent out as secondary waste. The exception is ^{14}C which will probably be released to the atmosphere as long as Clean Air Act standards are met.

Noble metals (Rh, Pd, RuO_2) are virtually insoluble in borosilicate glass. Previous studies have indicated that accumulation of these metals can cause premature failure of the low temperature, ceramic-lined melter (without agitation) due to electrical short circuiting at concentrations as low as 0.1 wt% in glass. Noble metals are not expected to accumulate as much in this melter as in the non-stirred melter because of the agitation of the glass melt. However, most of the agitation occurs only in the upper zone of the melt cavity, although increased convective flow can be expected in the lower zone as well. Crucible tests have demonstrated that RuO_2 agglomerates can grow to hundreds of microns in diameter in glass melts which are annealed at 1050 °C for 15 to 24 hours (Hrma 1991). However, electrical short circuiting is unlikely to occur under these conditions because the electrodes are vertically displaced instead of being horizontally opposed at the bottom of the melt cavity. Also, the stirred melter crucible may be replaced more often than a refractory-lined crucible, which further reduces the possibility of any noble metals interaction of importance.

Volatile losses from a liquid-fed melter are believed to be affected by certain parameters, including cold cap coverage, plenum temperature and feed/glass composition. The baseline operation for this melter is to operate without a cold cap (although it can be operated with a cold cap at lower production rates). Volatilization is expected to increase without a cold cap for certain species, but lower temperatures of operation could counteract this volatility effect. Offgas data are currently available only for melters operated with a cold cap, but Clemson University is initiating studies of offgas entrainment and volatilization to assess the performance of the stirred melter without a cold cap.

The maximum operating temperature of the stirred melter is about 1050 °C. This limitation is mostly due to the temperature limitation of the Inconel 690 materials used to fabricate the melt tank and agitator. Preliminary tests at 1150 °C have demonstrated that the impeller will mechanically fail because of stress under these conditions. When the original impeller failed due to excessive temperatures, corrosion from high levels of boric oxide and phosphate were also observed. These levels were about 20 wt% B_2O_3 and 1.7 wt% P_2O_5.

In-can melter tests done by PNL in the mid 1970's demonstrated that melt rates could be increased by 50 percent with mechanical agitation or bubblers (Platt 1974). Under these conditions, the Inconel 690 agitator corrosion rate

increased from 4 to 123 mils/month as the agitation velocity was raised from 0 to 153.6 linear m/min (0 to 504 linear ft/min) (McElroy 1974). It appears the corrosion of Inconel 690 in borosilicate glass is likely to be influenced by agitation velocity.

Initial testing has indicated the agitator can operate in glasses of 40 to 50 percent waste oxide. Processing rates with slurry feed vary from 19.5 kg/h-M^2 without stirring to 156.5 kg/h-M^2 of glass under optimum stirring conditions in a 0.092 M^2 (1.0 ft^2) test melter. Production rates of 220 kg/h-M^2 have been demonstrated with dry feed. In a reference joule-heated melter, processing rates are normally about 40 kg/h-M^2, or twice the rate observed in the small scale stirred melter without stirring because of the effect of increased thermal convection in larger size melters.

The Clemson stirred melter (6 in. by 6 in. with no superheater) has logged over 4,500 hours of operation. Glass production rates have varied from 1 to 2 kg/h when the melter is slurry fed. A somewhat larger 0.3 m by 0.3 m (1 ft by 1 ft) melter has been operated at Stirred-Melter, with measured glass production rates of 14.5 kg/h when slurry fed and 21 kg/h dry fed. Stir-Melter also has logged over 3,000 hours on a 15-cm by 15 cm (6-in. by 6-in.) stirred melter with 4.5 kg/h glass capacity when slurry and dry fed in combination. Clearly, this technology needs to be evaluated on larger scale to assess the likely performance of a production melter.

5.4.4.3 Data Needs. In addition to data needs defined in section 5.4.3.4 for the reference and high-temperature joule-heated melters, certain information is also required for the stirred melter. Better DF estimates need to be established for semi-soluble components in the glass, such as mercury, cadmium, cesium, chloride and technetium when processed in a stirred melter at 1050 °C without a cold cap. These components may have a significant effect on the design and performance of the MOG system and as such ought to be assessed before initiation of conceptual and detailed design of the plant.

Creep data are not available for Inconel 690 at temperatures in the range of 1140 °C. Future stirred melter system prototype testing is required to verify the adequacy of the Inconel alloy 690 material properties for the intended operating temperature. The superheater and agitator impeller are likely candidates for replacement within two years of operation. Both are remotely replaceable. A water cooled stainless steel shaft is proposed for the agitator because a solid Inconel 690 shaft is susceptible to overheating and significant stress at the impeller blade root and shaft attachment locations. The suitability of a water cooled mild steel agitator shaft for this type of operation needs to be verified through testing (Boomer et al. 1994). Corrosion data also needs to be developed for Inconel 690 in contact with high phosphate (3.0 wt%) and high fluoride (1.7 wt%) glass compositions in the operating temperature range of interest (1050 °C to 1150 °C).

Stirred melter performance characteristics must be assessed in larger scale melters to determine whether this technology is suitable for the production scale HLW vitrification plant.

5.4.5 Cold Crucible Melter

The cold crucible melter (CCM) was developed in both France and Russia as a derivative of the high frequency induction heated melter (Aleksandrov 1978, Elliot 1994). Conventional induction glass melters rely on an inductively heated metal crucible that heats and melts glass by thermal conduction. By electrically isolating vertical sectors of the metal crucible, cooling the sectors and increasing the frequency of the induction signal, the glass can be directly heated by the induction field. Because the crucible is cooled on the exterior surface, a frozen layer of glass protects the crucible from corrosion. This allows the melter to be operated at very high temperatures such that higher glass waste oxide loadings, production rates and melting of refractory waste components can be achieved.

5.4.5.1 Melter Design. The French have developed a water cooled CCM melter constructed of 60 Inconel segments arranged in a circular shape separated by a narrow gap of frozen glass such that each segment is electrically isolated. This arrangement allows the induction coils to couple directly to the glass. Because of the inefficiency of direct induction heating, CCMs are usually coupled to an evaporator or a rotary calciner so that the melter feed can be dried. Corrosion of the crucible is reduced or eliminated because the metal wall is kept below 200 °C producing a frozen layer of glass that protects the metal. The bottom of the melter is also water cooled to prevent corrosion/melting of the crucible. The important parameters to be controlled are the frequency of the induction signal, the electrical conductivity of the glass and penetration depth of the induced currents. The smaller the CCM, the higher the induction that is required. There are size limits imposed on the CCM by these constraints. Small CCMs (<15 cm diameter) are difficult to heat because the required induction frequency is very high. Large CCMs are difficult to heat because the induction frequency is so low that it will not couple to the glass.

The French CCM contains two bottom drains (freeze valves). One valve, the casting nozzle, extends into the melt so that the glass heel is maintained to allow continued induction heating. Glass flow through the casting nozzle is controlled either by a medium frequency, inductively-heated freeze valve or a separate mechanical shutter. The other nozzle, the drain nozzle, is flush with the melter bottom to allow draining of the glass heel at the end of the run. The flow of glass through the drain nozzle is controlled by an inductively-heated freeze valve. Air or argon can be injected into the melt to ensure thermal and chemical homogeneity by stirring if necessary.

Glass pouring is performed on a continuous basis. If batch pouring were attempted, the solid glass layer at the Inconel segments would separate from the wall because of the difference in thermal expansion coefficients.

Several thousand hours have been logged on the French CCMs (Moncouzoux 1991). The CCM can be operated at very high temperatures because it is a skull-type melter (Bradley 1991). The French CCM has been used to melt refractories up to 2500 °C. The maximum glass production capacity has been 25 kg/h (260 kg/h-M_2) for the 35-cm diameter CCM and 50 kg/h (210 kg/h-M_2) for the 55-cm diameter CCM. The 55-cm CCM is operated at 150 to 500 KHz and holds 300 kg of glass, 200 kg/pour, with a 100-kg heel). The French CCMs have been

agitated using both gas sparging and mechanical agitators. The LaHague vitrification glass formulation has been processed at temperatures ranging from 1150 °C to 1380 °C.

The Russians recently constructed a radioactive CCM system consisting of three 25 to 30 kg/h CCMs fed by a single wiped-film evaporator. The evaporator drys the feed to 20 percent moisture (Lifanov 1993). Agitation using both gas sparging and water-cooled mechanical agitators is used in the production of commercial glasses using Russian CCMs (Nezhentsev 1987).

5.4.5.2 Melter Performance Sensitivities. Noble metals should not accumulate to the same extent in the French CCM because air sparging and mechanical agitation can be used to keep noble metals suspended in the glass melt. Apparently, by using a manipulator, glass deposits also can be removed from the bottom of the CCM since cold glass does not adhere to the melter wall. Two separate drain systems are available for removing sludge and noble metal deposits from the melter if these deposits can be maintained in a fluid state at the operating temperature of the melter. The electrical conductivity of the noble metals layer is relatively unimportant since the CCM melter is heated by external induction coils. To the extent that the noble metals layer would be inductively coupled, localized hot spots could develop near the bottom of the CCM melter. Noble metals deposits could also plug the bottom drains such that the normal glass pouring operation would no longer be possible.

Volatilization could occur in both the calciner and CCM melter if the operating temperatures are too high. No information is available from which we can judge the likely volatility characteristics of the waste in the calciner. The French observed that a cold cap is probably necessary for volatility control in the CCM and glass temperatures should be low enough such that semi-volatiles will not escape during the glass pouring operation.

During the early 1980's, PNL operated a high-temperature ceramic melter (HTCM). Cesium volatilities were measured during these tests in the temperature range of 1200 °C to 1300 °C. The cesium DF was determined to be about 230 which corresponds to a loss of 115 mg/cm^2-h, or about one half the cesium loss that might be expected from a borosilicate glass at 1050 °C in the absence of a cold cap (Gray 1976). In melters without a cold cap, cesium volatilities were found to increase as the glass viscosity is reduced at constant temperature (Kupfer 1973, Ross 1980). Apparently, cesium volatilities are diffusion-limited when the melt surface is exposed to the atmosphere. If the volatility of cesium is too high, cesium oxide deposits could form in the offgas system and restrict MOG flow. A film cooler or mechanical reaming system may be required to alleviate this condition if the CCM melter is operated without a cold cap.

The French have typically used rotary calciners to boost the overall processing capacity of their melters. Calciners are currently being used to provide dry feeds to the LaHague, Marcoule and Sellefield plants. These calciner designs have been thoroughly developed and tested for acidic wastes from nuclear fuel reprocessing plants. When more than 50 percent of the waste is comprised of sodium, potassium and lithium oxides, aluminum must be added in the molar ratio 0.3 Al/Na to prevent caking or development of sticky

deposits in the calciner. This ratio is recommended for both calcination and vitrification of alkaline wastes. An acidic calcination process is generally preferred by the French. Acidic solutions with low solids are easier to meter and feed to the calciner. Also, an acidic process is more effective in that acidic scrubbing solutions can be used to dissolve all of the particulate material from the calciner, thus avoiding the sludges that would form under alkaline conditions in the scrubber. The French have also developed a method for controlling the particle size of the calcine by adding dry, granulated sugar to the calciner.

The French calciner is divided into four temperature control zones, ranging from 625 °C at the entrance to 825 °C at the discharge point of the calciner. The process solids and waste slurry are maintained in a thin layer and are evenly distributed around the bottom of the calciner by a rabble bar, which breaks up the calcined solids and keeps the walls of the calciner relatively clean. The dried process solids flow by gravity toward the CCM melter, while offgases from the melter flow in an upward direction through the calciner.

5.4.5.3 Data Needs. In addition to the general data needs described earlier, the CCM melter is unique in that a evaporator or calciner will be required for a production scale melter. This aspect of the feed preparation system must be critically reviewed and demonstrated with typical Hanford waste simulants. Since the French rotary calciners are undersized relative to the HLW vitrification capacity requirements, this review must also include an assessment as to whether the French technology can be successfully scaled up. A new vertical wiped-film evaporator is currently under development at Oak Ridge for radioactive wastes. It has been suggested that this technology could be used to increase the capacity of the reference joule-heated melter, but this technology could be equally important for the CCM melter. Glass composition and waste oxide loading estimates cannot be developed for the CCM melter without having more knowledge as to the optimum temperature, glass property constraints and operating conditions in the melter.

5.5 GLASS CHEMISTRY

High-level waste glass chemistry is largely a function of the waste chemistry as influenced by the waste feed preparation processes described in Sections 5.1 through 5.3. The melter selection process described in Section 5.4 is, in turn, influenced by the desired glass chemistry.

To achieve the desired glass chemistry, HLW solids must be dissolved into a molten mass of "glass formers." Glass formers are usually oxides of silicon (quartz), boron, or phosphorus. The melting process causes the crystalline structure of the glass former to break down to a more disorderly state, allowing waste components (as oxides) to mix into the molten mass to create a solution. To form an acceptable glass, the disorder achieved by the melting process must be preserved while the mass cools to form a rigid material. Otherwise, the glass components will crystallize without incorporating the chemical components of the waste material.

The numerous chemical components of HLW glass will have an effect on glass properties. Some materials that approach glass forming properties, but do not quite qualify, are called "modifiers" because they modify the properties of the glass. Some materials may act as glass formers in some compositions, and as modifiers in others. These materials are called intermediates.

A listing of the more common oxides by categories is given in Table 5.5-1. It is important to realize that there are no discrete lines between the classes "glass former," "intermediate," and modifier". The classification into three categories provides a convenient way of speaking to the relative glass forming tendencies of the various oxides, i.e., their relative abilities to create and maintain, singly, or in a mixture, the type of disorder characteristic of the glassy state.

Table 5.5-1. Functional Classification of Some Common Oxides Used in Glass Production.

Glass formers	Intermediates	Modifiers
B_2O_3	Al_2O	MgO
SiO_2	Sb_2O_3	Li_2O
GeO_2	ZrO_2	BaO
P_2O_5	TiO_2	CaO
V_2O_5	PbO	SrO
As_2O_3	BeO	Na_2O
	ZnO	K_2O

Other terms used to describe the ingredients in glass are stabilizers and fluxes. Stabilizers are those oxides that impart to the glass a high degree of chemical resistance. In addition, they control, in cooperation with the fluxes, the working characteristics of glasses for forming operations. Some common stabilizers are the alkaline earth oxide, CaO, MgO, BaO, etc., to which must be added Al_2O_3 for its special importance in improving the resistance of glasses to attack by water.

Fluxes are those oxides which react in the glass batch at relatively low temperatures, generally the Group I alkaline oxides. Glasses high in such fluxes tend to have low chemical resistance. High soda-silica glasses are soluble in water and in commerce are classed as soluble silicates or water soluble glasses.

In the following sections, the most important features and characteristic range of glass compositions will be described for each type of melter described in Section 5.4. The information was extracted from the *Feed Processability Study* (Lambert 1994).

5.5.1 Reference and High-Temperature Joule-Heated Melters

For low-temperature melters, including the stirred melter which will be discussed later, the waste form is assumed to be borosilicate glass. Borosilicate glass has been recommended based on its ability to immobilize a wide range of wastes, its insensitivity to radiation damage and general properties such as thermal stability, chemical durability and processability. The acceptable range of glass composition is normally defined by the range of compositions previously evaluated for the HWVP project (the Composition Variability Study [CVS] range of compositions for which the statistically derived glass property models are considered valid). Although most CVS composition information was developed for NCAW, the all tank blend is currently under development for the HLW vitrification plant (see Section 5.2). Preliminary glass formulation tests suggest that waste oxide loading for the all tank blend may be as high as 45 wt% for the low temperature stirred melter and 62 wt% for the high-temperature melter, compared to a typical standard of 25 to 28 wt% for the reference HWVP (NCAW) glass. Glasses being formulated for the high-temperature melter are predominately sodium alumina silicate glasses where silica is the only glass former added to the all tank blend composition. This formulation is possible because such glasses can be readily processed at 1350 °C with acceptable viscosity, durability and crystallinity (or liquid temperature) properties in the melter.

Iron, chrome, and nickel spinels are usually the first crystals to form in the NCAW glass upon cooling. Sometimes, especially with high zirconium feeds, zirconia containing crystals also form in the melt or in annealed samples of glass. The Waste Acceptance Preliminary Specifications (WAPS) do not specify a limit for the amount of crystalline material allowed in the glass produced. The concern with spinel formation or any crystalline phase is that such crystals will either reduce the durability of the glass or affect the operation of the melter by filling up the melt cavity with crystals. Glass compositions for high waste oxide loaded glasses are usually limited by the concentration of crystal forming components in the glass. Glass development for the all tank blend waste is being done to minimize formation of such crystals, which are observed after annealing the sample for 24 hours at 100 °C below the nominal melting temperature of the glass (viscosity of 4 Pa-s). The acceptance criterion is that the resulting glass must have less than 0.1 wt% crystals.

In general, the acceptable range of glass properties is specified by:

1. Redox (ferrous to ferric iron) ratio needed to control oxygen release and foaming tendency in the glass, and for overly reduced glasses, precipitation of noble metals, spinel and sulfide species. The Fe^{+2}/Fe^{+3} ratio should range from 0.005 to 0.3 for acceptable redox control.

2. Viscosity controlled in the range of 2 to 10 Pa-s (20 to 100 poise) to limit refractory erosion-corrosion on the low side and to ensure adequate mixing and reasonable melt rates below the upper limit.

3. Maximum liquidus temperature (crystallization temperature) set 100 °C below the nominal operating temperature of the melter so that crystals will not form in the melt.

4. Electrical conductivity controlled to allow joule heating of the glass. This aspect depends on the distance between electrodes and acceptable current densities and localized corrosion rates of the electrodes. Electrical conductivity at 1150 °C should be in the range of 0.18 to 0.5 S/cm, while the current density of the Inconel electrodes should be significantly below 1.6 A/cm^2, and more typically in the range of 0.8 A/cm^2.

5. Durability as determined by the acceptable leaching rate of the most soluble component in the glass (usually sodium or boron) compared to the EA glass which is the reference durability standard for HLW glass.

Waste loading is defined as the weight percent of waste (oxides) in the HLW glass. This value is extremely important as it determines the required production rate of the melter and the total amount of glass produced from Hanford Site waste. Glass quantities are important for several reasons. First, the repository charges are likely to range from $184,000 to $217,000 for the standard 0.6-m diameter by 3.05-m tall and 0.6-m diameter by 4.6-m tall (2-ft diameter by 10-ft tall and 2-ft diameter by 15-ft tall) canisters, respectively (1988 dollars, case 2 option 1 and case 2 option 2, Weston 1993). Overall, $2 billion in cost savings may be realized by increasing the waste oxide loading of Hanford Site waste from 25 wt% to 45 wt% (Merrill and Chapman 1993). Second, processing of each canister in the vitrification plant is very expensive. Each canister must be cooled, welded closed, decontaminated and stored. This operation is likely to be one of the most costly operations in the plant.

5.5.2 Stirred Melter

The specified waste form for this melter is borosilicate glass because of favorable processing characteristics at 1050 °C and acceptable chemical, thermal and durability properties of the glass. Redox control apparently is an important consideration for corrosion protection of the impeller. At Clemson University, it was found that the impeller life could be extended by sparging oxygen into the glass melt (Bennert 1994). Redox conditions should be controlled such that the ferrous to ferric iron ratio is maintained between 0.005 and 0.3 in the glass. Glass viscosities must be controlled because the stirred melter does not adequately mix the glass and waste if the glass viscosities are above 10 Pa-S (100 poise). In tests with Savannah River M area feeds, various amounts of boric oxide were added to the glass to establish the upper viscosity limit for the stirred melter. A lower viscosity limit of 2 Pa-S (20 poise) may be necessary to control etching or corrosion of the Inconel 690 pot.

The maximum liquidus temperature is set at 100 °C below the operating temperature of the melter (or at 950 °C) so crystals do not accumulate in the melter. This may not be a problem if crystals do not settle as a result of

agitation, or if crystals are removed with the bottom drain. However, it cannot be assumed that the stirred melter will necessarily tolerate a significant accumulation of crystals. The conservative approach then is to develop glass formulations that will minimize the possibility of glass melt crystallization. The electrical conductivity of the glass will be controlled in a range necessary for joule heating of the melt.

Since the stirred melter operates at a temperature of only 1050 °C, certain components such as chromium oxide and silica may not dissolve completely in the borosilicate glass matrix. Moreover, spinels may form at lower melt temperatures from high chromium, nickel and iron containing feeds and settle as sludge in the primary melter or superheater. Spinels are known to have refractory characteristics in that such crystals tend to remelt very slowly over a period of several months in borosilicate glass. If the glass composition is not adjusted to compensate for this effect, such crystals could easily fill and plug the melter bottom drain or superheater pour spout. Because of this concern, stirred melter glasses are expected to have lower waste oxide composition than glasses developed for the high-temperature joule-heated melter (0 to 26 wt% lower). This could have a significant effect on predicted glass repository life-cycle costs for HLW.

At 1050 °C, it is believed a waste oxide loading of 40 to 45 wt% could be achieved with the all tank blend, but this estimate needs to be experimentally verified in the laboratory.

Glass composition and waste oxide loading estimates derived for different tank farm blends must be experimentally verified. These composition estimates are currently being used for melter comparison and glass volume predictions for the HLW vitrification plant. Glass formulation results may have a significant impact on estimated waste oxide loading and glass volume predictions for the stirred melter and likely repository disposal costs for this melter system.

5.5.3 Cold Crucible Melter

For the CCM melter, the waste form is assumed to be sodium silicate glass where silica is the main glass former being added to the waste. Due to the operating temperature of the CCM melter, such glasses should be processable with an acceptable set of properties at 1350 °C. Also, preliminary glass formulation tests have shown that sodium and lithium oxides are more effective than boric oxide in suppressing the liquidus temperature of high waste oxide loaded sodium silicate glasses, an important consideration in formulating the optimum composition for the CCM melter (Kim and Hrma 1994).

Glass viscosity limits for the high-temperature CCM appear to be about 20 Pa-s (20 poise), while electrical conductivities should not be less than 0.1 S/cm. The CCM must include a feed drying system for a reasonable glass production capacity. Redox control may be required to suppress the volatility of RuO_2 and to control foaming tendencies in the CCM.

Several all-tank blend glass compositions have been developed for the high-temperature melter. For the all tank blend, it was determined that a

glass of acceptable composition was obtained at 62 wt% waste oxide loading (with a viscosity of 70 poise at 1350 °C and minimal crystallization when annealed for 24 hours at 1250 °C). Other glasses with acceptable viscosity, electrical conductivity and crystallinity properties at 1350 °C were developed from 50 wt% NCAW waste (Kim and Hrma 1994). Both glasses should be readily processable in the CCM. Using these compositions and the glass property models for glass formulation, similar compositions were also developed for each of the 15 identified tank farm blends. Due to the wide variation in composition, the predicted waste oxide loadings for these glasses ranged from 19 wt% to 84 wt% at the melting temperature of the glass (1350 °C).

5.6 PROCESS CONTROL

Process control requirements are highly dependent on the type of melter and the glass formulation used for the vitrification process.

5.6.1 Joule-Heated Melters

The quality of the product from a joule-heated melter depends on glass formulation and other factors. Glass development is done to assure that the final product will be at least as durable as the reference EA glass when tested with the Product Consistency Test (PCT) and MCC-1 leach test. Waste homogenization is assured by maintaining a sufficient residence time in the melter. For the DWPF (Savannah River) melter, the residence time averages two days. This long residence time may be necessary to assure proper dissolution and mixing of the waste and glass. Traced tests have indicated the melter acts as a continuous stirred tank reactor (CSTR) so the waste should be well mixed with the glass forming components in the melt. With a longer residence time, insoluble particles or crystals will have more opportunity to settle to the floor of the melter.

Certain measurements are required to assure safe process control in a remote operating environment. This includes temperature measurements in the glass, plenum space, glass discharge areas, refractories, and cooling water circuits. The most difficult parameter to control remotely is the amount of cold cap coverage. The feed must be controlled such that the melt pool is not completely flooded with feed because of potential bridging of the cold cap (large mounds of unmelted material on top of the cold cap). Insufficient cold cap coverage will lead to increased volatilization and gas release. The cold cap coverage is usually controlled based on past experience and plenum temperature measurements (which increase as the cold cap is melted by hot glass). Remote IR cameras have been investigated as a control option but have not been implemented to date. The melter plenum pressure must be controlled by maintaining a slight vacuum to avoid contamination of the process cells. This control is dynamic because of the variable nature of the melter cold cap.

Joule-heated melters operate continuously under very steady conditions such that process upsets are very rare. During idle periods, water can be fed to the melter to cool the upper glass surface to minimize volatilization and to increase convective mixing so noble metals will not settle in the melter. Ceramic-lined, joule-heated melters are based on a mature technology that has

been tested since the early 1970's for the vitrification of HLW. The only adaptations necessary for the high-temperature joule-heated melter are the electrode materials and concepts (shielded Inconel/molybdenum and refractory E-block electrodes) and bottom drain designs that must be utilized with certain sludge forming wastes.

5.6.2 Stirred Melter

Product quality may be a concern because the stirred melter tends to create bubbles in the glass melt, with the relative amount of bubbles depending on the speed and vertical displacement of the agitator shaft. During normal operations at Clemson, glass densities of 95 percent were obtained when the impeller was rotated at slower speeds near the surface of the melt (Bennert 1994). Theoretical densities of 75 percent were typically obtained by operating the melter with the agitator significantly submerged in the glass. Current information on glass density as a function of feed rate, impeller speed and position is not available. Since the glass is thoroughly mixed, glass residence times of 10 to 15 hours are considered adequate for the stirred melter. The homogeneity capabilities can be further controlled by increasing the melter depth and adjusting the penetration depth of the agitator.

5.6.3 Cold Crucible Melter

The conceptual CCM technology includes a calciner or evaporator attached to the CCM. This arrangement complicates the qualification of the product glass because wastes and glass formers are added on-line and not mixed beforehand for batch process control. The French and British vitrification plants have not only qualified this method of product control for domestic use but have also qualified this method with several foreign clients for the vitrification of reprocessing wastes. The French R7-T7 glasses when tested in distilled water at 60 °C for one hour, had a release rate 2 to 3 times lower than borosilicate glass.

The most important operating constraints for the CCM melter are to control the current and operating voltage of the induction coils and the volume and temperature of glass in the melter. Very little information is available on the operating conditions for the calciner. Small 25 kg/h rotary calciners have been successfully operated at the LaHague and Sellefield vitrification facilities. While these calciners have been used for the processing of acidic waste, very little experience has been gained from the processing of alkaline wastes such as Hanford Site waste. Remote CCM vitrification units have been operated in Russia on limited scale, while remote calciners have been operated in France and England. CCM melter lifetime may be several years, but the projected lifetime of the calciner is certainly much shorter since the calciners are more susceptible to failure in a remote operating environment. The graphite seals must be periodically replaced in the calciners. Potential contamination problems in the melter cell are minimized by using a metal bellows to seal the canister during the glass pouring operation.

5.6.4 Feed Forward Versus Feed Back Strategies

A feed forward versus product recycle study will be performed in FY 1995. The study will provide a decision basis for recommending vitrification process/product control strategy for HLW. This study will complete the effort started during phase II of the *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994). A high-temperature, joule-heated melter will be used as the basis for HLW. This study will focus on the three alternative process control concepts as described below:

1. **Feed Back.** Certifying product by direct analysis of product sample with product recycle capability. Process control used to minimize out-of-specification product.

2. **Feed Forward.** Precertifying vitrification process and equipment with no or infrequent product sampling and no product recycle. After process and equipment are certified, process control data are used to qualify product.

3. **Combination.** A strategy that uses feed forward and feed back will be evaluated as a third concept.

A complete set of issues will be generated early as part of the scope of work. Some of the issues that have been identified are as follows:

- Separate feeds to melter for waste and glass formers/product sampling for validation
- Combined waste and glass former slurry feed to melter/feed sampling for product validation.
- Product recycle for cullet and monolithic glass
- Impact on feed and product storage requirements including facility, tank farm, and other product storage areas.
- Delays due to feed batch characterization
- Number of glass formulations required for different waste types
- Sampling and analytical laboratory requirements
- Extent of sampling required to assure process continuity.
- How to certify process/equipment (pilot plant or small crucible tests; time required to certify each formulation)
- Disposition of out of specification product
- How to sample product
- Differences in process equipment or process control requirements.

The decision on which strategy will be adopted is based on the following criteria:

- Required sample frequency and sample turnaround time.
- Engineering judgment regarding need/feasibility
- Cost - additional facilities/operating costs/precertification costs/life cycle costs
- Time/motion review (feed and product lag storage)
- Glass storage capacity / off-spec glass handling
- Total Operating Efficiency
- Pilot plant facility requirements.
- Schedule impacts.

Unresolved issues and major uncertainties will be defined and proposed as future trade studies.

5.7 CANISTER CONFIGURATION OPTIONS

Supporting documentation for the *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994) examined 12 different options for HLW packages prepared for interim storage at the Hanford Site followed by final disposal at a deep geological repository. Each of the options examined the impact of various glass waste forms and containers on design, construction, operations, permits, safety, and overall cost. The following sections summarize the findings.

5.7.1 Glass Waste Form

The reference waste form is a glass monolith that formed by pouring molten glass into a container. The advantage of this form is that it is the simplest and cheapest glass waste form to produce. The main disadvantage of using the monolith form is the perceived difficulty of reworking an out of specification product (see Section 5.6). Heat dissipation issues may also limit the size of the monolith. Repository cost analyses may dictate that a smaller number of large containers may prove to be more cost effective than the reference waste form. The *Tank Waste Remediation Facility Configuration Study* (Boomer et al. 1994) examined three different waste forms as alternatives to monoliths as described below:

- A cullet waste form that is formed by quenching (rapid cooling) of molten glass. The resulting chunks of glass are ground and sorted to provide a uniform size distribution. The fines are recycled by the process.

- Marbles that are formed by dropping molten glass onto rollers that form the glass into spheres. The brittleness of the resulting product is removed by heating in another furnace.

- Gems that are formed by dropping molten glass onto conveyor belts. The glass cools on the belts in a form similar to vanilla wafer cookies: flat on the bottom with a rounded circular edge and a convex top. Gems also require heating in a separate furnace to reduce the brittleness of the product.

The study concludes that the technical concerns associated with the remote maintenance of complicated equipment makes the use of marbles or gems unfavorable over the use of a monolith waste form.

5.7.2 Waste Form Containers

The TWRS reference waste form container is a 0.68-m by 4.57-m (27-in. by 15-ft) unshielded canister in an underground vault covered by an inexpensive metal building. The canister is moved to the borehole in a shielded canister. Unshielded packages require shielded buildings (or boreholes) for interim storage. Shielded packages, however, can be stored on pads. The *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994) examined 11 container configurations in addition to the baseline:

- Unshielded 4-pack overpack canisters for small unshielded canisters

- Metal shielded casks for unshielded 4-pack overpack canisters

- Concrete shielded casks for unshielded 4-pack overpack canisters

- Large shielded casks

- Large unshielded canisters and metal overpack shielded casks

- Large unshielded canisters and concrete overpack shielded casks

- Large unshielded canisters, unshielded overpack canisters and metal overpack shielded casks

- Large unshielded canisters, unshielded overpack canisters, and concrete overpack shielded casks

- Large unshielded containers

- Unshielded 7-pack overpack canisters for small unshielded canisters

- Unshielded 4-pack overpack canisters for unshielded HWVP-Type (0.6-m by 3.05-m [2 ft by 10 ft]) canisters.

The study concludes that the use of unshielded canisters are the most cost effective of the container options presented. The inclusion of an overpack as part of the package reduces technical concerns associated with fill methods, decontamination and drop tests.

5.7.3 Waste Form and Waste Form Container Combinations

Of the 12 options discussed in the supporting documentation for the *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994), the most favorable option appears to be the one that uses small (0.68-m by 4.57-m [27-in. x 15-ft]) stainless steel unshielded canisters that are filled with monolithic glass. The filled canisters are placed in quantities of four into unshielded overpack canisters. The overpack containers are stored onsite on an interim basis in a container storage building. This option is judged as favorable because it uses the monolith waste form which is the simplest form to manufacture; it uses unshielded canisters which are the most cost effective container; and it uses an overpack concept which enhances the containment of radioactive material and reduces the number of units handled and emplaced at the repository. The enhanced containment of the overpack concept may help to reduce the need for extensive decontamination of the fill container thereby reducing equipment costs and plant down time caused by decontamination equipment.

The preferred option has the potential to reduce the total estimated cost of the waste form by as much as $40 million. The savings, however, could be partially, if not totally, offset by other costs such as the operating costs of the storage building. The data provided by the waste form study will be useful in deriving a preferred configuration for the entire HLW system.

6.0 HIGH-LEVEL WASTE VITRIFICATION FACILITY LAYOUT OPTIONS

The *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994) examined numerous options for the layout of the pretreatment, LLW vitrification and the HLW vitrification facilities. Additionally, the study examined various concepts for each of these facilities. The concepts and the cost estimates for several of these options as they pertain to the HLW program are summarized below.

6.1 DETACHED HLW VITRIFICATION PLANT

The detached HLW vitrification facility provides equipment and services to turn the HLW fraction of the tank waste into glass. The facility packages the material for both interim storage and repository disposal. In addition to facility concepts, Boomer et al. (1994) examined disposal methods and melter options.

6.1.1 Process Description

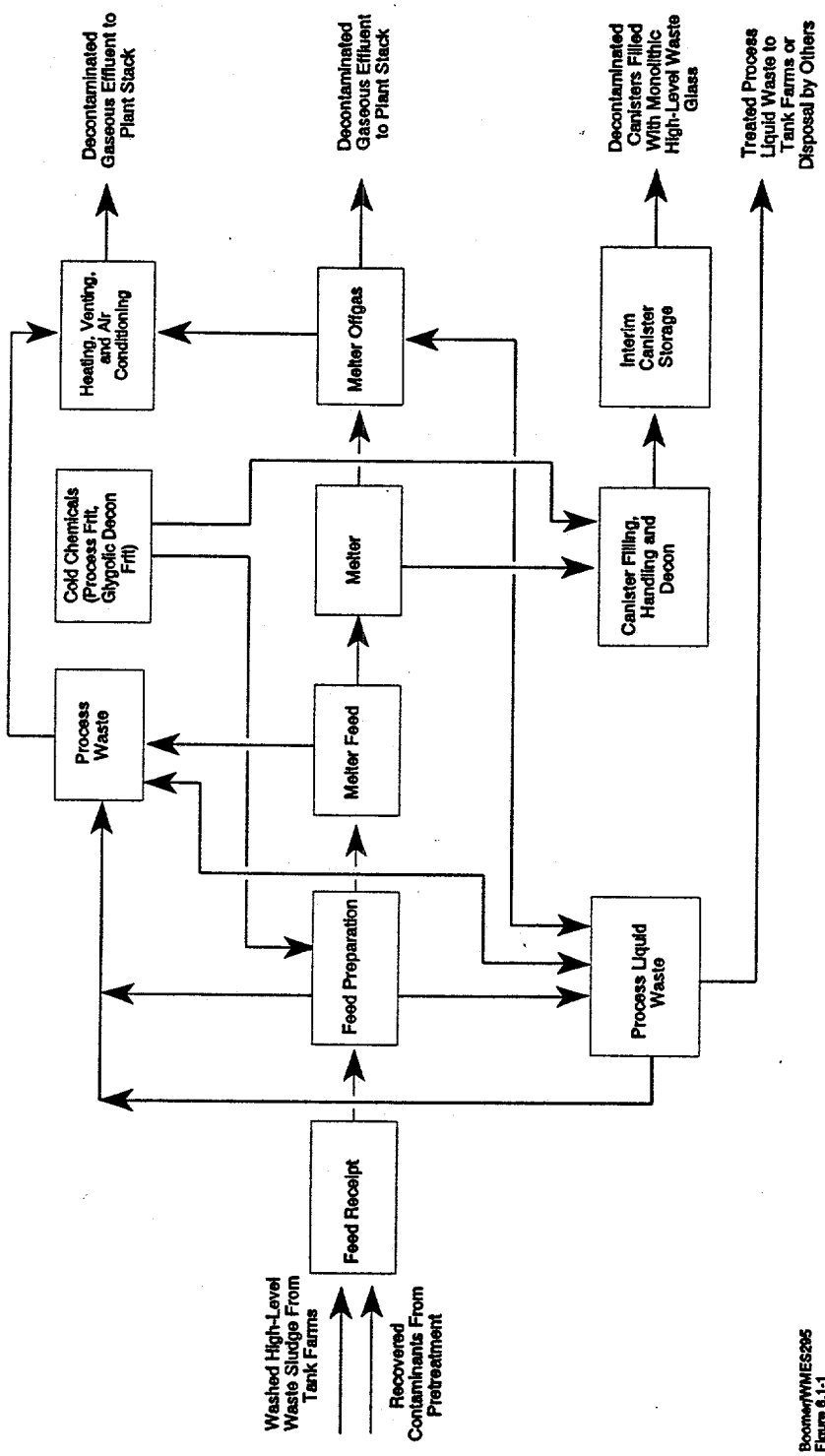
The two facilities considered include a 10-Mg/d facility and a 20 Mg/d facility. The 10 Mg/d facility is a standalone system that uses a joule heated high temperature melter to vitrify the waste. The 20 Mg/d facility is part of an integrated disposal system (pretreatment, LLW and HLW processing) that uses a combustion melter to vitrify the waste. Both facilities use a pour monolith canister system for packaging the waste. Other melter and packaging systems are discussed in Section 5.0. The system for packaging cullet instead of poured monoliths is a variant of the integrated facility concept.

6.1.1.1 10 Mg/day Process Description. This case assumes a borosilicate glass formulation that contains a 45 wt% waste oxide loading for equipment sizing. This value reflects the waste oxide loading anticipated with the projected separations performance of ESW, and the current understanding of required glass properties and melter operating constraints. This capacity option produces 22,700 Mg of HLW glass, filling approximately 6,300 canisters (1.3 m^3 of monolithic glass per canister).

Figure 6.1-1 is a block flow diagram overview of the process systems associated with this case. The plant feed, consisting of washed HLW slurry and recovered radionuclides from separations, are blended into a homogeneous mixture in storage tanks located outside the facility fence line. The feed receipt system permits the recirculation of this process mixture between the storage tanks and piping manifolds located inside the facility.

The feed receipt system delivers the plant feed slurry to the feed preparation system where excess water is driven off by evaporation. The concentrated slurry is then adjusted with glycolic acid and blended with recycled and fresh frit slurries before undergoing batchwise transfer to the melter feed system. The overhead condensates from the feed preparation system

Figure 6.1-1. Ten Megagrams Per Day Detached High-Level Waste Vitrification Process Description.



are routed to the process liquid waste system for treatment before discharge from the plant.

The melter feed system periodically receives batches of melter-ready feed slurry containing solids and glass-forming frit from the feed preparation system. The melter feed system provides a continuous and controlled delivery of prepared melter feed slurry to the melter system.

A joule-heated melter converts the incoming feed slurry into molten borosilicate glass containing 45 wt% waste oxides. Volatilized melter feed components form a separate stream of offgas that passes overhead. The hot glass is semi-continuously poured into 0.7 m diameter by 4.6 m high cylindrical, stainless steel canisters.

Filled canisters are plugged, cooled, water-washed, blasted with frit slurry to remove exterior contamination, and finally welded closed. Spent wash liquids and decontamination frit slurry are recycled to the process liquid waste system for evaporation of excess water and recycle of the recovered contaminants. Decontaminated canisters, filled with monolithic HLW glass, are transferred from the vitrification building to interim storage while awaiting eventual shipment to a federal geologic repository.

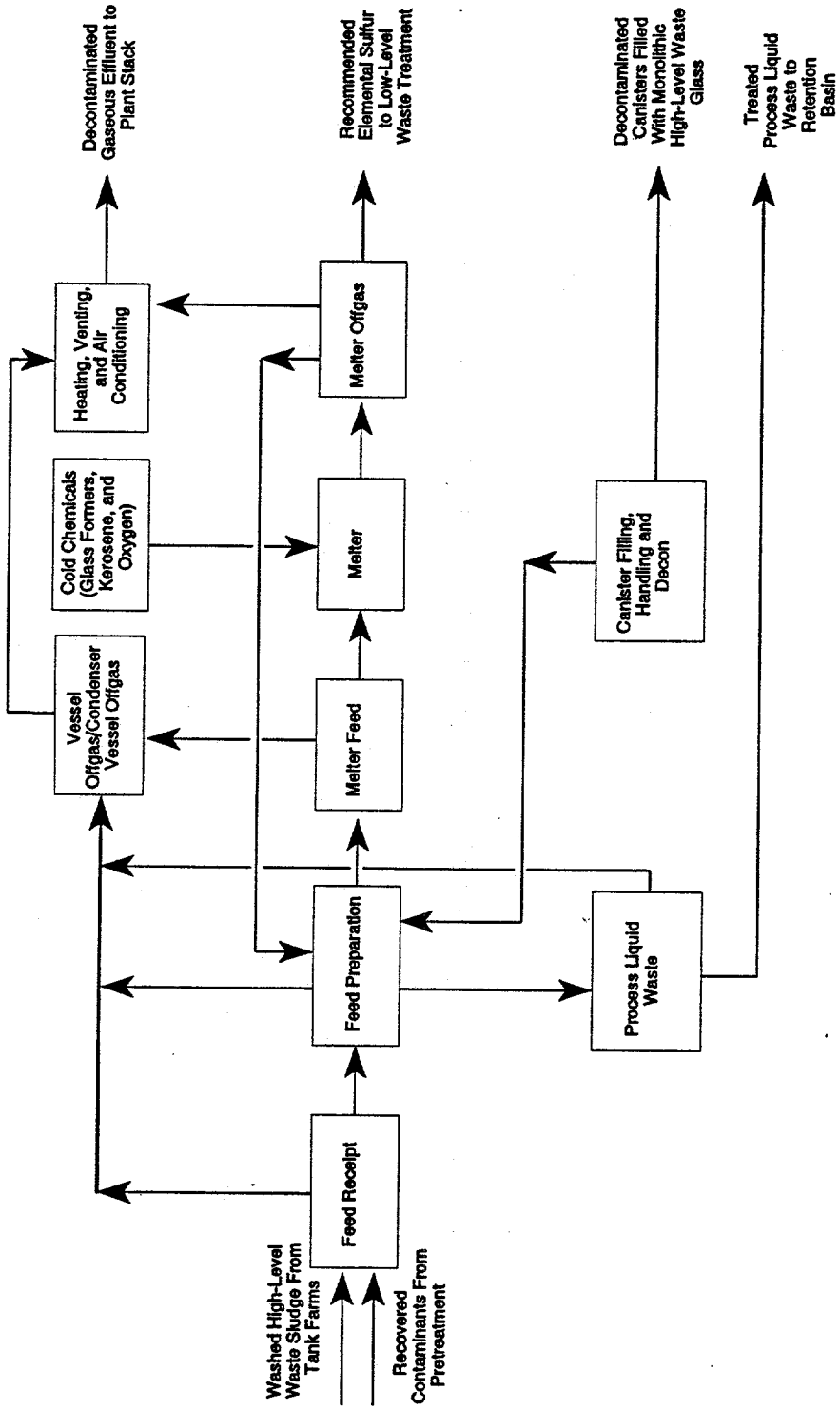
In the MOG system, the hot gases from the melter plenum are first cooled by blending with air and low-pressure saturated steam. Subsequent water quenching of MOG in an ejector venturi scrubber provides further cooling, resulting in significant water vapor condensation and capture of entrained particulates and water-soluble contaminants. Excess process condensates are continuously purged to the process liquid waste system while quenched offgas passes through a mist eliminator and multiple stages of high-efficiency filtration where most of the remaining radionuclides are captured. The treated MOG combines with the vessel offgas (VOG) from the process vessel ventilation (PVV) system before passing through NO_x abatement equipment enroute to the heating, ventilating, and air conditioning (HVAC) system.

6.1.1.2 20 Mg/d Process Description. The HLW vitrification facility receives HLW from tank farms. The stream passes through the Waste Storage and Sampling Facility (WSSF) that contains six 400-m^3 tanks. From the WSSF, the stream enters the facility for processing in the single HLW vitrification line (see Figure 6.1-2).

After sampling, the washed HLW slurry transfers to the HLW feed preparation system that removes excess water from the process loop. The water removal first occurs by centrifuging the HLW slurry then by evaporation of the centrate and aqueous purges from other systems. The resulting condensates transfer to the process generated liquid waste system. After sampling, cooling, and necessary adjustments, the retained process slurry transfers to the HLW melter feed system.

The HLW melter feed system periodically receives batches of melter-ready process solutions from the feed preparation systems and, in turn, provides continuous, controlled deliveries to the HLW melter system. The process feed and dry glass formers blend on entering the melter combustion chambers where liquid kerosene burns with enriched oxygen. The concurrent contact between

Figure 6.1-2. Twenty Megagrams Per Day Detached High-Level Waste Vitrification Process Description.



Boomer/WMES295
Figure 4.3-2
6/20/94

Table 6.1-1. Detached High-Level Waste Vitrification Feed and Product Composition.

Species	Feed to high-level waste	Product from high-level waste
Radioactivity (Megacuries)		
^{137}Cs and ^{137}Ba[1]	99.4	99.1
^{90}Sr and ^{90}Y	139	138
^{99}Tc	0.00924	.00918
Transuranics	0.195	0.195
Total	239	237
Mass (Megagrams)		
Total Mass	64,000	22,700
Volume	50,000	8,200
Aluminum (Al)	365	793
Chromium (Cr)	36.9	36.9
Iron (Fe)	809	809
Sodium (Na)	1,420	1,880
Phosphorus (P)	239	239
Uranium (U)	1,280	1,280
Zirconium (Zr)	559	552
Chloride (Cl^-)	3.47	
Fluoride (F^-)	58.7	
Nitrite (NO_2^{-2})	106	
Nitrate (NO_3^-)	2,660	
Cancrinite	2,700	
Other	4,910	17,100

[1]Cesium-137 makes up approximately 51 percent of the combined cesium and barium curies.

the process solids/glass former mixtures and the hot combustion gases produces molten HLW borosilicate glass.

The HLW glass stream continuously pours from separator sections downstream of the melter combustion chambers. Glass pours from the melter into 0.7 m diameter by 4.6 m canisters. The canisters are welded shut and decontaminated before being loaded into an interim storage cask. The transporter moves the loaded storage casks to a pad for interim storage until shipment to the repository.

The HLW MOG systems receive the hot combustion gases from the glass separator section of the melter. Quenching of these offgases by countercurrent contact with cool scrub water removes most of the entrained particulates and water-soluble contaminants, and condenses much of the water vapor. Excess condensates from both the HLW MOG systems recycle to the HLW Feed Preparation System for re-evaporation. The scrubbed melter offgases cool and pass through successive stages of filtration and flow to a sulfur dioxide adsorption process and a catalytic de-NO_x reactor before final discharge to the HVAC System. The Claus unit converts recovered sulfur dioxide into elemental sulfur that packages its product for disposal.

6.1.2 Facility Description

Layouts were developed for a 10 Mg/d and 20 Mg/d facility. Both facilities employ remote operation and remote maintenance design philosophy using a canyon design. Both facilities could use the transfer aisle layout employed in the combined floor facility.

6.1.2.1 Ten Megagrams per Day Detached High-Level Waste Vitrification Facility. The 10-Mg/d HLW facility layout is sized to provide a historical tie to previously considered vitrification facility designs. The layout shown in Figure 6.1-3 maintains the facility footprint of the former HWVP design. The criterion of maintaining the footprint did not allow for significant incorporation of upgrades and design improvements evident in the other layouts presented in this study.

The 10-Mg/d facility has five areas: product handling and receipt, melter equipment, canister handling, cold chemical make-up, and HVAC. The facility has overall dimensions of 138 m long by 46 m wide with a height of 56 m, of which 4 m extends belowgrade. Figure 6.1-3 depicts the process level which resides at 4 m belowgrade. The facility has three other levels at grade, 16 m, and 30 m.

The process level contains the feed receipt and handling, melter equipment, and canister handling. The feed receipt and handling receives the waste from the WSSF located external to the facility. A second cell houses the melter equipment that receives the feed adjusted waste. A separate cell houses the mechanical operations supporting canister handling.

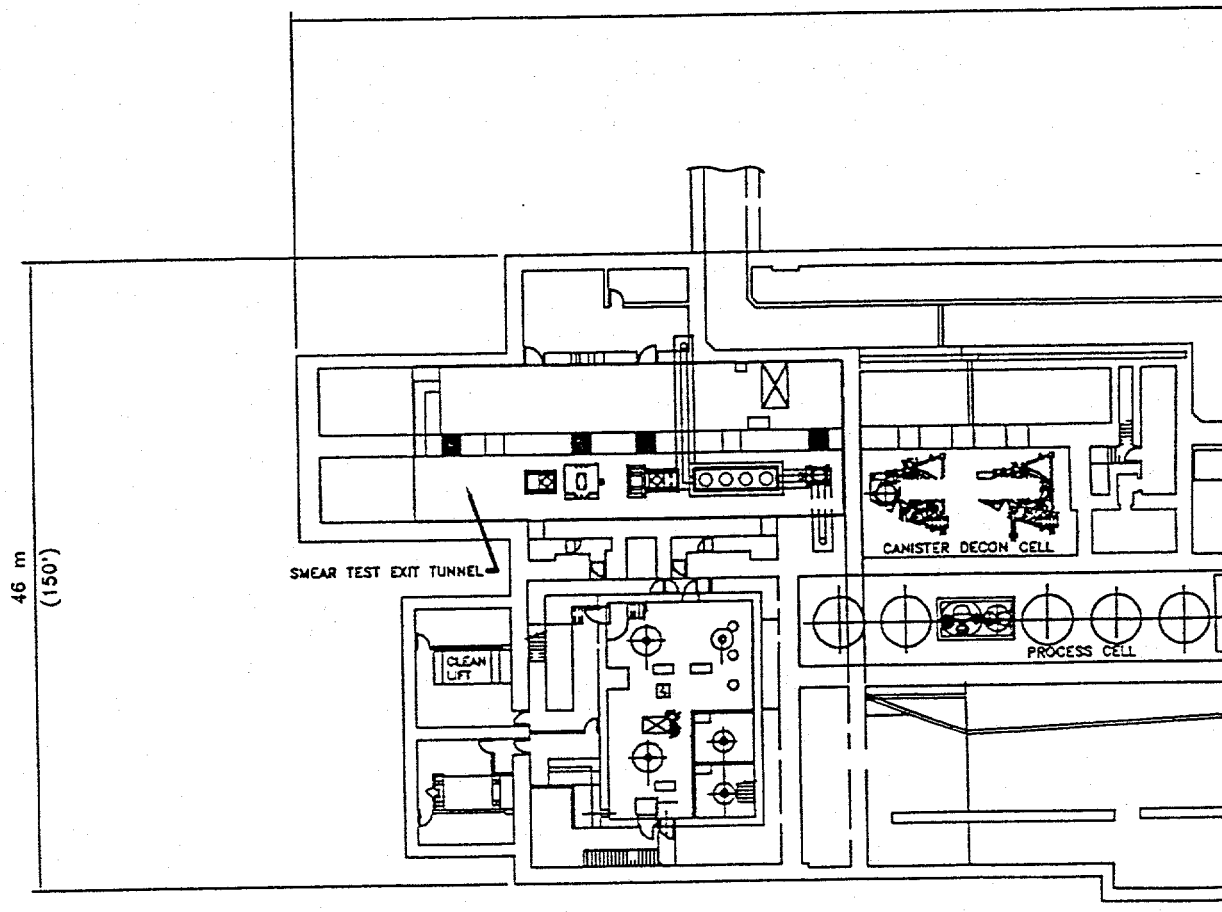
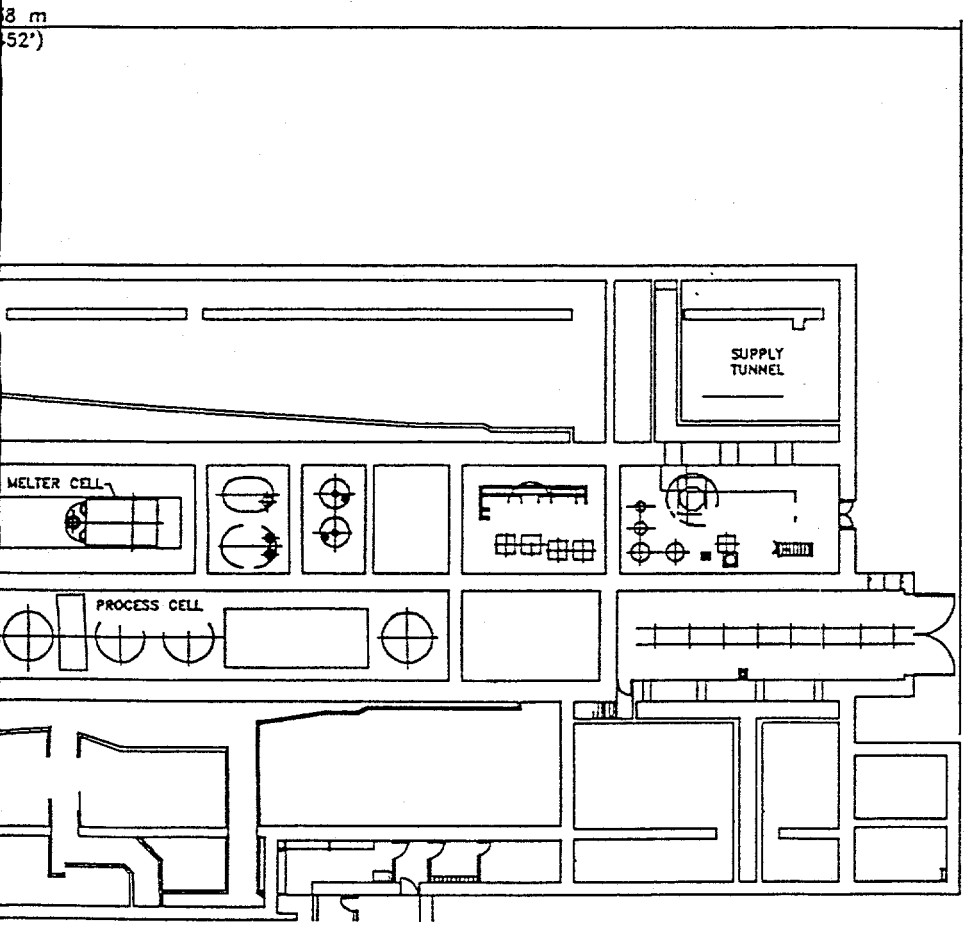

46 m
(150')
SMEAR TEST EXIT TUNNEL
CLEAN LIFT
CANISTER DECON CELL
PROCESS CELL

Figure 6.1-3. Ten Megagrams per Day Detached High-Level Waste Vitrification Facility.



The grade level has process maintenance support areas for the process. The 16-m level contains maintenance areas for the crane and cold chemical make-up areas. The 30-m level contains the HVAC equipment. The facility has several annexes to support operation (e.g., regulated entrance, cold maintenance, and others).

6.1.2.2 Twenty Megagrams per Day Detached High-Level Waste Vitrification Facility. The 20 Mg/d facility has six areas: feed receipt and sampling, process evaporation, melter operations, maintenance areas, canister loading, cold chemical make-up, and HVAC. Figure 6.1-4 depicts the process level for the facility that extends 4 m belowgrade. The facility has an overall height of 58 m, of which 13 m extend belowgrade. In addition to the process level, the facility has three other levels at -13 m, +13 m, and +20 m. The facility has an overall floor space of 23,200 m^3 and a volume of 354,000 m^3.

The process level contains the feed receipt and sampling, process evaporation, melter operations and the maintenance area. The chemical process cell contains the feed receipt and sampling vessels. The tanks receive feed from 6 200-m^3 tanks that sit in an adjacent structure.

The process cell also includes tanks to support the process evaporator. Finally, this cell contains feed tanks to the melter. The melter cell contains the HLW melter and offgas equipment. The maintenance area provides space for the repair and disposal of failed equipment.

The other three levels provide the remainder of the support facilities. The -13 m level houses the canister loading and handling equipment. The +13 m level contains service corridors at the top of the cover blocks. The +20 m level provide crane maintenance and cold chemical make-up.

6.1.3 Cost Estimates

This section provides cost information on detached HLW vitrification in three areas: capital, operating, and miscellaneous. This information provides the basis for cost comparison.

6.1.3.1 Capital Cost. Table 6.1-2 shows the capital cost for the 10 Mg/d with cullet processing and 20 Mg/d with canister and cullet processing facilities. The 10 Mg/d includes the costs for support facilities that 20 Mg/d does not have. In the current estimate, the difference between canister and cullet processing totals $90 million. The majority of this cost comes from the increased building foot print required for cullet casks.

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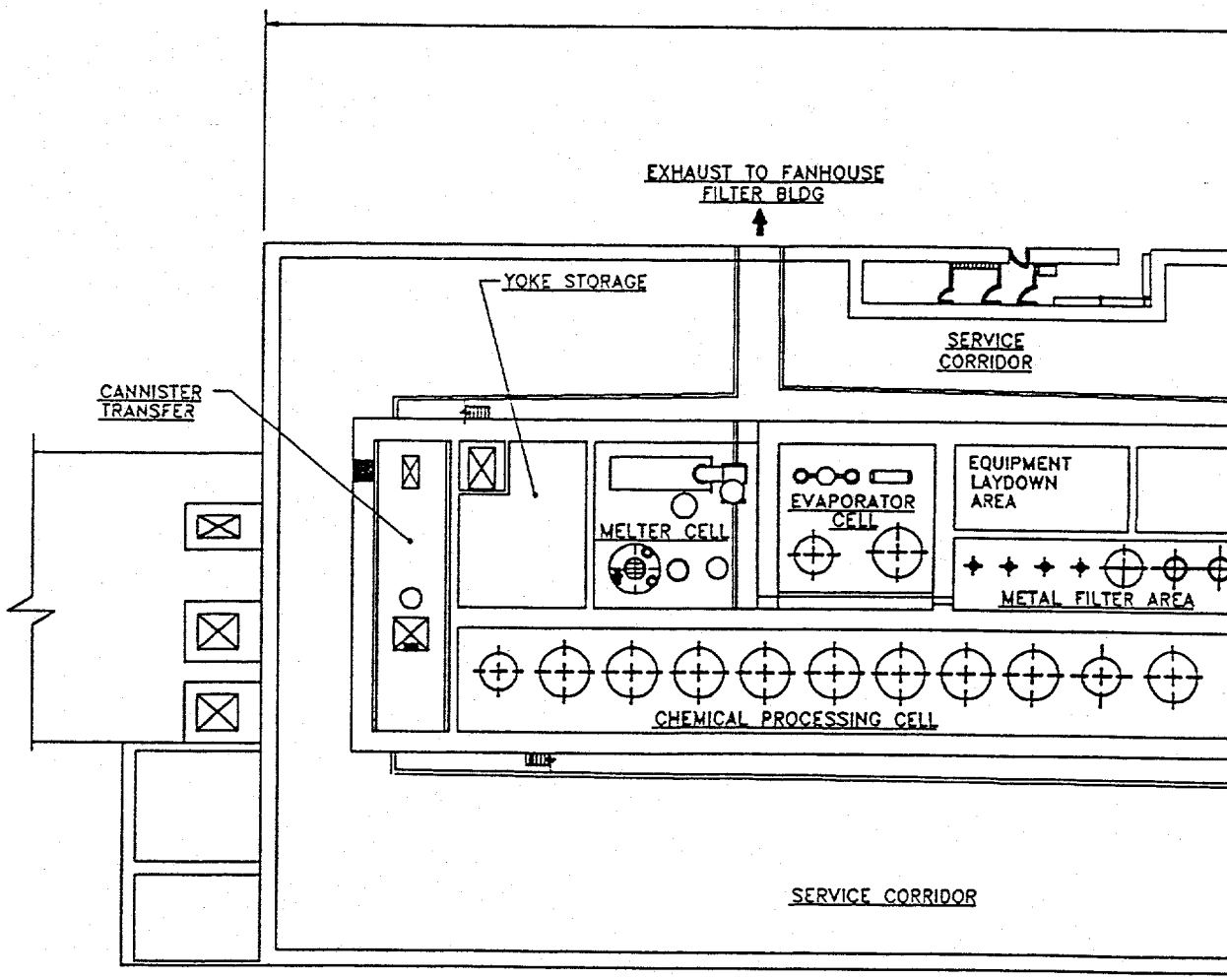

EXHAUST TO FANHOUSE
FILTER BLDG
YOKE STORAGE
SERVICE
CORRIDOR
CANNISTER
TRANSFER
MELTER CELL
EVAPORATOR
CELL
EQUIPMENT
LAYDOWN
AREA
METAL FILTER AREA
CHEMICAL PROCESSING CELL
SERVICE CORRIDOR

Figure 6.1-4. Twenty Megagrams per Day Detached High-Level Waste Vitrification Facility.

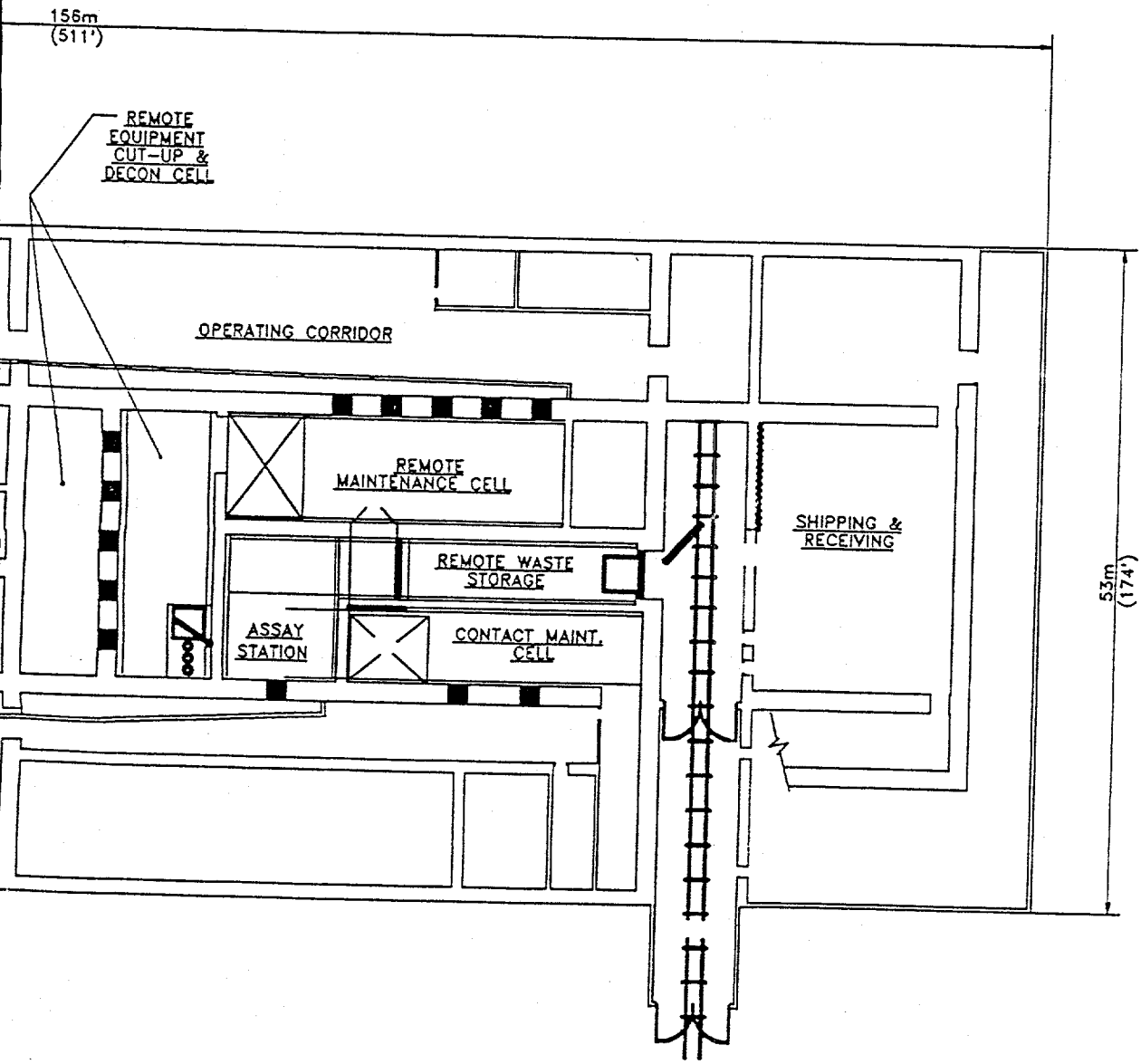


Table 6.1-2. Potential Improvement in Capital Costs for a Detached High-Level Waste Vitrification Facility.

Description	Potential Cost Improvement: HLW Vitrification Facility as Part of a Complex	
	Monolith ($M)	Cullet ($M)
Engineering	170	150
Buildings	50	0
Special equipment/process systems	20	0
Laboratory equipment	0	0
Total potential improvement[1]	240	150

[1]Cost is in 1994 dollars and includes 40 percent contingency.

The support facilities included in the 10 Mg/d facilities include the office, warehouse, and utilities space. Section 6.2 identifies these facilities for the complex which totals about $500 million. The cost difference between the 10 Mg/d and 20 Mg/d consist of the cost for providing support facilities, utilities, and services. The support facility, utilities, and services cost estimate has the same value for one facility or for the complex.

Figure 6.1-5 shows the construction schedule for the detached HLW facility. With a start date of 2009, construction should start in 2000 to minimize interference during construction. This date advances plant construction by two years over the Tri-Party Agreement date.

6.1.3.2 Operating Cost. The operating cost for the detached HLW vitrification facility consists of labor and consumables cost. The detached HLW facility has an operating cost between $30 million and $53 million per year. This cost includes either $22 million or $45 million for labor and $8 million for consumables. The labor range depends on number of other (one or two) facilities operating. The consumables range depends on the process (sludge wash or enhanced sludge wash) in use. Table 6.1-3 shows the amount and the cost of consumables for the life of the facilities for both the sludge washing and ESW cases.

Figure 6.1-5. Detached High-Level Waste Vitrification Construction Schedule.

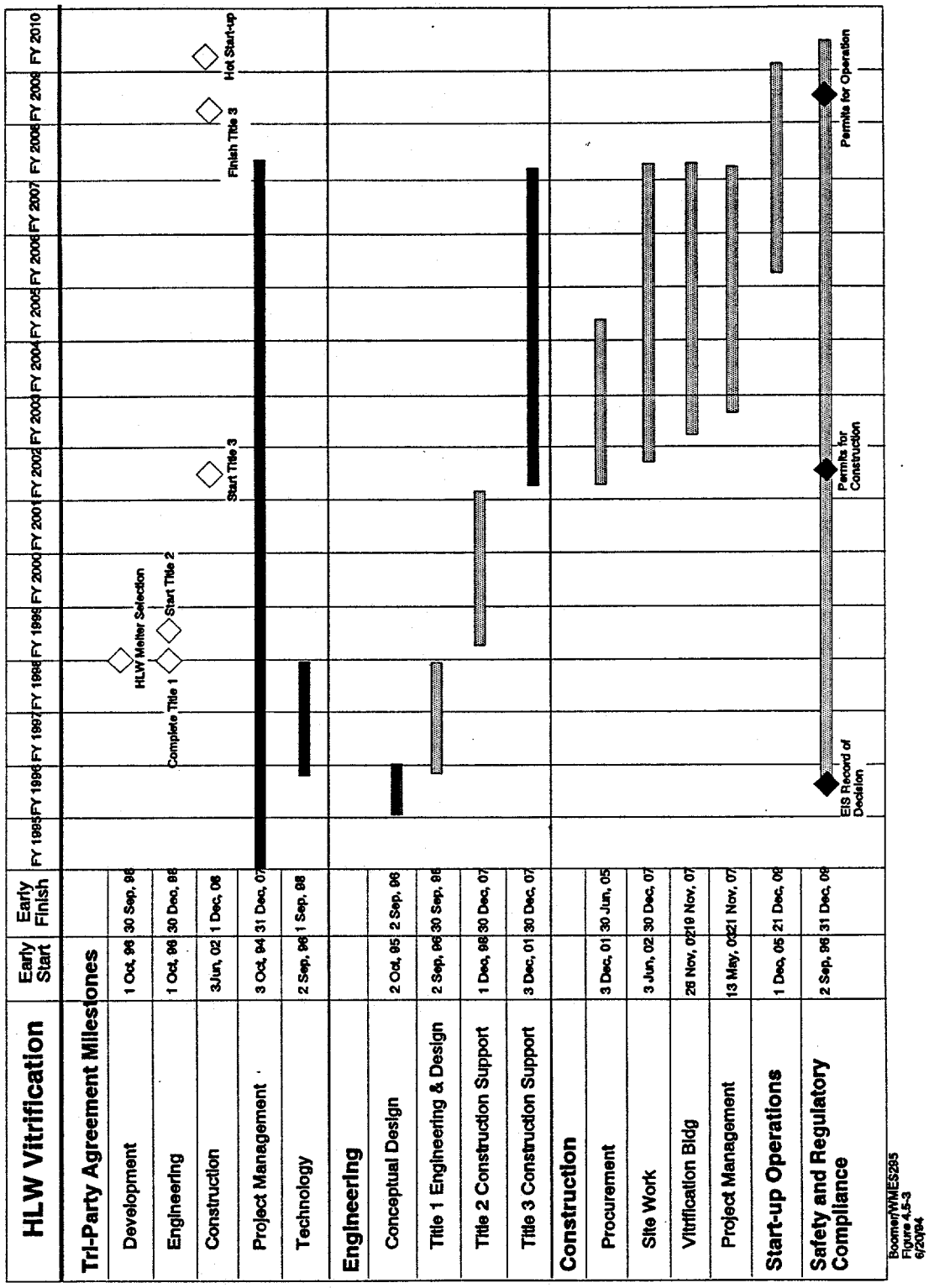


Table 6.1-3. Consumables for Detached High-Level Waste Vitrification.

Consumables	Unit cost $/each	Quantity	Cost ($M)
Glass Formers (Mg)	660	12,100	8.0
B_2O_3 (Mg)		2,180	
Li_2O (Mg)		606	
SiO_2 (Mg)		9,340	
Kerosene (Mg)	150	6,220	0.9
Ammonia (Mg)	350	276	0.1
Raw Water (m^3)	3	8,000,000	24
Steam (Mg) at 15 MPa	5	32,000	0.2
Electricity (MWh)	30	2,300,000	69
Total for 14 years			102

6.1.3.3 Miscellaneous Cost. In addition to the costs above, the detached HLW vitrification facility has the following costs:

- Development
- Start-up
- Spares and equipment replacement
- Canister
- Shielded interim storage canisters and storage pads
- Repository disposal fee
- Decontamination and decommissioning.

The development and start-up costs occur before operation of the facility. These costs along with the capital cost give the TPC for the facility. For purposes of this study, the development cost came from a draft of the TWRS *Multi-Year Program Plan* (WHC 1994) and totals $250 million. The start-up cost for a facility includes such items as the staff training, acceptance testing, permit preparation, and safety documentation. This work would begin 5 years before the start-up of the facilities and has an assumed cost of 3 years of facility staff cost.

The spares and equipment replacement cost covers the routine expenditures for facility wear and tear. The detached HLW vitrification facility design replaces failed equipment in the melter system and product handling system as necessary. This cost covers melter system, product handling system, and small item replacements such as valves and pumps. The detached HLW facility has a spares and equipment replacement cost of $5 million per year.

The HLW canisters cost about $10,000 each. For the *Facility Configuration Study* (Boomer et al. 1994), the volume of glass produced by enhanced (caustic) sludge washing has been assumed. This assumption leads to the need for 6,300 canisters, which translates to a canister cost of $63 million. If the standard (water) sludge washing process is used, this canister requirement increases to 17,900 with a cost of $180 million.

The interim storage casks have a cost of about $60,000 each. Each cask can hold 4 canisters, which leads to a total number of 1,580 casks and two storage pads. The casks cost $95 million and the pads costs $26 million for an enhanced sludge wash process. If the standard sludge wash is used, this case would require 4,800 cask and four storage pads. This calculates to a cask cost of about $270 million and the pad cost to $52 million.

The repository cost depends on many events, but the OCWRM has provided an estimate for a similar case. The OCWRM estimate for 2,300 10-m^3 cask totaled about $2 billion. For purposes of this report, the poured canister repository disposal has a cost of $1.5 billion.

The decontamination and decommissioning occurs after the completion of all process campaigns. This cost pays for the removal of equipment and gross radioactivity from the facility and disposal of the debris. For purposes of this study, the decontamination and decommissioning cost consists of 30 percent of the initial capital and three years of staff cost spent over a 5-year period.

6.2 SERVICES AND UTILITIES FOR THE INTEGRATED HIGH-LEVEL WASTE VITRIFICATION PLANT

To process the tank waste in an integrated facility configuration, the pretreatment and vitrification facilities will require an integrated site layout as described in detail in Chapter 5.0 of the *Facility Configuration Study* (Boomer et al. 1994). This section summarizes the basis for site requirements, staffing requirements, and site location.

6.2.1 Site Infrastructure and Staffing Requirements

The site infrastructure and staffing requirements differ very little between the configurations. The design of a centralized complex performing the same process steps leads to this lack of distinction. Should changes occur to either the design or process assumptions, then the cost basis would change. Table 6.2-1 shows the cost for centralized facilities, utilities, and services.

Table 6.2-1. Cost for Centralized Facilities, Utilities, and Services.

Description	Cost ($M)
Engineering	130
Buildings	290
Special equipment/process systems	100
	520

6.2.1.1 Common Utilities and Services. Each of the facilities provides most of the process support equipment it requires. Common utilities and cold chemical areas provide common headers for services to support the individual systems in the plants. These common services include the following:

- Medium Pressure Steam (Consumed) and Condensate
- Compressed Air (Instrument/Plant Air)
- Cooling Tower
- Water
  - Sanitary Water
  - Process Water
  - Demineralized Water
  - Raw Water and Fire Water
- Effluent Treatment Facility
- Sanitary Sewer
- Non-Radioactive Liquid Waste Processing
- Cold Chemicals Bulk Storage and Make-Up (including Glass Formers)
- Bulk Cold Chemical Building Vent System
- Oxygen
- Electricity.

Medium Pressure Steam System provides consumed steam (e.g., steam jets) to the facilities as a shared utility. The steam trap condensate collection systems are located in the individual facilities. The Medium Pressure Steam and Condensate System takes 15 MPa saturated steam from the site steam distribution system and reduces its pressure to 11 MPa. Table 6.2-2 shows each configuration utility usage.

Certain systems within the individual processing plants require closed loop steam (to minimize the amount of potentially radioactive material leaving the area). This steam is provided by packaged Process Steam Generators located within each facility. The closed loop process steam system is completely independent of the medium pressure steam system. See Appendixes A through G of the *Tank Waste Remediation System Facility Configuration Study* (Boomer et al. 1994) for more detail on Process Steam within each facility.

The Compressed Air System provides instrument air for pneumatically controlled components, plant air for spargers, jets, and general maintenance use. The plant air is provided preferentially to critical plant air users. This utility source is located in the Mechanical Utilities Building.

Table 6.2-2. Configuration Utility Usage.

Configuration	Water		Steam		Electricity	
	Maximum rate (m^3/min)	Annual consumption (m^3)	Maximum rate (Mg/h)	Annual consumption (Mg)	Connected load (MW)	Operating load (KW)
1	36.3	2,360,000	13.7	11,300	115	97,000
2	36.3	2,360,000	13.7	11,300	117	98,700
3	36.3	2,330,000	14.2	11,300	118	98,600
4	36.3	2,360,000	13.7	11,300	115	97,100
5	36.3	2,330,000	14.2	11,300	117	98,700

The Cooling Tower System removes heat from the normal processing operations of the various cooling water systems, and rejects that heat via evaporative cooling. It includes a cooling tower, cooling tower water circulation pumps, inhibitor addition pump, and distribution piping. Raw water is used for cooling tower make up. Bleedoff is routed to the 200 area Treated Effluent Disposal Facility.

Liquid effluents from the process facilities consists of condensates from evaporators. The condensates from the process facilities collects in a retention basin. From the retention basin, the condensate either recycles to support retrieval of tank waste or goes to the Liquid Effluent Treatment Facility (LETF) Project C-018. This facility currently supports operation of 242-A Evaporator.

The Sanitary Water System supplies water for domestic uses and for HVAC humidifiers. It is also the source for the Process Water System. The Sanitary Water system consists of distribution piping installed in a loop around its users/facilities.

The Process Water System is the source water for the low pressure process water tanks and other users in the separations, vitrification treatment facility(ies) and facility(ies) annex, the Bulk Cold Chemical Building, the Waste Staging and Handling Facility, and demineralizer and other users in the Mechanical Utilities Building. It is the source for chemical dilution water, priming for pumps, and equipment flushing. Sanitary water, separated from the process water by a backflow preventer, is used as the source for the Process Water System.

The Nonradioactive Liquid Waste Processing System receives, collects, stores, and disposes of all non-radioactive liquid waste in a safe and environmentally acceptable manner. Chemically contaminated liquid wastes are sufficiently neutralized prior to transfer to the 200 Area Treated Effluent Disposal Facility. It includes hold tanks, neutralization tanks, sumps, and pumps.

The Cold Chemicals Bulk Storage and Make-Up System includes all facilities required to receive, store, prepare, and feed cold chemicals to process users. It includes storage tanks, make-up tanks, feed tanks, sump tanks, and appurtenances, such as pumps, agitators, heaters, and distribution facilities. Glass former bins and transport equipment is also a part of this system.

The site will require approximately 120 MVA to support the operations of the facility cases. A new power line will be provided to the 200 Area site. This will be accomplished by providing a new 230 KV power line approximately 2 km long. The power line which will feed to the TWRS Treatment Complex Switch Yard.

6.2.1.2 Support Buildings. The process facilities share support buildings/facilities. These facilities provide space for non-process activities and for personnel when not working in the process plant.

Operations Support Building (OSB)
Regulated Entrance Building (REB)
Operations Control Building (OCB)
Bulk Cold Chemical Building
Switch Gear/Generator Building
Mechanical Utilities Building
Cooling Tower
Fabrication and Mock-up Shops
Warehouses
Switchyard
Railroads.

The OSB serves as the administration building for the complex. The OSB has 5,574 m^2 combined facilities space. About 40 percent (2,308 m^2) of the floor area is office space. The remaining 60 percent of the floor area (3,266 m^2) consists of a lunch room, conference rooms, storage and equipment areas, and other personnel spaces. The other personnel spaces consist of operations supply room, clean and dirty laundry storage, tool rooms, miscellaneous storage rooms, copier rooms, etc.

The REB is the single point of entry into the facility for maintenance and operating personnel. It provides the health physics controlled entry and exit, change room, lunch rooms, conference rooms, and first aid clinic. The REB provides 6,503 m^2 office space for 131 (114 + 15 percent contingency) workers in 1,462 m^2 of office area. In addition, the REB provides 4,112 m^2 support for the office workers and 225 other workers. These 225 workers do not require office space.

The OCB houses the central control rooms for the entire TWRS Treatment Complex. The required size for the OCB to accommodate combined process facilities is 2,090 m^2. It contains 1 central control room, 1 health physics control room, 2 safety class rooms, 2 electrical equipment rooms and 2 HVAC equipment rooms.

The bulk cold chemical building is a one story facility approximately 91 m by 91 m providing 8,361 m^2 of space. This floor space houses anhydrous NH^3, kerosene, HNO^3, sulfur, DCPD, CPD oligomer, and NaOH storage equipment. Chemical make-up will also be located in this facility.

The Switchgear/Generator Building is a one story facility approximately 91 m by 91 m provides 8,281 m^2 floor space. This floor space houses switchgear and generator which will service the TWRS Treatment Complex. This facility will be unoccupied.

The Mechanical Utilities Building is a one story facility approximately 91 m by 91 m and provides a floor space of 8,281 m^2. The utility systems residing in this building are the plant air system, used for spargers, jets, and general maintenance; the instrument air system for pneumatically controlled components in the plant; the chilled water system used by the HVAC and Process; the demineralized water system used as make-up to the process cooling water, melter cooling water expansion tank, and process steam and condensate system.

Four small buildings or shelters external to the mechanical utilities building support water distribution of the raw water and fire water. These building include the booster pumphouses (used to increase the low pressure water source to that required for cooling tower make-up and fire protection), fire water pumphouse, and manifold shelter building. The Cooling Tower is located at one end or corner of the TWRS Treatment Complex. The approximate size is 61 m by 61 m.

The support building also consists of two shops and three warehouses. The Fabrication Shop is a one story facility approximately 46 m by 91 m for a floor area of 4,181 m^2. The Mock-Up Shop is a one story facility approximately 46 m by 91 m for a total of 4,181 m^2 of floor area. The three warehouses that are one story facilities approximately 46 m by 91 m, for a total of 4,181 m^2 of floor area each.

The switch yard/substation serving the TWRS Treatment Complex consists of incoming 230 kV transmission dead end towers feeding a double-ended bus with a single tie breaker. The bus feeds redundant transformers rated 230 kV - 13.8 kV, with a capacity of approximately 100 MVA. The 13.8 kV transformer secondaries feed a double-ended switchgears located in a switchgear building, which also include utility monitoring and control equipment. The substation will be approximately 119 m by 149 m or 17,748 m^2.

6.2.1.3 Staffing. This section presents operating staffing profiles based on the independent operation of any single process function, any combination of two or three process functions housed within a single facility, or a complex of two or three facilities. The staffing profiles for each of these conditions are summarized in Tables 6.2-3, 6.2-4, and 6.2-5.

Table 6.2-3. Operating Staff--One Process Function.

	Exempt	Non-exempt	Bargaining unit	Total
Building Support	63	18	74	155
Engineering and Support	38	9	0	47
Process Staff	31	14	50	95
Maintenance	26	5	122	153
Total	158	46	246	450

Table 6.2-4. Operating Staff--Two Process Functions.

	Exempt	Non-exempt	Bargaining unit	Total
Building Support	80	18	110	208
Engineering and Support	49	11	0	60
Process Staff	35	14	88	137
Maintenance	26	5	132	163
Total	190	48	330	568

Table 6.2-5. Operating Staff--Three Process Functions.

	Exempt	Non-exempt	Bargaining unit	Total
Building Support	89	18	146	253
Engineering and Support	60	11	0	71
Process Staff	35	14	112	161
Maintenance	26	5	136	167
Total	210	48	394	652

These estimates were derived through a heuristic estimate of minimum levels of operating support based on staffing for similar European facilities and best judgement as to a representative number and type of work stations. In addition, these estimates consider the effects of the following two fundamental assumptions:

1. A certain minimum core staff (which may or may not be fully loaded with work) is required regardless of the complexity of the operation in question. Furthermore, additional unit operations or process functions do not result in a direct multiplication of staff due to the effects of existing core staff assuming a full and leveled work load. Therefore, each additional unit operation put on line only required a relatively small incremental change in staffing levels.

2. A single line management organization will be implemented to take advantage of the benefits of sharing resources across all three process functions. A single management team concept is a logical and necessary result of the high degree of interrelationship between the process functions. A single management team has a net positive impact on staffing requirements due to common management objectives and integrated prioritization of activities.

The program offices for each of the process functions have developed operating staff estimates based on three separate facilities operating under separate line management organizations. These estimates are offered below and reflect the impact of the assumptions used in developing staffing estimates.

- Program office derived separations staffing estimate = 687 fulltime equivalents (FTEs).

- Program office derived LLW staffing estimate = 964 FTEs.

- Program office derived HLW staffing estimate which is based on HWVP planning = 1,113 FTEs.

These differences will be resolved during FY 1995.

6.2.1.3.1 Direct Staffing. As shown in Table 6.2-6, the direct staff required to support the three waste processing functions housed as a single facility or a complex of facilities was determined to be 652 FTEs. These staffing levels are consistent with staffing levels necessary to operate facilities of similar size and complexity such as the PFP and PUREX plant. The principle set of conditions and assumptions used to develop the baseline staffing levels are as follows:

- The facilities will be managed as a single operation regardless of the number of facilities. The Operations function as well as all support functions (Maintenance, Health Physics, Safety, Engineering, Training, Job Control, Quality Assurance and Analytical Laboratories) will report through direct lines to a single facility manager who will be responsible for all waste processing operations within the facility or facilities complex.

Table 6.2-6. Staffing Levels. (Sheet 1 of 3)

Title	SHIFT STAFFING																					Total
	Day Shift			A Shift			B Shift			C Shift			D Shift			Training Shift			Sub Total			
POSITION	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	
BUILDING SUPPORT																						
Plant Management																						
Plant Manager	1																		1			1
Assistant Plant Manager	1																		1			1
Technical/Budget Analysts	2																		2			2
Clerical	1	2																	1	2		3
Job Control																						
Managers	2																		2			2
Clerical		3																		3		3
Facility Administrator	3																		3			3
Job Control Specialists	3																		3			3
Material Specialists	2																		2			2
Schedulers	8																		8			8
Planners	8																		8			8
Crane Planners	2																		2			2
Plant Engineering																						
Managers	1																		1			1
Clerical		2																		2		2
Designers / Drafters		2																		2		2
Plant Engineers	14																		14			14
Analytical Laboratory																						
Managers / Supervisors	1			1			1			1			1			1			6			6
Clerical		2																		2		2
Chemists	3			3			3			3			3			3			18			18
Chemical Technicians			4			11			11			11			11			11			59	59
Standards Laboratory																						
Managers	1																		1			1
Clerical		1																		1		1
Chemists	2																		2			2
Chemical Technicians			2																		2	2
Radiation Protection																						
Managers	1																		1			1
Clerical		1																		1		1
Health Physics Technologists			3			4			4			4			4			4			23	23
Facility Services																						
Managers/Supervisors	1																		1			1
Clerical		1																		1		1
Process Operators			18			2			2			2			2			2			28	28
Crane Operators			3			2			2			2			2			2			13	13
Power Operators			4			3			3			3			3			3			19	19
Driver			2																		2	2
Computer Support																						
Managers	1																		1			1
Clerical		1																		1		1
System Admin. / Analyst	3																		3			3
Document Control																						
Managers	1																		1			1
Clerical		2																		2		2
Task Analysts	2																		2			2
Technical Editor	2																		2			2
Program Office																						
Program Managers	1																		1			1
Clerical		1																		1		1
Program Scheduler	1																		1			1
Program Administrators	1																		1			1
Subtotal	89	18	36	4		22	4		22	4		22	4		22	4		22	89	18	146	253

Table 6.2-6. Staffing Levels. (Sheet 2 of 3)

Title	SHIFT STAFFING																					Total
	Day Shift			A Shift			B Shift			C Shift			D Shift			Training Shift			Sub Total			
POSITION	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	
ENGINEERING & SUPPORT																						
Process & Technology Engineer																						
Managers	3																		3			3
Clerical		4																		4		4
Shift Engineers	3			1			1			1			1			1			8			8
Process Engineers	5			3			3			3			3			3			20			20
Technicians		2																		2		2
Surveillance & Testing																						
Manager	1																		1			1
Clerical		1																		1		1
Surveillance & Testing Engrs.	2																		2			2
Quality Assurance & Control																						
Manager	1																		1			1
Clerical		1																		1		1
Quality Control Inspectors	3																		3			3
Quality Assurance Engineer	2																		2			2
Safety Engineering																						
Managers	1																		1			1
Clerical		1																		1		1
Radiation Engineers	4																		4			4
Nuclear Engineers	4																		4			4
Industrial Safety Engineers	1																		1			1
Nuclear Materials Administration																						
Managers	1																		1			1
Clerical		1																		1		1
Specialists	2																		2			2
Training																						
Managers	1																		1			1
Clerical		1																		1		1
Trainers	6																		6			6
Subtotal	40	11		4			4			4			4			4			60	11		71
PROCESS STAFF																						
Operations Management																						
Operations Manager	1																		1			1
Shift Manager	2			1			1			1			1			1			7			7
Shift Support Manager	2			1			1			1			1			1			7			7
Clerical		2			1			1			1			1			1			7		7
Operators																						
Receipt			1			2			2			2			2			2			11	11
Cesium Ion Exchange			1			2			2			2			2			2			11	11
Effluents			1			2			2			2			2			2			11	11
Evaporators			1			2			2			2			2			2			11	11
LLW Melter			2			3			3			3			3			3			17	17
HLW Melter			2			2			2			2			2			2			12	12
Product Handling			2			2			2			2			2			2			12	12
Hazardous Material Control																						
Manager	1																		1			1
Clerical		1																		1		1
Technicians		2																		2		2
Engineers	8																		8			8
Environmental Control																						
Manager	1																		1			1
Clerical		1																		1		1
Technicians		2																		2		2
Engineers	4																		4			4
Radiation Protection																						
Managers / Supervisors	1			1			1			1			1			1			6			6
Clerical		1																		1		1
Health Physics Technologists			7			4			4			4			4			4			27	27
Subtotal	20	9	17	3	1	19	3	1	19	3	1	19	3	1	19	3	1	19	35	14	112	161

Table 6.2-6. Staffing Levels. (Sheet 3 of 3)

Title	SHIFT STAFFING																					Total
	Day Shift			A Shift			B Shift			C Shift			D Shift			Training Shift			Sub Total			
POSITION	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	E	NE	BU	
MAINTENANCE																						
Manager	1																		1			1
Clerical		1																		1		1
Maintenance Engr.	3																		3			3
Training Coordinator	1																		1			1
Mechanical Maintenance																						
Managers/Supervisors	1			1			1			1			1			1			6			6
Clerical		1																		1		1
Person in Charge	1																		1			1
Mill Wrights			6			2			2			2			2			2			16	16
Pipe Fitters			8			2			2			2			2			2			18	18
Insulators			2																		2	2
Riggers			2			2			2			2			2			2			12	12
Drivers			1			2			2			2			2			2			11	11
Welders			2																		2	2
Carpenters			2																		2	2
Painters			2																		2	2
Sign Writer			1																		1	1
I&E Maintenance																						
Managers/Supervisors	1																		1			1
Clerical		2																		2		2
Person in Charge	1			1			1			1			1			1			6			6
I&E Technicians			8			2			2			2			2			2			18	18
Electricians			6			2			2			2			2			2			16	16
Manipulator Maintenance																						
Managers/Supervisors	1																		1			1
Clerical		1																		1		1
Person in Charge	1			1			1			1			1			1			6			6
Mill Wrights			2			2			2			2			2			2			12	12
Electricians			2			2			2			2			2			2			12	12
I & E Technicians			2			2			2			2			2			2			12	12
Subtotal	11	5	46	3		18	3		18	3		18	3		18	3		18	26	5	136	167
TOTAL	140	43	99	14	1	59	14	1	59	14	1	59	14	1	59	14	1	59	210	48	394	652

- Shift support will be provided using a five shift rotation to maintain operating continuity 24 hours per day, 7 days per week. The operator compliment for each shift was developed based on the anticipated number of duty stations with contingency for supernumeraries and training/certification requirements. Each shift is also supported by maintenance, health physics, engineering and analytical laboratory personnel to ensure operating continuity.

- Facility design and control technology will result in efficiencies in the use of personnel resources such that complex facilities can be operated with fewer people. However, current trends in the regulatory climate are such that some of the potential gains in operating efficiency may be offset by additional "paper" related activities.

- The proximity of the facility or facilities complex will allow shared use of personnel resources.

- Where applicable, support function staffing (e.g., maintenance) requirements were based on experience at similar European facilities with consideration given to differences in maintenance and operations philosophies that may drive increases in required staffing.

6.2.1.3.2 Indirect Staff. A staff of 29 FTEs reporting indirectly to the facility or facilities complex manager will be required (see Table 6.2-7). This staff will provide support from organizations such as Data Standards Administration, Regulatory Support, Documentation and Records Management, Maintenance Programs Administration, etc. This estimate was developed by reviewing Cost Account Plans from former operating facilities and using best judgments as to scaleup or scaledown based on perceived needs. In addition, an estimated $1 million per year will be required for laundry services. This number was derived by using the highest of either actual 1993 or estimated 1994 costs.

6.2.2 Site Location

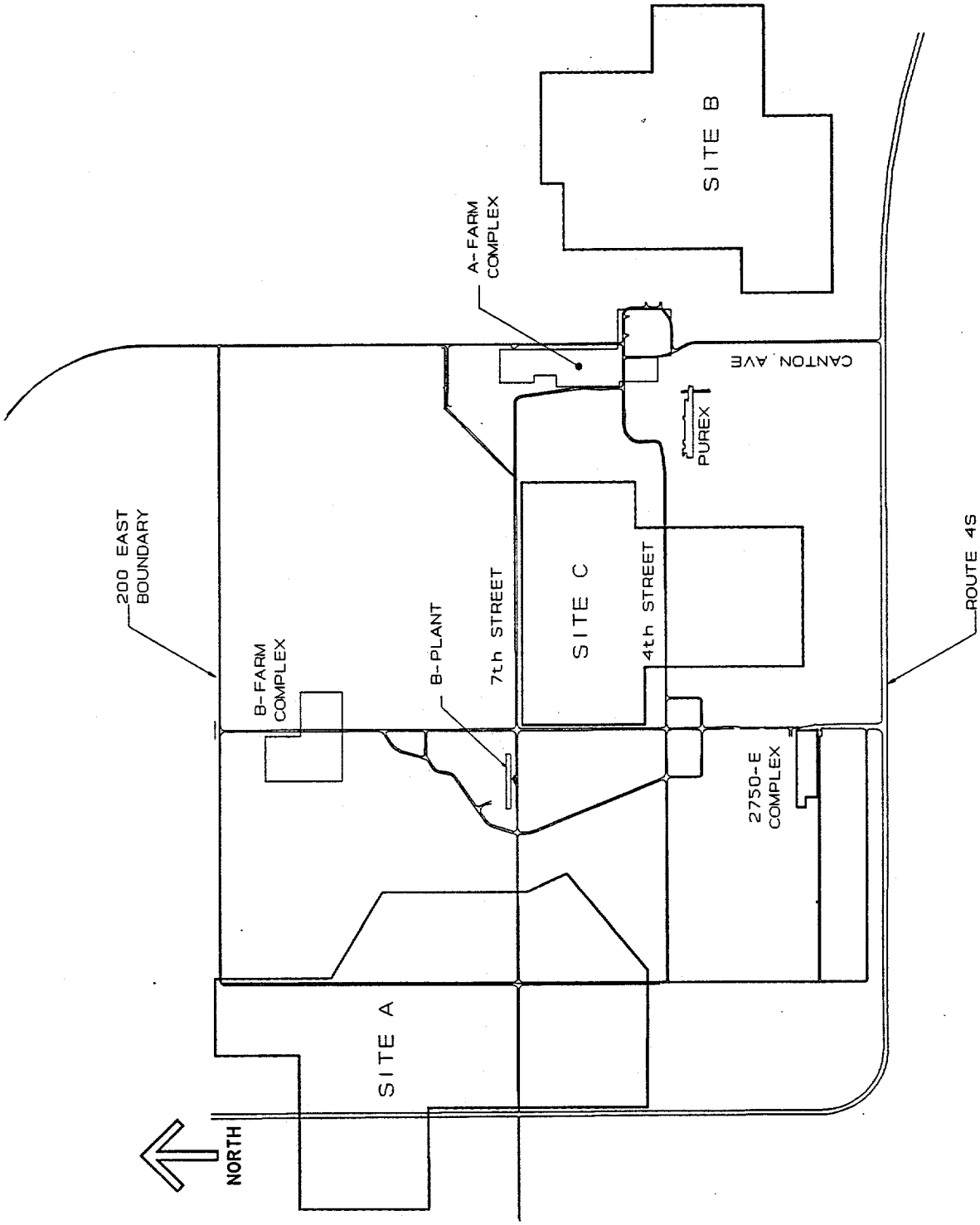
The TWRS processing complex must integrate with the other activities at the Hanford Site. The *Hanford Mission Plan* (DOE/RL 92-07) calls for the 200 Areas Plateau to serve as the site for future processing and disposal activities. This decision allows consideration of a large expanse for facility placement.

Though not a final selection, three potential sites are under consideration for further evaluation. Figure 6.2-1 shows these sites which adjoin or reside in the 200 East Area. Site A, West of the 200 East Area, consists of the original HWVP site and additional areas in the 200 Area corridors. Site B, East of the 200 East Area, consists of the Grout site and surrounding areas. Site C, in the 200 East Area, consists of area previously dedicated to facility expansion for the Hanford Site production mission.

Table 6.2-7. Indirect Costs.

	Full time equivalents
Data Standards Administration	1
Fabrication Services	2
Regulatory Support	3 (1 each for NEPA, Air and Water Permits, and RCRA)
Documentation and Records Management	4
Environmental Data Management	2
Safeguards	1
Traffic Operations	1
Maintenance Programs Integration	4
Criticality Engineering and Analysis	1
Checking Services	1
Hanford Analytical Services	4
Manufacturing and Welding Engineer	1
Engineering and Technology Support	4 (2 Safety Analysts, 2 miscellaneous engineering analysis support)
Total	29

Figure 6.2-1. Site Location.



Two facts favor placement of the facilities nearer the 200 East Area than the 200 West Area: consolidating facilities and the changing site boundaries. Hanford has consolidated activities over the past 20 years in the 200 East Area as opposed to the 200 West Area which has placed much of the necessary facilities and infrastructure closer to the 200 East Area. The freeing of portions of the Hanford Site for other uses has reduced the travel path for airborne releases from process facilities. The proposed placement of the West Boundary at Highway 240 would reduce the 200 West Area travel path to 11 km and the 200 East Area travel path to 20 km.

In selecting a site, many factors require consideration which include the impacts on construction, operation, and infrastructure. The construction impacts arise from the need to have sufficient space to stage material into the construction site without interference from other activities. The operation impacts come from locating the facilities such that the new facilities interact favorably with the old. The impacts to infrastructure come from placing the site to limit the additional construction of facilities to support the processing activities. Table 6.2-8 shows how the sites qualitatively compare on these three impacts.

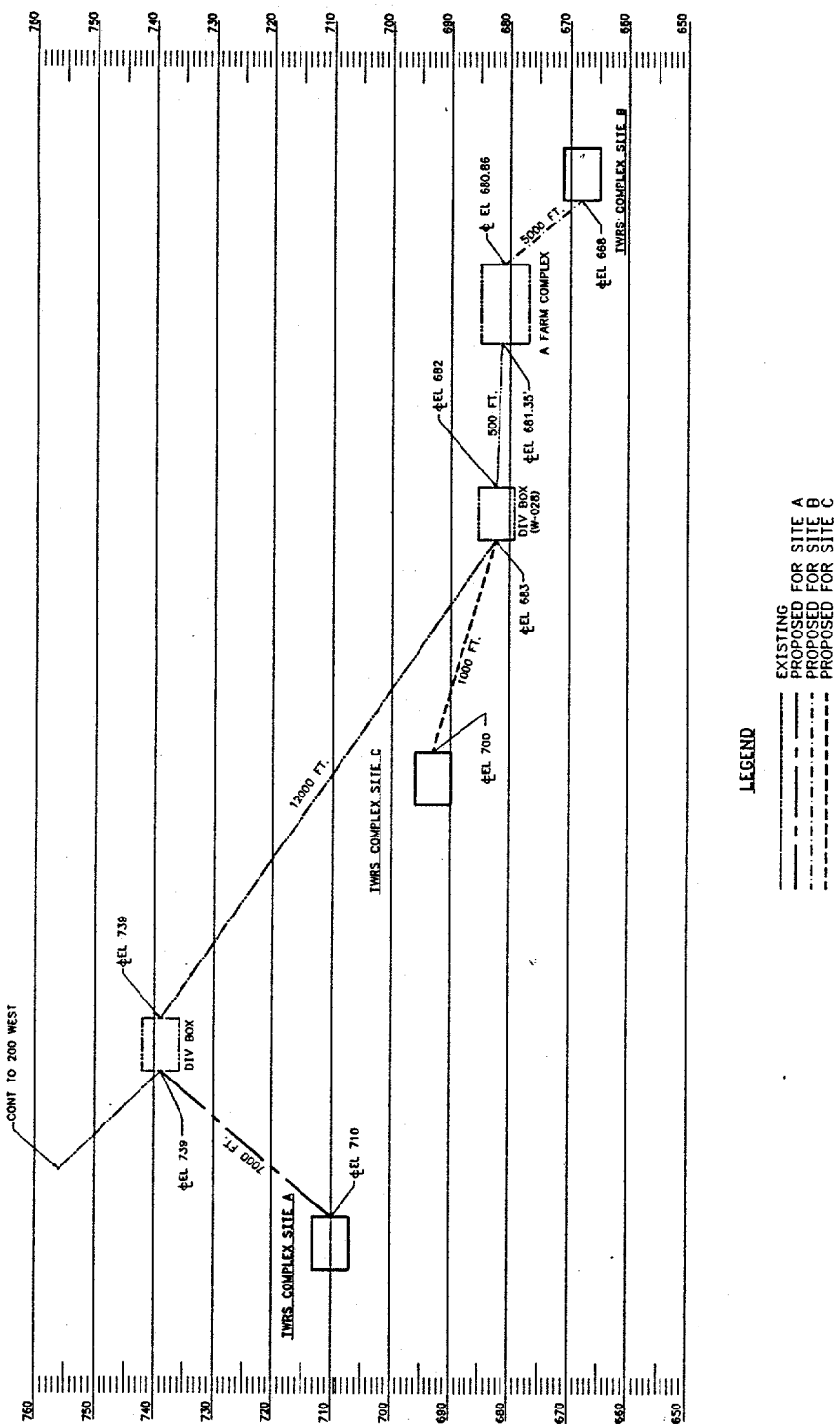
Table 6.2-8. Qualitative Comparison of Three Potential Sites.

	Site A	Site B	Site C
Construction	+	-	+
Operation	-	+	+
Infrastructure	0	0	0

The site selection can have a major impact on the ease of construction. Site A has large areas around it and has few interferences from other activities. Site B has limited areas and has impacts from other activities. Site C provides plenty of area, but has many impacts from other activities. The area required has more importance than the impacts from other activities because administrative actions or site improvements can control personnel access or enhance access to the site, reducing the impacts.

The selection can have a negative impact on operations by requiring additional transfers, dilution of transfer solution, and transfers with unfavorable hydraulics. The majority of the transfers to and from the process facility come from interaction with the 25 existing DSTs located in the east side of 200 Area East. Figure 6.2-2 shows the hydraulics and transfer distances for the three sites with relation to these tanks. Site A has the farthest distance and least favorable hydraulics. Site B has a short distance with second best hydraulics. Site C has the shortest distance and the best hydraulics.

Figure 6.2-2. Site Location--Hydraulics.



Linear distance is not to scale.
"A Farm Complex" refers to the East Area DSTs.

Selection of one of the three sites shown has little impact on the cost for providing infrastructure to support the processing facilities. The infrastructure at the site may cost up to $500 million, but providing utilities to the site costs only $10 to $20 million. The delta between the three sites consists of distances required to extend water, electricity, and rail service.

6.3 COMBINING HLW VITRIFICATION PLANT WITH THE LOW-LEVEL WASTE VITRIFICATION FUNCTION

The combined LLW and HLW vitrification facility provides all of the equipment and services necessary to melt all of the tank waste. The collocation of the melters allows the recycle of species removed from the LLW offgas (e.g., ^{99}Tc) to the HLW melter for incorporation into HLW glass. This recycle reduces the need for separation of such species from the LLW stream in the detached separations facility.

6.3.1 Process Description

The combined LLW and HLW vitrification facility receives separate LLW and HLW from tank farms. Both streams pass through the separate WSSFs that each contain six 400-m^3 tanks. From the waste storage and sample facilities the stream enters the facility for processing in either two LLW vitrification lines or the single HLW vitrification line.

After sampling, the LLW supernatant transfers to the LLW feed preparation system where the LLW recycle streams blend with the new feed before concentration by the evaporator. The evaporator overhead condensates collect in the process generated liquid waste system. After sampling, cooling, and any necessary adjustments, the evaporator bottoms transfer to the LLW melter feed system.

After sampling, the washed HLW slurry transfers to the HLW feed preparation system that removes excess water from the process loop. The water removal first occurs by centrifuging the HLW slurry then by evaporation of the centrate and aqueous purges from other systems. The resulting condensates transfer to the process generated liquid waste system. After sampling, cooling, any necessary adjustments, the retained process slurry transfers to the HLW melter feed system.

The HLW and LLW melter feed systems periodically receive batches of melter-ready process solutions from the HLW and LLW feed preparation systems and, in turn, provide continuous, controlled deliveries to the HLW and LLW melter systems. The process feed and dry glass formers blend on entering the melter combustion chambers where liquid kerosene burns with enriched oxygen. The co-current contact between the process solids/glass former mixtures and the hot combustion gases produces molten HLW and LLW borosilicate glasses.

Table 6.3-1. Combined Low-Level Waste and High-Level Waste Vitrification Feed and Product Composition.

Species	Product to low-level waste	Product to high-level waste	Product from low-level waste	Product from high-level waste
Radioactivity (Megacuries)				
^{137}Cs and ^{137}Ba[1]	0.701	99.4	0.799	99.0
^{90}Sr and ^{90}Y	1.27	139	1.40	138
^{99}Tc	0.0306	0.00924	0.0156	0.0204
Transuranics	0.00857	0.195	0.00877	0.195
Total	2.01	239	2.22	237
Mass (Megagrams)				
Total Mass	607,000	64,000	533,000	22,700
Volume (m^3)	455,000	50,000	200,000	8,200
Aluminum (Al)	4,030	365	4,030	793
Chromium (Cr)	128	36.9	128	36.9
Iron (Fe)	9.90	809	9.24	808
Sodium (Na)	73,400	1,420	73,300	1,890
Phosphorus (P)	5,040	733	1,640	239
Uranium (U)	79.8	1,280	81.1	1,280
Zirconium (Zr)	13.6	559	13.4	552
Chloride (Cl^-)	484	3.47		
Fluoride (F^-)	1,110	58.7		
Nitrite (NO_2^-)	10,500	106		
Nitrate (NO_3^-)	110,000	2,660		
Cancrinite	.178	2,700		
Other	32,600	49,100	454,000	17,100

[1]Cesium-137 makes up approximately 51 percent of the combined cesium and barium curies.

The HLW and LLW glass streams continuously pour from separator sections downstream of the melter combustion chambers. Glass cullet forms as the molten glass streams undergo co-current contact with cool water in quench flumes. After sampling as aqueous slurry, the cullet handling systems for HLW and LLW streams de-watered the cullet by screening and air dried and send the cullet to storage to await discharge from the facility. Slurried cullet fines from HLW and LLW cullet handling return to the respective feed preparation systems for ultimate recycle to the melters.

The HLW cullet product is pneumatically conveyed to fill shielded, 10-m^3 casks that are shipped to a suitable offsite repository. The LLW cullet product is blended with molten sulfur and pumped to nearby concrete disposal vaults where the sulfur solidifies upon cooling and forms an impermeable cement matrix.

The LLW and HLW melter offgas (MOG) systems receive the hot combustion gases from the glass separator sections of the respective melters. Quenching of these offgases by countercurrent contact with cool scrub water removes most of the entrained particulates and water-soluble contaminants, and condenses much of the water vapor. Excess condensates from both the HLW and LLW MOG systems recycle to the HLW Feed Preparation System for re-evaporation. The scrubbed melter offgases cool and pass through successive stages of filtration before being combined into a single stream. The combined LLW and HLW offgas flow to a sulfur dioxide adsorption process and a catalytic de-NO_x reactor before final discharge to the HVAC System. The Claus unit converts recovered sulfur dioxide into elemental sulfur that discharges its product to LLW cullet and sulfur mixing.

6.3.2 Facility Description

One layout concept was developed. The facility has a remote operation and remote design philosophy, with some contact maintenance. The design uses the transfer aisle concept for melters and associated processing and the flasking concept in tank feed areas.

The facility contains ten areas: receipt and sampling, process evaporation, LLW and HLW melter operations, cullet processing for LLW and HLW, sulfur operations, maintenance area, cold chemical make-up, and HVAC. Figure 6.3-1 depicts the process level for the combined LLW and HLW facility that extends 21 m belowgrade. The facility has an overall footprint of 156 m by 100 m with an overall height of 40 m, of which 21 m extend belowgrade. In addition to the main process levels the facility has levels at -28 m, grade, and +8 m. Overall, the facility contains 35,300 m^2 of floor space and has an overall volume 372,000 m^3.

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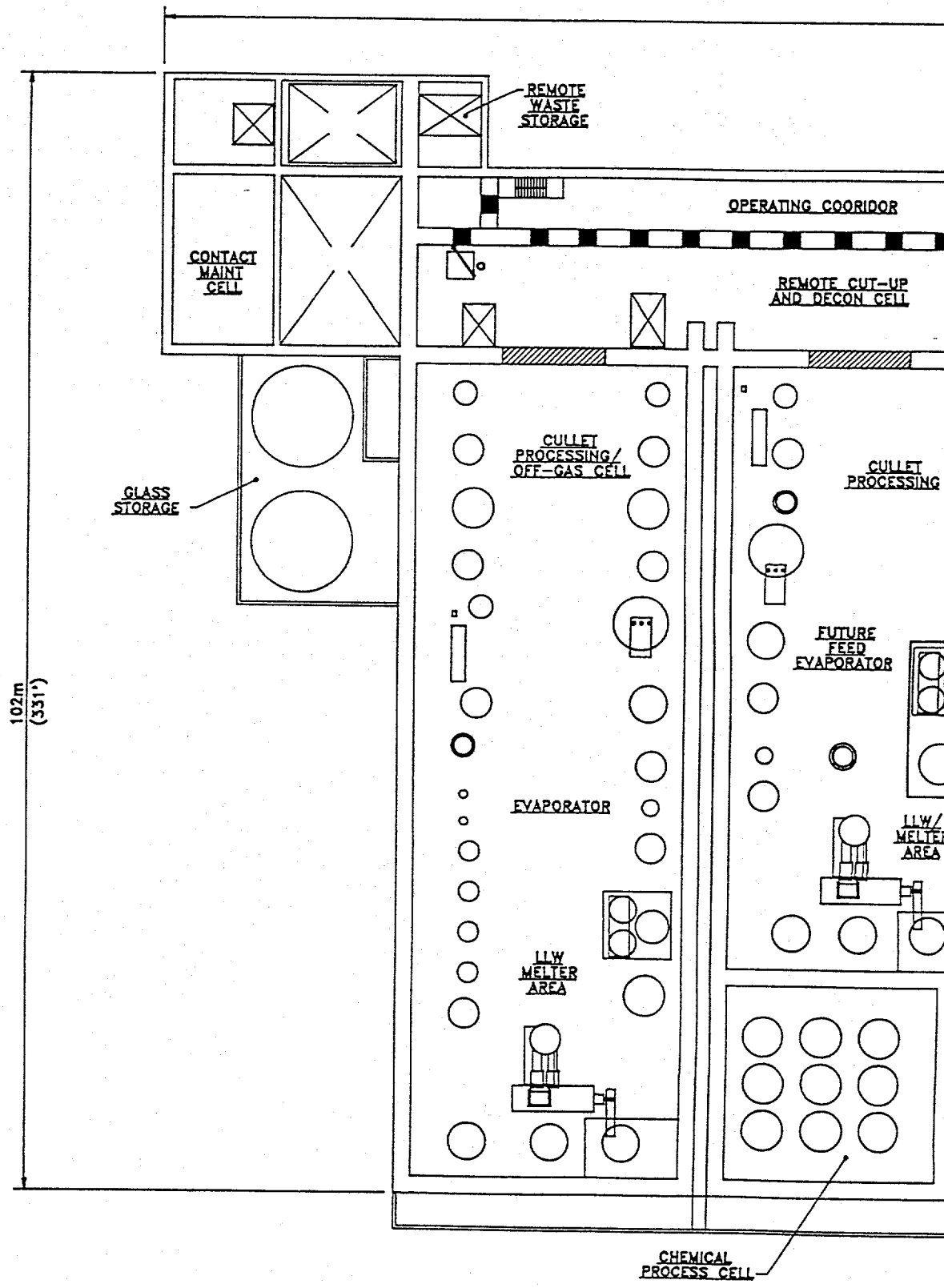
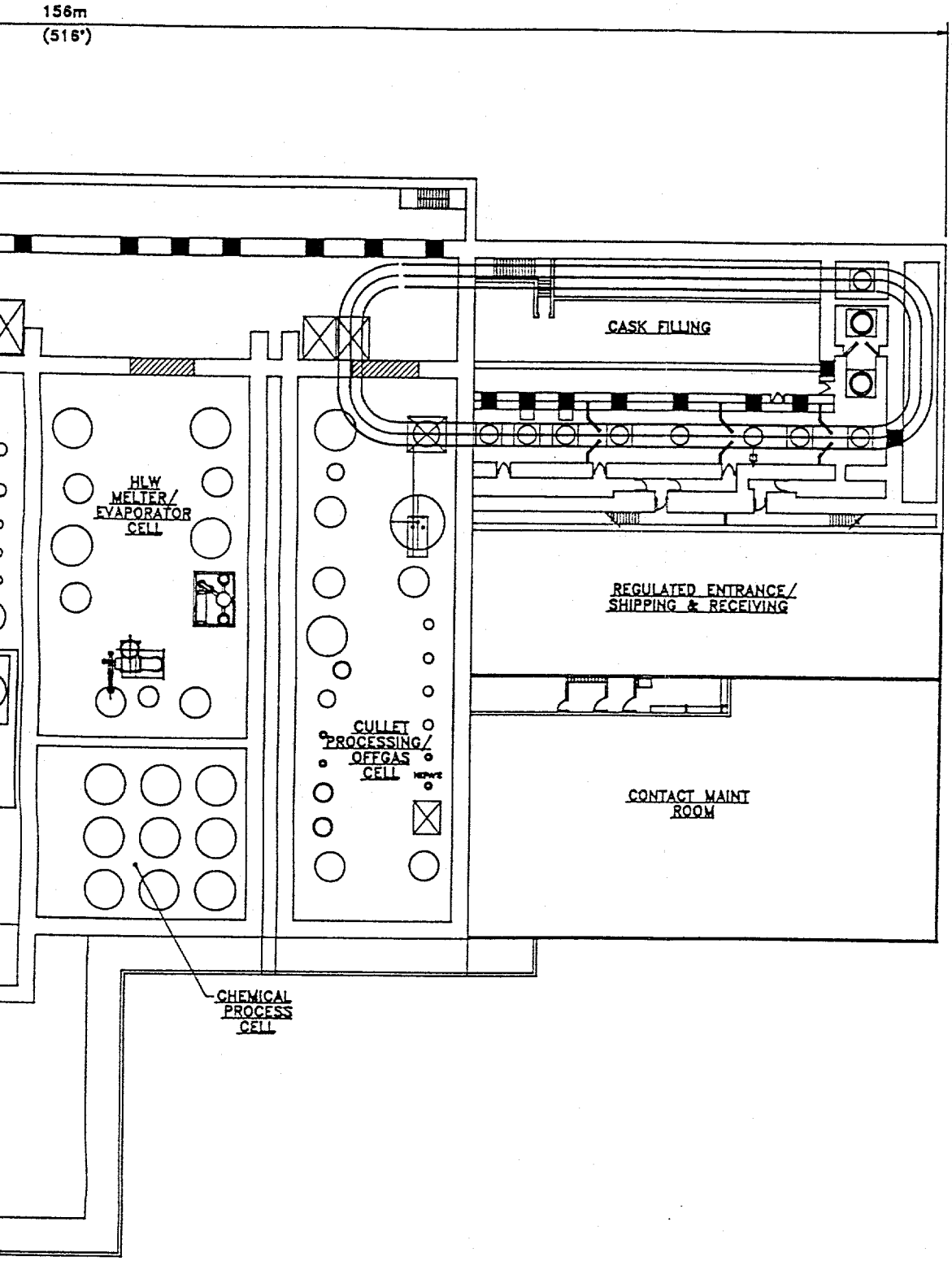

REMOTE WASTE STORAGE
OPERATING COORIDOR
CONTACT MAINT CELL
REMOTE CUT-UP AND DECON CELL
CULLET PROCESSING/ OFF-GAS CELL
CULLET PROCESSING
GLASS STORAGE
FUTURE FEED EVAPORATOR
102m (331')
EVAPORATOR
LLW MELTER AREA
LLW/ MELTER AREA
CHEMICAL PROCESS CELL

Figure 6.3-1. Combined Low-Level Waste and High-Level Waste Vitrification Facility.



The main process level contains feed receipt, both melters areas, cullet handling for LLW and HLW, sulfur process equipment, and maintenance area. Two process cells contain the separate feed receipt areas for LLW and HLW. Each cell receives waste from a dedicated set of six 200-m^3 tanks. These cells also contain evaporation and melter/feed tanks. Two transfer aisles contain the two LLW vitrification trains. A third transfer aisle contains HLW process evaporator and melter. The fourth transfer aisle contains the cullet processing for the HLW. All of the transfer aisles connect to the maintenance area by a ventilation door.

The other levels provide support to the process level. The -28 m level provides cullet handling quench tanks LLW and cullet cask handling HLW. The grade level provides flasking areas to maintain the equipment below, valve and operating corridors, contact maintenance, regulated entrance, and railroad access to the facility. The +8 m level contains electrical supply and crane maintenance space.

6.3.3 Cost Estimates

This section provides cost information in three areas for the combined LLW and HLW facility: capital, operating, and miscellaneous. This information provides the basis for the configuration cost comparison.

6.3.3.1 Capital Cost. Table 6.3-2 shows the capital cost for the combined LLW and HLW vitrification. The majority of the cost for the facility comes from the $1,160 million equipment cost.

Table 6.3-2. Capital Cost for Combined Low-Level Waste and High-Level Waste Vitrification Facility.

Description	Cost ($M)	Detached facilities cost
Engineering	600	660
Buildings	760	870
Special Equipment/Process Systems	1,160	1,080
Laboratory	30	100
Total[1]	2,310	2,710

[1]Cost is in 1994 dollars and includes 40 percent contingency.

The comparable detached facilities have a total cost of $2,710 million. The detached high source term LLW vitrification facility has a cost of $1,350 million. The detached HLW vitrification has a cost $1,360 million. The combination of these functions represents a $400 million reduction over the construction of detached facilities. The combination reduces building cost by about 40 percent, but has little impact on equipment cost.

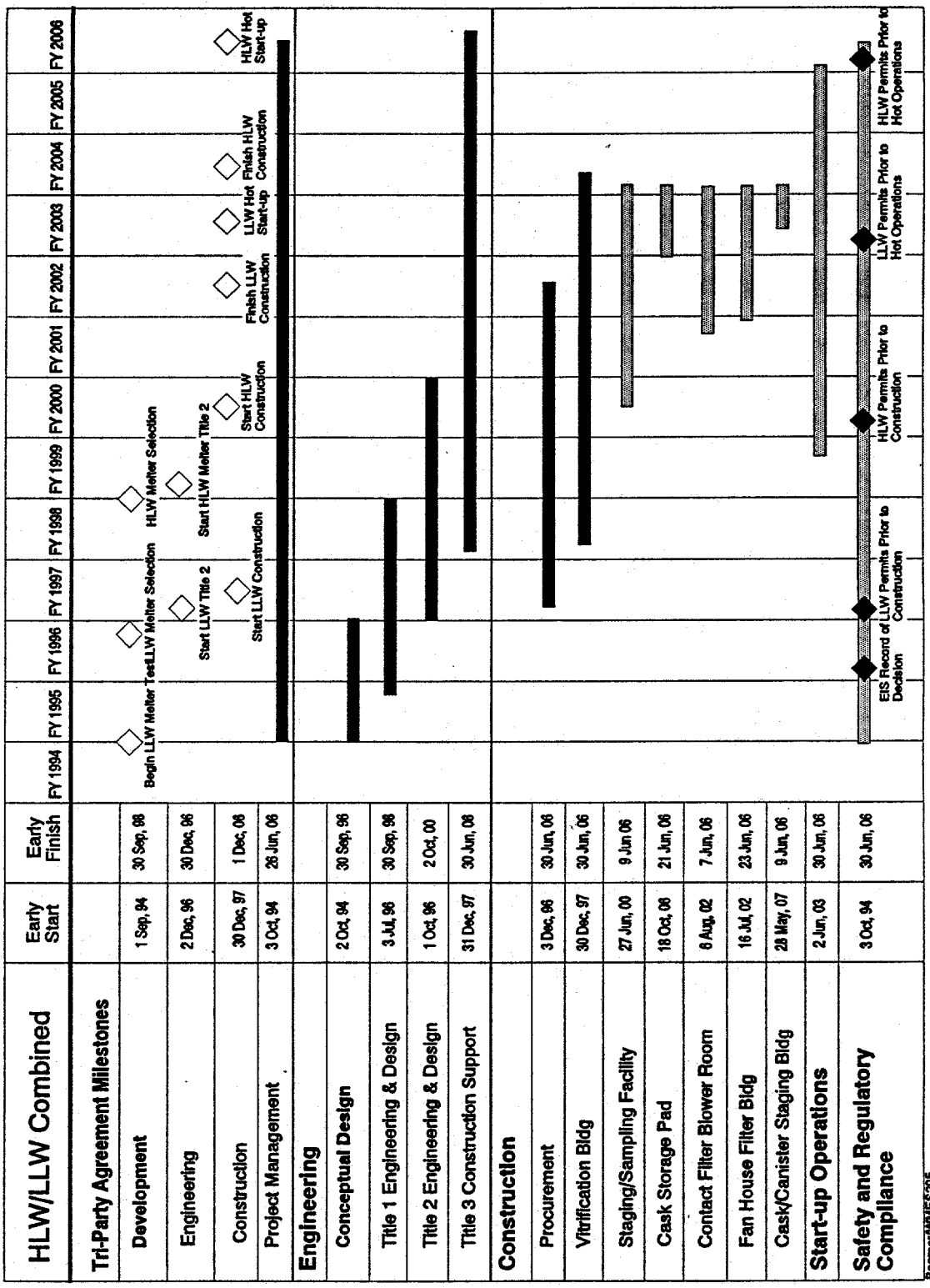
Figure 6.3-2 shows the construction schedule for the combined LLW and HLW Vitrification Facility. The combined facility begins operation in FY 2005. This date represents a 4-year acceleration in the start of the LLW vitrification operations found in the Tri-Party Agreement as Milestone M-60-05. To avoid this acceleration, the deployment scheme for the combined LLW and HLW facility could use phased construction. This scheme would construct the LLW portion and necessary civil work for the HLW first and remainder of the HLW portion of the facility as necessary to meet the Tri-Party Agreement.

6.3.3.2 Operating Cost. The combined LLW and HLW vitrification facility has an operating cost between $85 million and $97 million per year. This cost includes either $44 million or $56 million for labor and $41 million per year for consumables. The labor range depends on operation of the detached separations facility. Table 6.3-3 shows the amount and the cost of consumables for the life of the facility.

Table 6.3-3. Consumables for Combined Low-Level Waste and High-Level Waste Vitrification.

Chemicals	Unit Cost ($/each)	Quantity	Cost ($M)
Glass Formers (Mg)	660	298,000	200
Boron Oxide (B_2O_3) (Mg)		45,700	
Calcium Oxide (CaO) (Mg)		3,110	
Lithium Oxide (Li_2O) (Mg)		16,200	
Magnesium Oxide (MgO) (Mg)	—	3,110	
Silica (SiO_2)		227,000	
Kerosene (Mg)	150	60,000	9.1
Ammonia (Mg)	350	8,990	3.1
Dicyclopentadiene (Mg)	620	3,470	2.2
Oligomer (Mg)	620	3,470	2.2
Sulfur (Mg)	370	131,000	48
Raw Water (m^3)	3	20,500,000	62
Steam (Mg) at 15 MPa	5	96,000	0.5
Electricity (MWh)	30	8,500,000	250
Total (over 14 years)			580

Figure 6.3-2. Combined Low-Level Waste and High-Level Waste Construction Schedule.



6.3.3.3 Miscellaneous Costs. In addition to the above costs, the combined separations and HLW vitrification facility has costs for the following:

- Development
- Start-up
- Spares and equipment replacement
- Vault cost
- Cullet canisters
- Shielded interim storage canisters and storage pads
- Repository disposal fee
- Decontamination and decommissioning.

The development and start-up costs occur before operation of the facility. These costs along with the capital cost give the TPC for the facility. For purposes of this study, the development costs came from a draft of the TWRS *Multi-Year Program Plan* and totals $530 million. The start-up cost for a facility includes such items as the staff training, acceptance testing, permit preparation, and safety documentation. This work would begin 5 years before the start-up of the facilities and has an assumed cost of 3 years of the facility staff cost.

The spares and equipment replacement cost covers the routine expenditures for facility wear and tear. The combined LLW and HLW vitrification facility design replaces failed equipment in the melter system and cullet handling system as necessary. This cost covers melter system, cullet handling system, and small item replacements such as valves and pumps. The facility has a spares and equipment replacement cost of $20 million per year.

The vault cost includes the money to build and close the vaults. The vaults cost about $5 million to build and to close. This cost totals to $210 million. The cost would occur over the life of the project on an as needed basis.

The HLW cullet canisters cost about $25,000 each. For this report, the volume of glass produced by ESW has been assumed. This assumption leads to the need for 1,000 canisters, which translates to a canister cost of $25 million. If the sludge washing volume is used, this cullet canister requirement increases to 2,900 and a cost of $75 million.

The interim storage casks have a cost of about $60,000 each. Each cask can hold 1 cullet canister, which leads to a total number of 1,000 casks and one pad. The casks have a cost of $60 million and the pad costs $13 million. If sludge washing occurs, this case would need 2,900 casks and 3 pads. The cask cost increases to about $180 million and the pad cost increases to $39 million.

The repository cost depends on many events, but the OCWRM has provided an estimate for a similar case. The OCWRM estimate for 1,000 10-m^3 cask totaled about $1 billion. For the purpose of this study, the repository disposal cost for cullet canister has a cost of $1,000 million.

The decontamination and decommissioning occurs after completion of process campaign. This cost pays for the removal of equipment and gross

radioactivity from the facility and disposal of the debris. For purposes of this study, the decontamination and decommissioning cost consists of 30 percent of the initial capital and three years of staff cost spent over a 5-year period.

6.4 TIME PHASING OF LLW AND HLW VITRIFICATION CAMPAIGNS SUCH THAT BOTH FUNCTIONS COULD BE PERFORMED IN A SINGLE FACILITY

Plans for FY 1995 include the development of a facility concept that uses dual vitrification lines for the processing of LLW until the need for high LLW throughput diminishes to the extent that one of the LLW lines can be converted to HLW processing. It is anticipated that the maximum savings can be achieved by sharing the maximum amount equipment for both LLW and HLW vitrification.

6.5 FACILITY DESIGN TYPE/OPERATING "PHILOSOPHY"

This section evaluates the three major facility design concepts, distinguished by their different maintenance and operations characteristics, that are applicable to an HLW vitrification facility. Refer to Figure 6.5-1 for pictorial representation and Table 6.5-1 for a functional comparison of the concepts. The three design concepts, defined in detail below, are (1) flasking areas, (2) center aisle cells with valve corridors, and (3) canyon cells with cover blocks. Many of the 13 configurations presented in the *Facility Configuration Study* (Boomer et al. 1994) are hybrid designs, using more than one of the design concepts. For example, all cases in the *Facility Configuration Study* except 3A and 3B use flasking areas.

6.5.1 Designs with Flasking Areas

Designs with flasking areas can be divided into two subconcepts. The first subconcept is based on the "no-maintenance" philosophy of designed-for-life tankage with fully welded piping and the use of power fluidics devices for liquid transfers, mixing, and agitation. Where the use of power fluidics cannot be adopted, flaskable mechanical devices such as pumps and agitators are used. These flaskable units are strategically located below, and close-coupled to the flasking gallery and are designed to be remotely removed and replaced using a flasking system. Flasked components are transferred to a remote maintenance cell where they are repaired or disposed of after decontamination. All flaskable pump, valve, and agitator drives; control boxes; etc.; are located in the flasking gallery, external to the radioactive environment.

The second subconcept is based on more conventional material handling equipment designs that are manually disconnected (using localized shielding, long-handled tools, and respiratory protection as required) then remotely removed and replaced using a flask. Flasked components are transferred to a remote maintenance cell where they are repaired or disposed of after decontamination. Reconnection of the equipment is also a manual operation. In this case the flasking system replaces the in-cell crane for equipment transfers.

Table 6.5-1. Facility Design Concepts.

Item	Designs with flasking areas	Designs with a center aisle cell and valve corridors	Typical Hanford designs with canyon cells and cover blocks
Construction costs	Building costs are lower than the other concepts due to the smaller building volume which is achieved by the designed-for-life plant philosophy. This is partially offset by higher equipment costs due to increased wall thicknesses and improved metallurgy.	Somewhat higher construction costs are indicative of remote facilities. The costs are incurred by remote handling equipment and precision requirements of modules and jumpers.	The facility has a higher construction cost due to the size of the building, remote handling equipment and precision requirements of modules and jumpers.
Contamination control	Contamination spread in no-maintenance areas is minimized by the use of all welded construction. Replacement of flaskable pump and valve internals should not cause significant contamination spread. Non-flaskable components have the potential for contamination due to leakage from mechanical pipe connectors.	The facility is designed to contain contamination within the secondary containment. In the secondary containment there is a potential for contamination due to leakage from mechanical pipe connectors.	The facility is designed to contain contamination within the secondary containment. In the secondary containment there is a potential for contamination due to leakage from mechanical pipe connectors.
Decontamination and Decommissioning	Decontamination is carried out with pre-installed wash rings and nozzle assemblies. Spare ceiling plugs are incorporated into the design to cover installation and operation of additional wash and decontamination equipment. Equipment removal is via contact methods and knockout wall panels after decontamination.	Disassembly, decontamination and decommissioning is easily done with remote in-cell equipment.	Decontamination and decommissioning is simplified due to the existing remote handling capabilities.
Equipment design	Uses flaskable technology which may be of a specialized design. Some equipment is duplicated. This is generally instrumentation although spare fluidic devices may be installed, depending on the material being handled. Corrosion allowances are commensurate with plant life.	Equipment is designed to be remotely replaced. Standard materials and corrosion allowances are used on modified, commercial equipment. Valve corridors use special remote equipment to repair or replace failed piping systems.	Equipment is designed to be remotely replaced. Standard materials and corrosion allowances are used on modified, commercial equipment.

Table 6.5-1. Facility Design Concepts.

Item	Designs with flasking areas	Designs with a center aisle cell and valve corridors	Typical Hanford designs with canyon cells and cover blocks
Flexibility	Process flexibility, while limited, is enhanced by the provision of "active" connection areas, these designated areas enable various permutations of intertank pipework. It is advantageous for flowsheets/process chemistry to be well defined before finalizing design.	The facility allows for process flexibility, minimizes failure consequences, and allows upgrading. Design can proceed prior to resolution of all process uncertainties.	The facility allows for process flexibility, minimizes failure consequences, and allows for upgrading. Design can proceed prior to resolution of all process uncertainties.
Radiation exposure	Radiation exposure during normal operation is low because contact maintenance is not required. Repair of non-flaskable equipment will lead to increased exposure since contact operations are required.	Radiation exposure is low because entrance into remote areas for maintenance is not required or allowed. Limited contact maintenance can be performed in a contact maintenance cell.	Radiation exposure is low because entrance into remote areas for maintenance is not required or allowed. Limited contact maintenance can be performed in a contact maintenance cell.
Space Utilization	Least building volume due to techniques and philosophies adopted, i.e., flasking systems for removable equipment, in-for-life tankage and all weld construction.	The facility requires additional space to access, decon and repair individual equipment modules. It has reduced vertical height as compared to canyon facilities.	The canyon facility has the greatest building volume due to its double height requirement.
Technology maturity	These philosophies have been used in Europe since the 1970's. As plants have been built and gone on stream lessons learned have been incorporated into later designs. The technology has been constantly upgraded and improved over the last 25 years, which is reflected by the reduction of average dose uptake to personnel.	The technology has been used in the U.S. at Oak Ridge and INEL and in Germany and Japan. Remote facilities in general have been in use since the 1940's at Hanford.	The technology has been used in the U.S. at Hanford and Savanna River since the 1940's.
Training	Moderate skills are necessary to operate flasking systems.	Special skills are necessary to operate electro-mechanical manipulators and in-cell cranes.	Special skills are necessary to operate electro-mechanical manipulators and in-cell cranes.

Large equipment such as melters and evaporators are located adjacent to a remote maintenance facility. These components, after manual disconnection from ancillary equipment located within the respective cells, are transferred to the maintenance facility using self propelled carts through large ventilation seal doors.

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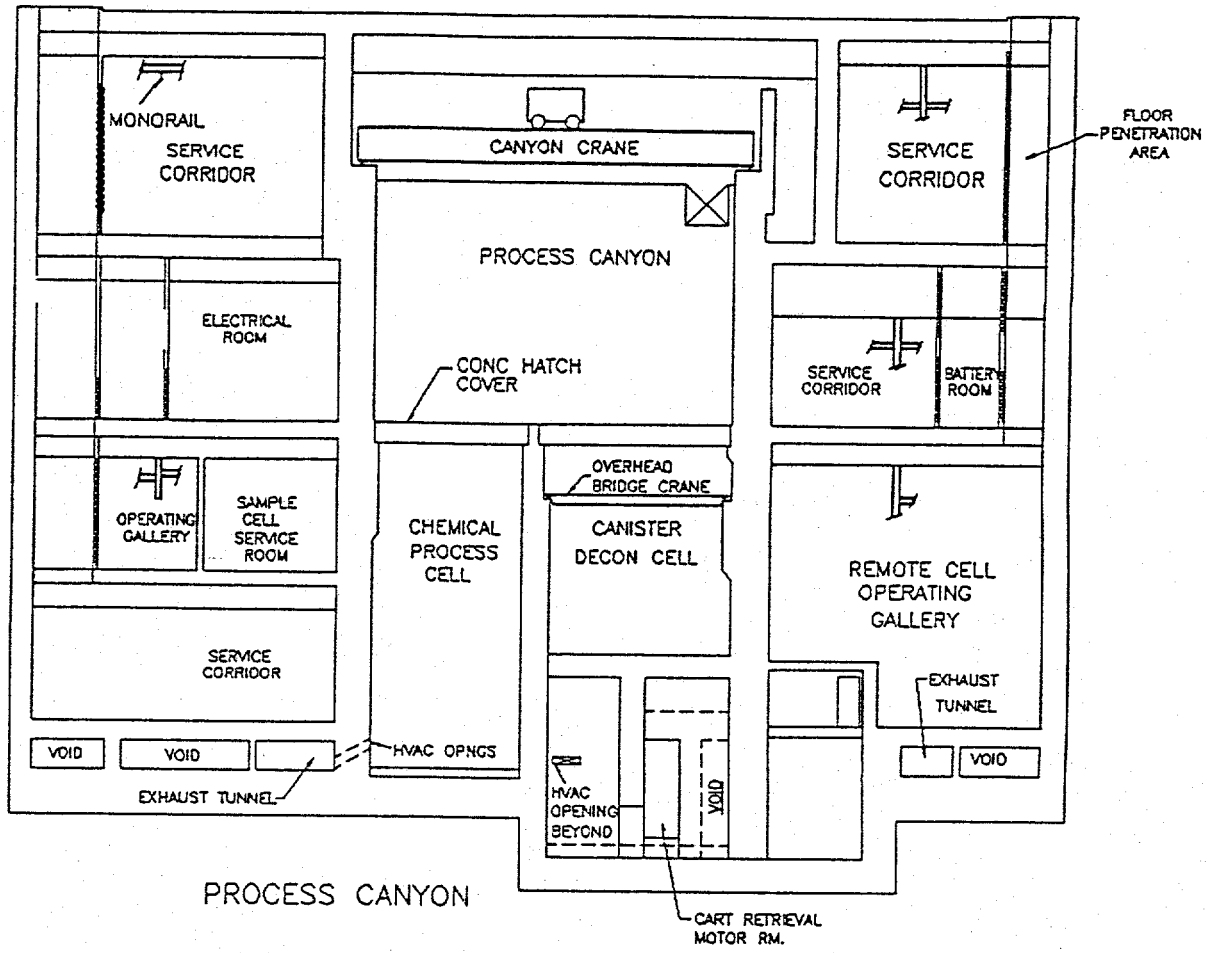

MONORAIL
SERVICE CORRIDOR
CANYON CRANE
SERVICE CORRIDOR
FLOOR PENETRATION AREA
PROCESS CANYON
ELECTRICAL ROOM
CONC HATCH COVER
SERVICE CORRIDOR
BATTERY ROOM
OVERHEAD BRIDGE CRANE
OPERATING GALLERY
SAMPLE CELL SERVICE ROOM
CHEMICAL PROCESS CELL
CANISTER DECON CELL
REMOTE CELL OPERATING GALLERY
SERVICE CORRIDOR
EXHAUST TUNNEL
VOID
VOID
HVAC OPNGS
VOID
EXHAUST TUNNEL
HVAC OPENING BEYOND
VOID
PROCESS CANYON
CART RETRIEVAL MOTOR RM.

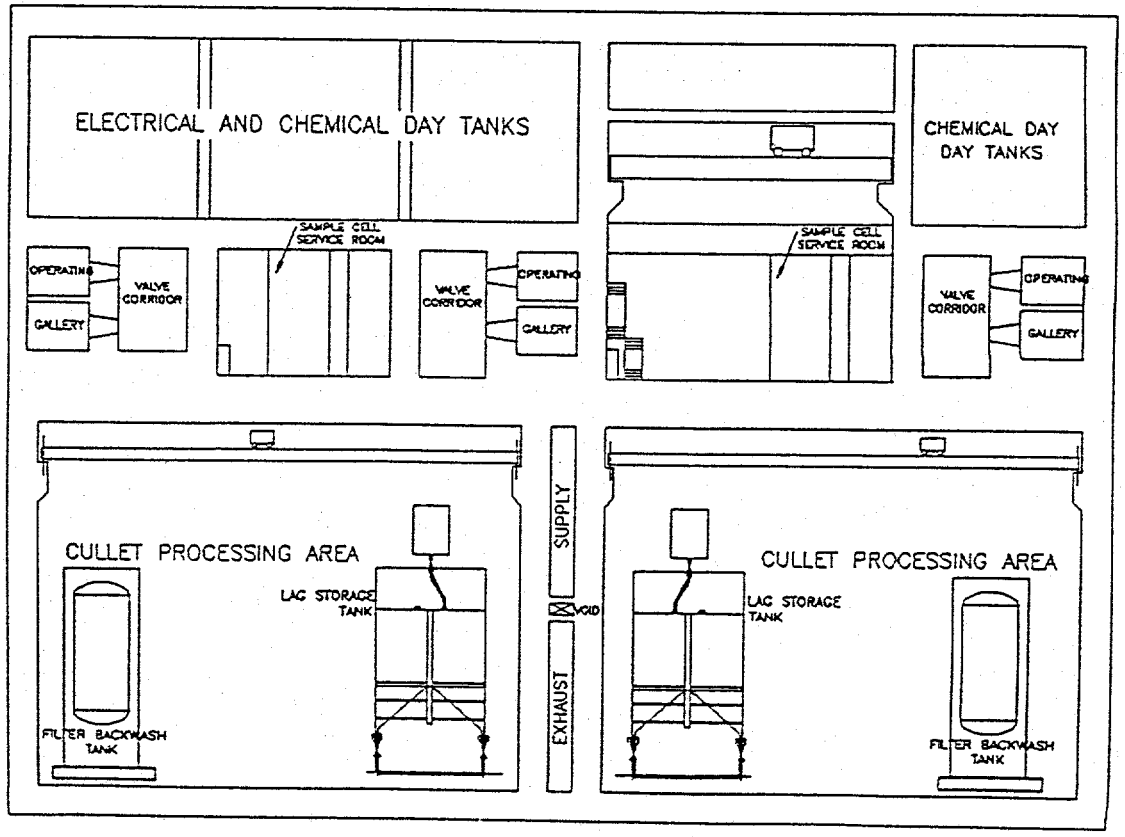
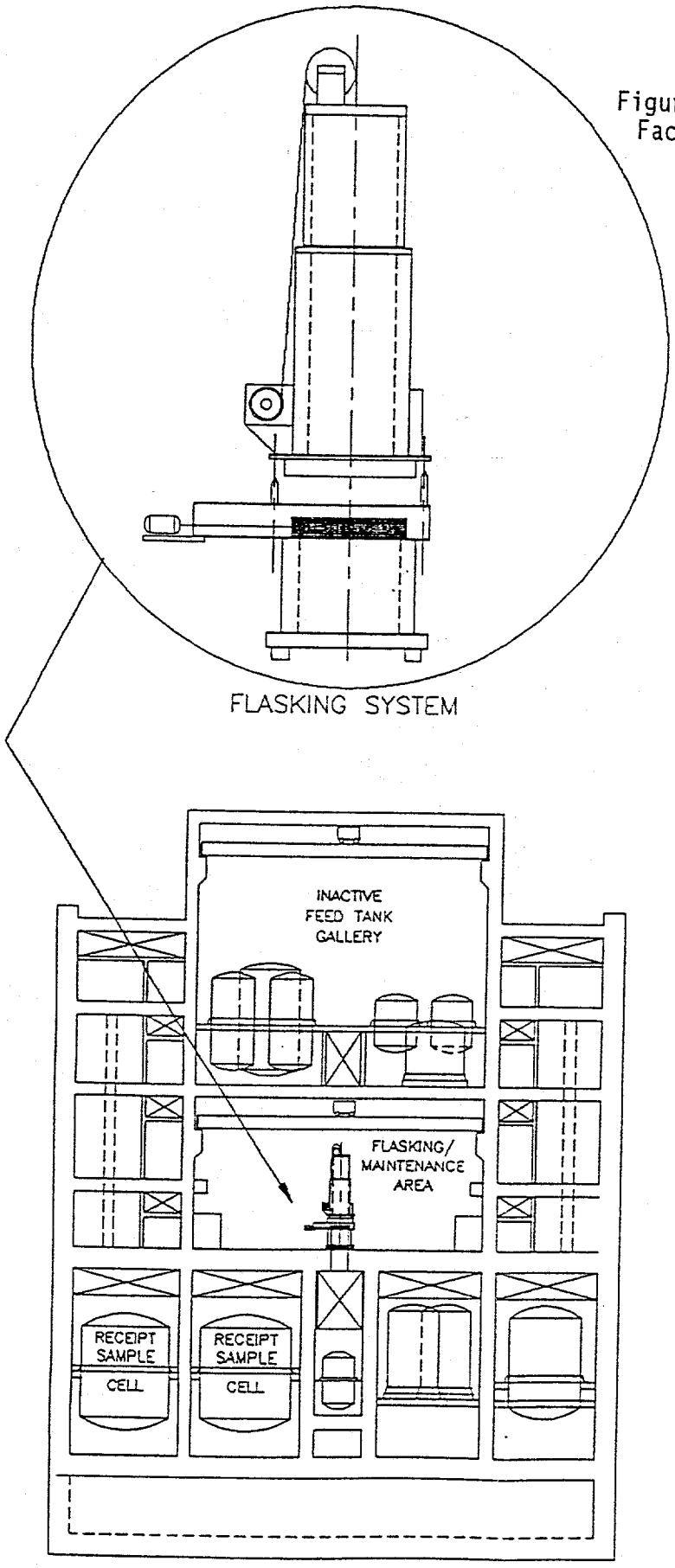

ELECTRICAL AND CHEMICAL DAY TANKS
CHEMICAL DAY DAY TANKS
SAMPLE CELL SERVICE ROOM
SAMPLE CELL SERVICE ROOM
OPERATING
GALLERY
VALVE CORRIDOR
VALVE CORRIDOR
OPERATING
GALLERY
VALVE CORRIDOR
OPERATING
GALLERY
CULLET PROCESSING AREA
LAG STORAGE TANK
FILTER BACKWASH TANK
SUPPLY
VOID
EXHAUST
CULLET PROCESSING AREA
LAG STORAGE TANK
FILTER BACKWASH TANK
CENTER AISLE

Figure 6.5-1. Comparison of Facility Design Concepts.



6.5.2 Designs with a Center Aisle Cell and Valve Corridors

The center aisle cell and valve corridor concept applies to vessels and equipment that are mounted on modules and removed horizontally through a center aisle to a remote maintenance cell using an in-cell crane. Valves are located in valve corridors above the equipment cell and are removed remotely by electro-mechanical manipulators and transported to the maintenance cell. Small components can be removed in place from the modules using the in-cell crane. Long equipment items in the modules that need to be replaced require that the module be moved into the maintenance cell. Modules to be replaced are lifted approximately 150 cm and moved horizontally through the center aisle to the maintenance cell using the in-cell crane. Jumpers with remote flanges connect the embedded pipe to the modules. Jumpers are disconnected and handled by the in-cell crane.

6.5.3 Typical Hanford Design With Canyon Cells and Cover Blocks

The canyon cell concept applies to facilities that have individual cells accessible through cover blocks by a canyon crane from above. Vessels and equipment are mounted on modules which are located in the cells. Modules are removed and replaced vertically by the canyon crane through cover block openings. Small equipment can be removed from in place modules using the canyon crane. Failed equipment or modules are transferred to a remote maintenance cell for repair or disposal. Jumpers with remote flanges connect the embedded pipe to the in-cell components. Jumpers are disconnected and handled by the canyon crane. In-cell control valves are contained on jumpers and are replaced and repaired by removing the jumper. Out-of-cell control valves are contact maintained.

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7.0 ACQUISITION STRATEGIES

The *Low-Level Waste Vitrification Plant Project Contracting Strategy Decision Analysis Report* (Felise and Phillips 1994) examined ten alternatives for a contracting strategy. Most of the information in the *Report* is directly applicable to the HLW program. This section summarizes the results.

7.1 PRIVATIZATION (GOVERNMENT BUYS PRODUCT FROM THE PRODUCER)

Privatization was considered in four of the contracting alternatives discussed in the *Low-Level Waste Vitrification Plant Project Contracting Strategy Decision Analysis Report* (Felise and Phillips 1994). Alternative 10, a fixed-price design/build/operate contract awarded through a competitive selection process, was considered the best strategy to privatization because of the elements of competition and ownership.

7.1.1 Description

A description of this strategy is as follows:

- Two or more contracting teams are selected through the Request for Qualification process.
- A definitive set of design requirements and plant performance requirements are available before the start of proposal preparation.
- The contracting teams, on a cost reimbursable but not to exceed a fixed amount basis, must develop and submit to WHC a comprehensive proposal that includes:
  - Design concept
  - Privatization-type scheme for completion of design, plant construction, and operation through to completion of the project mission
  - No advanced conceptual design is planned.
- The selected contracting teams will execute the above scope and be reimbursed according to the terms of the privatization agreement.

7.1.2 Advantages

The advantages of this strategy are as follows:

- Multiple contracting teams provide the opportunity for more facility concepts to be developed and examined.

- The design concepts will be fully developed to generate information necessary for fixed price, competitive privatization bidding.
- Design concepts will be meaningful and realistic because design will not start until melter test program data are available, WHC site studies are completed, plant performance requirements are set, etc.
- The strategy provides for selecting the "most qualified" subcontracting teams while maintaining life-cycle plant cost as a key factor for continuation beyond the conceptual phase
- The team performing the design concept is the one continuing into subsequent design phases thus maintaining continuity.
- This approach provides a fixed plant cost and schedule.
- This approach is competitive, creative, and innovative.
- Competitive design concepts and bidding with life-cycle cost considerations creates an atmosphere conducive to obtaining the best value plant for the government.
- There is clear placement of design and plant performance responsibility with the contractor.
- This strategy likely is optimum schedule to producing a facility.
- The HLW vitrification program mission cost is fixed.
- No major cost is incurred by the government until product is being produced.

7.1.3 Disadvantages

The disadvantages of this strategy are as follows:

- Many new institutional and management issues must be resolved because of "privatization."
- It requires a definitive set of design requirements and plant performance specifications.
- It minimizes WHC input after definition of design requirements and plant performance requirements.
- The strategy is less responsive to program changes.
- The strategy is heavily reliant on the plant performance specification to ensure getting a high-quality plant.

- If design or performance requirements change, the potential for very large cost increases exist because the impact carries forward through the lifetime operations of the plant.
- The contractor will expect much higher profit margins in return for long-range financing of plant costs plus the risks assumed.
- If the plant does not perform as the contractor expects, there is an undefined risk to the government/WHC in meeting Tri-Party Agreement milestones, mission objectives, etc.

7.1.4 Cost Issues

The contracting evaluation team concluded that the privatization strategy may be more costly than a competitive, government-funded design, build, and operate strategy. The basis for this conclusion is the high cost of venture capital. Lenders expect a high return for a high-risk investment. While privatization solves a near-term government funding problem, the taxpayers may pay more over the long term. Privatization essentially shifts the cost burden to a future administration.

7.1.5 Efficiency

With full ownership from the beginning through the operational phase, the subcontractors would naturally seek to minimize costs through the optimization of facility hardware. The resulting design would focus on features related to production (at an acceptable level of safety) rather than "zero risk" or other conflicting requirements imposed by outside interests.

7.1.6 Programmatic Risk

The risk associated with this strategy is not as extensive as it would be for the LLW program. The LLW program needs a high-capacity (100- to 200-tons/day) facility unlike any other vitrification facility in existence. The HLW vitrification facility, however, could incorporate much of the design and operating experience from other vitrification facilities from around the world.

7.2 COMMERCIALIZATION (TURN KEY FACILITY OPERATED BY GOVERNMENT)

Commercialization was considered as one of the contracting alternatives discussed in the *Low-Level Waste Vitrification Plant Project Contracting Strategy Decision Analysis Report* (Felise and Phillips 1994). Under Alternative 2, a single contract is awarded for design and construction management. A separate operating contractor would perform the startup, cold operations, and then hot operations.

7.2.1 Description

A description of this strategy is as follows:

- A single contract is awarded for design and construction management.
- The Architect-Engineer (A-E)/Construction Management (CM) services are obtained through a Request for Qualification (RFQ) process.
- The conceptual design is performed on a cost plus fixed fee (CPFF) with options for Title I, II and III. Alternatively, the contract could be CPFF, cost plus incentive fee (CPIF), fixed price, etc., depending on whether the requirements are well defined and stable.
- Major equipment is procured through competitive bids.
- The site operations contractor performs the startup.
- The site operations contractor performs cold operations.
- The site operations contractor performs hot operations.

7.2.2 Advantages

The advantages of this strategy are as follows:

- Since the Request for Qualification (RFQ) process is used for A-E services, the program is assured that the design is performed by a highly qualified team
- This strategy eliminates the A-E constructor interface of the traditional approach described in Section 7.3 below.
- This strategy provides design continuity assuming that the same A-E team performs the CD, Title I, II, and III design
- Since the RFQ process is used for the selection of an A-E/CM, CM is performed by a highly qualified team.
- This is a better alternative when the requirements are not well defined or highly subject to change
- This strategy maximizes input from the site operating contractor and outside interests
- This strategy is flexible to funding, schedule, or mission changes
- This strategy uses well-defined methods to manage and control work
- This strategy could use fixed-price subcontracts for construction.

7.2.3 Disadvantages

- This approach on DOE contracts of this scale has the potential for, and the history of, large cost increases and schedule slippages.
- The large amount of WHC interface and input to design results in dilution of A-E ownership of the design.
- There is no inherent risk to the government other than cost/schedule overruns inherent with the contracting methodology.
- May not get lowest prices because of CPFF portions.

7.3 TRADITIONAL GOVERNMENT-DESIGNED, BUILT, AND OPERATED

The *Low-Level Waste Vitrification Plant Project Contracting Strategy Decision Analysis Report* (Felise and Phillips 1994) also examined the traditional approach (Alternative 1 in the report) and compares it to the other approaches described previously. A summary of the analysis is given below:

7.3.1 Description

A description of this strategy is as follows:

- Two major contracts would be awarded: one for design and one for construction.
- A-E services would be obtained through an RFQ process.
- The A-E generates a conceptual design on a CPFF contract with options for Title I, II and III. Alternatively, the contract could be CPIF, fixed price, etc., depending on the stability of the requirements imposed by the process.
- Construction management and procurement services (General Construction Contractor [GCC]) would be through a separate subcontract largely with a CPFF basis.
- The procurement of major equipment would be through competitive bids.
- The site operations contractor performs the startup.
- The site operations contractor performs cold operations.
- The site operations contractor performs hot operations.

7.3.2 Advantages

The advantages of this strategy are as follows:

- Since the RFQ process is used for A-E services, the program is assured that the design is performed by the most qualified team.
- This strategy provides design continuity assuming that the same A-E team performs the CD, Title I, II, and II design.
- Since the RFQ process is used for the selection of a CM, CM is performed by the most qualified GCC.
- This is a good alternative when the requirements are not well defined or highly subject to change.
- This strategy maximizes input from the site operating contractor and outside interests.
- This strategy is the most flexible to funding, schedule, or mission changes.
- This strategy uses well-defined methods to manage and control work.
- The GCC could use fixed-price subcontracts for construction or perform the construction at WHC direction to maximize the benefit to the government.

7.3.3 Disadvantages

- The two separate contracts would require large amounts of interface management.
- This approach on DOE contracts of this scale has the potential for, and the history of, large cost increases and schedule slippages.
- The large amount of WHC interface and input to design results in dilution of A-E ownership of the design.
- There is no inherent risk to the government other than cost/schedule overruns inherent with the contracting methodology.
- May not get lowest prices because of CPFF portions.

7.4 OTHERS

The *Low-Level Waste Vitrification Plant Project Contracting Strategy Decision Analysis Report* (Felise and Phillips 1994) discussed other contracting alternatives which amount to variations of the three discussed above.

In general, commercialization schemes are designed to shift ownership of the work to the contractors who are performing the service. Privatization takes this idea one step further in that the capital needed for construction comes from the private sector. The shift in ownership is designed to provide meaningful incentives to contractors to provide products that are on time and within cost projections. The down-side of these approaches is that the HLW vitrification program is much less responsive to changes induced by outside interests. The program is particularly vulnerable to changes due to its 20-year duration.

The traditional approaches, however, are better suited for a changing regulatory environment. Ownership is diluted and all parties maintain an avenue of input throughout the duration of the program. The down side is that the program becomes vulnerable to cost overruns and schedule slippages.

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8.0 SCHEDULE

Each of the activities described in this document are identified in the 1994 *Tank Waste Remediation System Multi-Year Work Plan*, WHC-STP-1101 (WHC 1994). The schedule for each of the assessments is summarized in Figure 8.0-1. All assessments are scheduled for completion before the start of definitive design, which is scheduled for December 1998.

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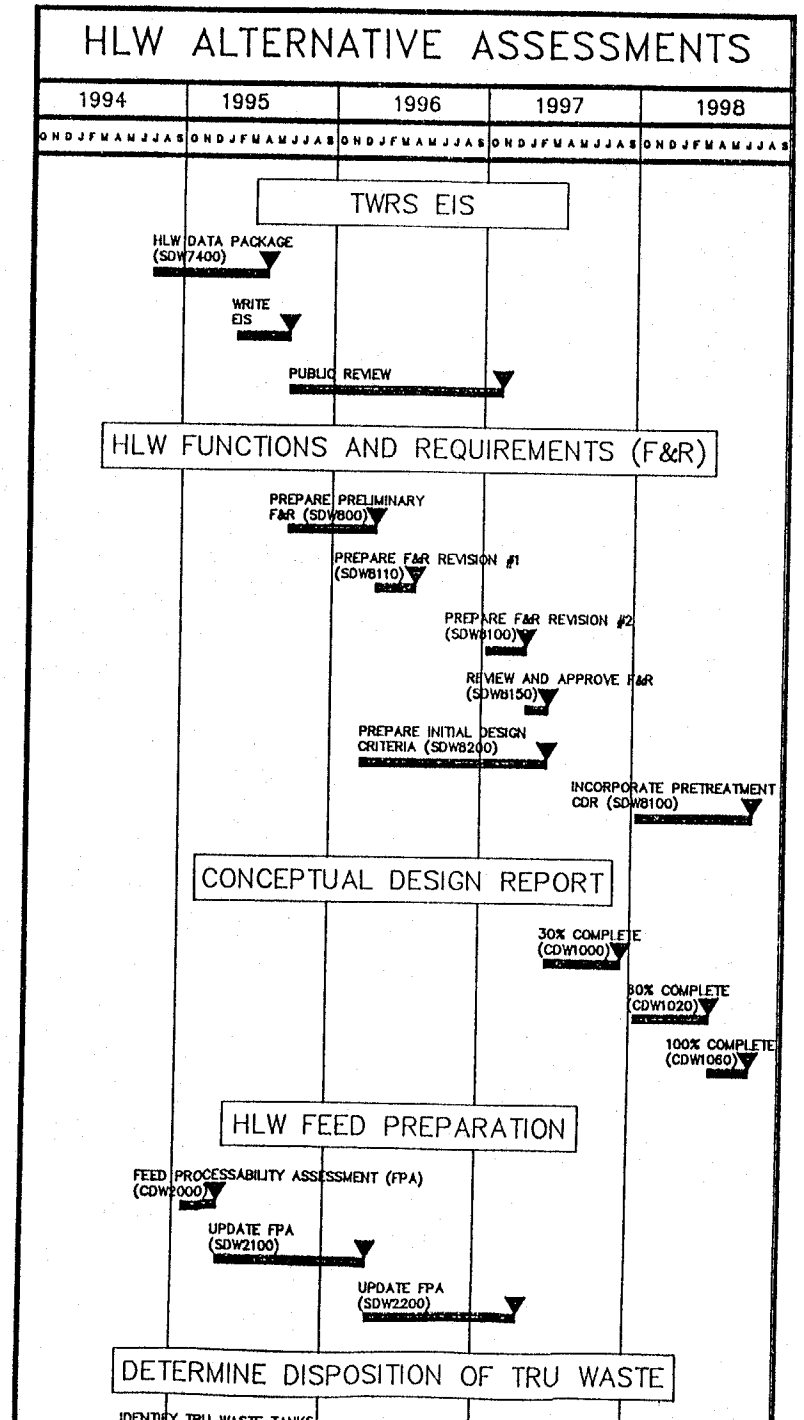
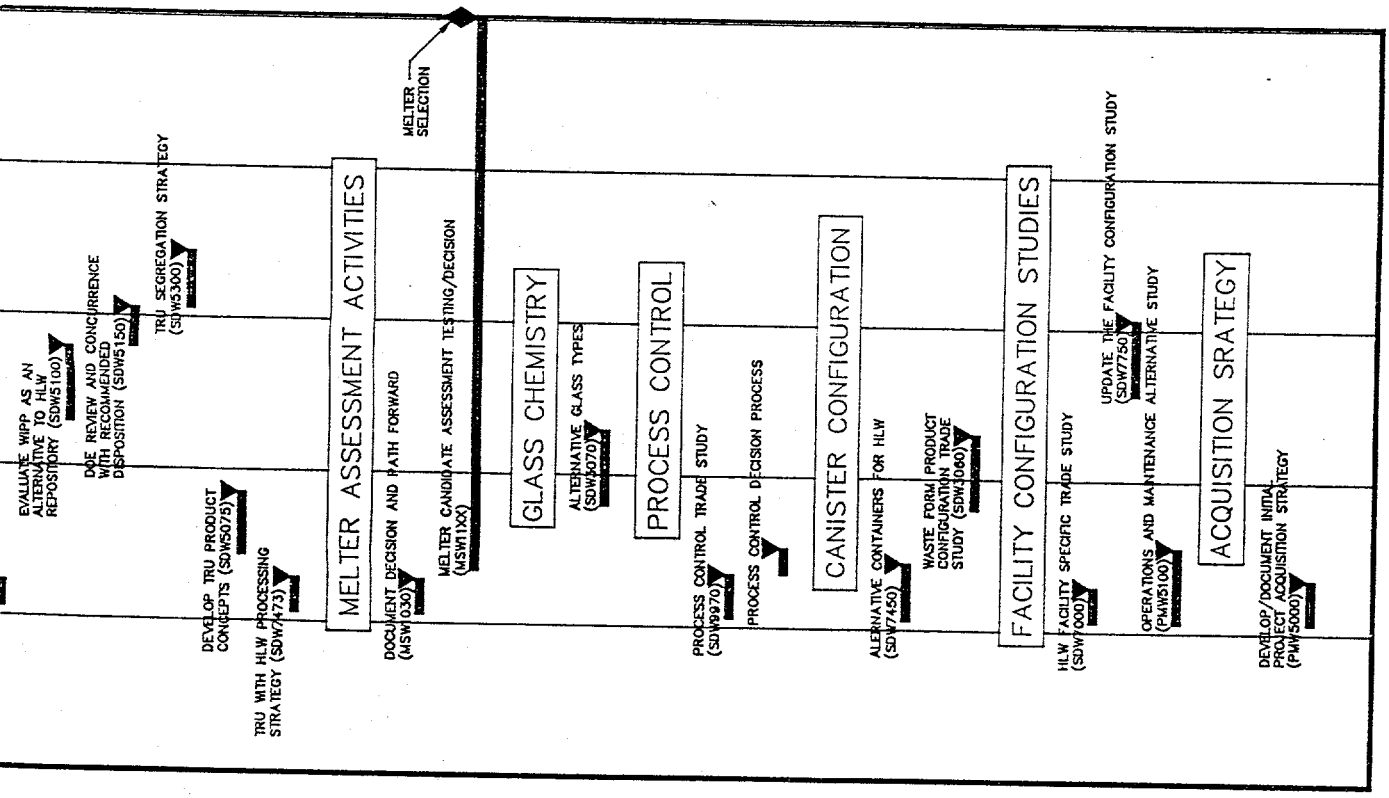

HLW ALTERNATIVE ASSESSMENTS
1994
1995
1996
1997
1998
O N D J F M A M J J A S
TWRS EIS
HLW DATA PACKAGE (SDW7400)
WRITE EIS
PUBLIC REVIEW
HLW FUNCTIONS AND REQUIREMENTS (F&R)
PREPARE PRELIMINARY F&R (SDW800)
PREPARE F&R REVISION #1 (SDW8110)
PREPARE F&R REVISION #2 (SDW8100)
REVIEW AND APPROVE F&R (SDW8150)
PREPARE INITIAL DESIGN CRITERIA (SDW8200)
INCORPORATE PRETREATMENT CDR (SDW8100)
CONCEPTUAL DESIGN REPORT
30% COMPLETE (CDW1000)
80% COMPLETE (CDW1020)
100% COMPLETE (CDW1060)
HLW FEED PREPARATION
FEED PROCESSABILITY ASSESSMENT (FPA) (CDW2000)
UPDATE FPA (SDW2100)
UPDATE FPA (SDW2200)
DETERMINE DISPOSITION OF TRU WASTE

Figure 8.0-1. High-Level Waste Alternative Assessment Schedule.



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