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7. Abstract <p>Radioactive Pilot-Plant testing needs and alternatives are evaluated for enhanced Sludge Washing and High and Low-Level Vitrification efforts. Also investigated was instrument and equipment testing needs associated with the vitrification and retrieval process. The scope of this document is to record the existing March 1994 letter report for future use.</p> <p>A structured Kepner-Trego™ decision analysis process was used to assist analysis of the testing needs. This analysis provided various combinations of laboratory and radioactive (hot) and cold pilot testing options associated with the above need areas. Recommendations for testing requirements were made.</p>		

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**IDENTIFICATION OF RADIOACTIVE PILOT PLANT
TEST REQUIREMENTS**

**W. J. Powell
E. F. Riebling**

March 1995

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LIST OF TERMS

ALARA	as low as reasonably achievable
BWIP	Basalt Waste Isolation Process
D&D	decontamination and decommissioning
DNAAS	Delayed Neutron Analysis Activation System
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FFFCM	fossil-fuel-fired cyclonic melter
HLW	high-level waste
HWVP	Hanford Waste Vitrification Plant
LLW	low-level waste
NRC	U.S. Nuclear Regulatory Commission
PA	performance assessment
PCT	product consistency test
SEM	scanning electron microscope
SST	single-shell tank
TRU	transuranic
TWRS	Tank Waste Remediation System
WHC	Westinghouse Hanford Company

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IDENTIFICATION OF RADIOACTIVE PILOT PLANT TEST REQUIREMENTS

W. J. Powell
E. F. Riebling

1.0 PURPOSE

This document evaluates radioactive (i.e., hot) pilot plant testing needs, and alternatives to radioactive pilot plants for the following activities:

- Enhanced sludge washing (i.e., caustic leaching) of tank sludge
- High-level waste (HLW) and low-level waste (LLW) vitrification product qualification testing and process evaluation
- Development of instrumentation and control equipment for the above.

The information in this document will be used in a subsequent document on pilot plant needs, justifications, and options, similar to WHC-SD-WM-TA-143 (Howden 1993). The subsequent document will include factors such as pretreatment needs, costs, and other evaluations.

2.0 SCOPE

Evaluations are made in this document regarding the need for hot pilot plants for sludge washing, LLW vitrification, HLW vitrification, and associated equipment testing; alternatives to hot pilot tests are evaluated; and risks associated with not performing the hot pilot tests are estimated. The evaluations are performed using Kepner-Tregoe™ Decision Analysis techniques (Figure 1). Where pilot plants are recommended, the type of plant is specified, as well as a best estimate of the size of the plant and the utilities required to service it. Where applicable, a best estimate of process flow inputs is given.

The hot pilot plant areas of investigation did not include pretreatment of waste, other than that involved in enhanced sludge washing. Acid-based sludge process and advanced sludge process testing were not addressed, as it is not included in the *Hanford Federal Facility Agreement and Consent Order*, also known as the Tri-Party Agreement (Ecology 1994). Cesium ion exchange, organic destruction, acid-based scenarios for separation of components, evaporation of moisture from wastes, and costs were not included in the evaluations of these pilot plant options.

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Figure 1. Decision Analysis Flowchart for Hot Pilot Plants.

Estimates for completion of technology development and deployment are based on Tri-Party Agreement milestones; features required for testing are included; and issues for each potential hot pilot plant area are described, as well as alternatives to the hot pilot plants. Results needed are discussed in the issues section. Estimates of process variability are given in the facility requirements. A short discussion of the risk analysis and justifications are given for selected alternatives.

The evaluation was started on February 15, 1994. An outline of the document was issued on February 24, 1994, and a rough draft was issued for review on March 14, 1994. The product was a letter report, which was modified to this supporting document after a final review. This document is ment to record the existing analysis for future use. It was not upgraded to include costs, and other analysis performed since March 1994.

3.0 ASSUMPTIONS

Evaluations were based on the following assumptions:

- Tri-Party Agreement Beta Case, as given in the Fourth Amendment (Ecology 1994)
- Restriction on LLW hot pilot plants noted in the Tri-Party Agreement disregarded to ensure an unbiased technical evaluation
- Tank Waste Remediation Systems (TWRS) flowsheets and technical strategy as outlined in *Tank Waste Remediation System Technical Strategy* (Alumkal 1994)
- Both LLW and HLW vitrification product quality at least as good as that required for near-surface land disposal in grout vaults.

4.0 BACKGROUND

This document is part of a set of documents defining the anticipated hot pilot plant development testing needed for the disposal of tank wastes. The final overall document will determine the need for hot test facilities and the infrastructure to support that testing. The TWRS Process Technology group was assigned to help assess needs for hot pilot plants to test TWRS disposal technologies.

The TWRS Process Technology group has identified support requirements for HLW and LLW vitrification regarding the form of pretreated wastes for feed to the pilot scale melter(s) and final waste form qualification. Enhanced sludge washing (i.e., caustic leach) hot process testing needs and equipment and instrumentation required for new processes relating to the above are included.

The *Encyclopedia of Chemical Technology* (Kirk-Othmer 1982) gives the following description of pilot plants in general; it is somewhat modified to be appropriate to this report.

A pilot plant is a collection of equipment constructed to investigate some critical aspect(s) of a process operation or to perform research. A pilot plant can range in size from a laboratory bench-top unit to a near-commercial unit, but is usually intermediate in size. There are several different types of pilot plants, depending on the purpose. The complete pilot plant duplicates the full-sized situation as closely as possible. The functional-testing pilot plant may test only one or several elements of the entire scheme being the most critical or unknown.

Kirk-Othmer further states that ". . . scale-up is successful if the plant produces a product at planned rates and costs and of desired quality."

This source definition will be used to define "major program impacts" for this report. The product must include all of the above (i.e., rates, costs, and quality) to be successful and avoid major program impacts.

5.0 ENHANCED SLUDGE WASHING STRATEGY

The strategy for in-tank processing of tank wastes containing sludge is based on the need to supply insoluble metal oxide waste to the HLW vitrification plant at a rate of 5 MT/day. The only pretreatment processing considered in this report for waste sludge is in-tank caustic leaching and washing.

In-tank processing will be used to separate high-level radioactive waste sludge from nonradioactive compounds, which are soluble in water or alkaline solutions.

6.0 ENHANCED SLUDGE PROCESSING, PROCESS TECHNOLOGY AND EFFECTS

In-tank processing of waste sludge reduces the amount of HLW by dissolving and removing nonradioactive compounds in HLW sludge. This concept of completing the waste processing in existing carbon steel waste storage tanks, called "in-tank processing," was developed to eliminate the cost of building new facilities. The processing is accomplished with the following three operations: (1) alkaline leaching of certain compounds from the sludge, (2) water washing of the sludge, and (3) separation of liquid from sludge. More details are listed in Appendix C, "Enhanced Sludge Processing."

Failure of the enhanced sludge processing, or not doing it at all, would mean that the number of HLW canisters would increase 6,800 to about 19,000 and the number of LLW vaults would decrease. The HLW canisters are about 69 cm (27 in.) in diameter, 4.6 m (15 ft) long, and hold about 1.44 m³ (51 ft³) of vitrified product (Claghorn and Powell, 1994). Complete failure of enhanced sludge processing would triple the amount of waste sent to the HLW repository and increase the cost of disposing of the waste. The other impact of the potential failure of enhanced sludge processing is that the HLW melter may be

improperly sized. There are only minor impacts to the LLW melter because of its larger capacity and the large LLW feed inventory.

7.0 VITRIFICATION

The Hanford Waste Vittrification Plant (HWVP) was originally to have been patterned after the Savannah River Defense Waste Processing Facility Program, which involved extensive "cold" test work. The proposed HWVP testing plan and schedule were reported in WHC-EP-0522 (Randklev 1993). The planning was based on the double-shell tank (DST) inventory only and a projected melter size of about 2 tons/day. The work was to include five scales of testing, ranging from the numerous cold and hot laboratory-scale crucible melts to hot and cold bench-scale (1/50 size), then cold-scale tests in pilot scale (1/10 size), demonstration scale (1/4 size), and finally to full-scale cold glass melts in the HWVP. This information was to be used to predict the properties of the hot waste form product glass and to establish scale-up parameters.

After the full-scale, joule-heated, HWVP plant had been built and tested with cold runs, full-scale hot runs would have been attempted in an effort to confirm preliminary work.

In late 1993 the TWRS baseline was changed by negotiations on the Tri-Party Agreement (Ecology 1994) to include single-shell tanks in the evaluations. This increased the effective waste inventory. Grout was replaced with glass as the LLW disposal form of choice. Enhanced sludge washing was chosen over the more complex acid-based pretreatment process. The HLW plant volume estimate increased from about 2 tons/day to the current best estimates of 8 to 20 tons/day. The LLW vitrification facility capacity is estimated to be about 140 tons/day, which is planned to be provided by two 100 tons/day melters (Orme 1994).

Previous evaluations of pilot plant needs have been performed on joule-heated, liquid-fed ceramic melters by staff from Pacific Northwest Laboratory and Westinghouse Hanford Company (WHC) (May 1992 and Sevigny 1991). Kupfer, in WHC-SD-WM-TA-138, (Kupfer 1994) combined the acid-based pretreatment process evaluation with HLW pilot plant needs. All these evaluations were based on the lower feed rates needed for the HWVP. If another vitrification technology is adopted, these evaluations would be only partly appropriate for the present TWRS strategy, primarily as a result of technology considerations and the size of the smallest available pilot plant. Currently, vendor proposals are being evaluated to determine what type of vitrification technology will be used for HLW and LLW (Weber 1994). Determination of a melter system will help determine the pilot plant needs for the program.

8.0 EQUIPMENT AND INSTRUMENTATION

In this analysis the term "equipment" will include instrumentation. Two categories of equipment needs are evaluated. The first is nonmelter equipment, which includes enhanced sludge washing equipment and general nonmelter process control equipment. The other category is melter equipment, which includes product quality control instrumentation and process control equipment.

The philosophy for control of the waste feed composition is being developed. It is apparent that uniform feed to vitrification systems is not possible even with the additional DSTs to be put online in the future. The HWVP assumed four different feeds to the melter (Randklev 1993). There will be variations in waste feed compositions that will cause operating concerns and require process modifications. Product control, using long duration feedback, is not practical at LLW vitrification rates of 100 to 200 tons/day. Therefore, short duration product quality verification maybe required. This drives a process more oriented toward feedback control than feedforward control.

Equipment development and testing will be required for short duration product quality verification. A discussion of the individual equipment needs and issues is outlined in Appendix E.

9.0 DECISION ANALYSIS PROCESS

A summary of the Kepner-Tregoe™ decision analysis process is shown in Figure 1. This process was used to determine whether enhanced sludge washing, LLW vitrification, HLW vitrification, or associated equipment testing needs required radioactive (hot) pilot plant testing. The size and type of hot pilot plant also was estimated from the needs.

In the decision analysis process, there are frequently three challenges: (1) focusing on a favorite alternative, (2) ignoring the consequences of a choice, or (3) using inadequate information. The decision analysis process provides a systematic framework to make a decision, with each step following logically from the previous step. When the purpose of the decision is clear, three basic ideas are followed in order.

1. *Objectives* are set that establish a clear focus on the results to be achieved and provide criteria for evaluating alternatives.
2. *Alternatives* are chosen that may satisfy the objectives. Information about each alternative is gathered and assessed against the objectives.
3. *Adverse Consequences* are evaluated, which is an assessment of risk. By determining the risks associated with the alternatives, a decision can be made with the full knowledge of both benefits and risks.

The purpose of this decision analysis will determine whether a hot pilot plant is needed in any of the four areas previously noted and be used to develop the information listed in Section 2.0, "Scope." The next step would be to establish objectives and criteria with which to evaluate alternatives. This is done by evaluating the issues having to do with radioactivity in the waste for each area (e.g., enhanced sludge washing and vitrification). Selected issues are translated into "needs" (or wants) and "requirements" (or musts); each alternative must meet the requirements and be evaluated against the needs. The needs are "weighed" on a 0 to 10 scale using the best engineering judgment of the authors. The weight of a need is based on how important it is to the program. A need that is very important (e.g., as low as reasonably achievable [ALARA]) may be rated the most important, or a 10, on the scale. Appendix D, Table D-1, shows the weights in the second column. These weights stay the same during the evaluation of different alternatives.

Options and alternatives are then generated. The alternatives are combinations of options that meet the minimum requirements. Alternatives not meeting the minimum requirements are not shown.

The alternatives are evaluated against the needs and assigned a "score" (Appendix D, Table D-1, column four). This score (from 0 to 10) is a judgment of how well the alternative meets the want. This judgment requires gathering quality information about each alternative as this forms the basis for the judgment.

When the scoring is complete, a weighted score is calculated, which is the product of the weight and score. Then the weighted scores for each alternative are totaled. The highest weighted score may indicate the best alternative.

The adverse consequence evaluation is performed next, which considers the risks associated with the remaining alternatives. The analysis examines the probability that the risk identified will occur and allows for the computation of the seriousness of the effects should it happen.

The final choice is made by assessing the relative benefits and risks.

10.0 ISSUES

This section lists issues that may be translated into "needs" for the decision analysis process. The list was developed through interviews with personnel and a review of literature. The extent to which the issue could be resolved using the appropriate type of "cold" pilot plant or equipment testing before resorting to hot testing also is evaluated.

10.1 ENHANCED SLUDGE WASHING ISSUES

Issues associated with enhanced sludge washing are listed below. These issues were augmented by discussions with G. T. MacLean and C. M. Winkler:

- Effectiveness of sludge washing and caustic leaching in separating challenging vitrification components, including leaching and settling rates of tank waste (PNL 1994)
- Effectiveness of HLW volume reduction and requirements for sludge washing and caustic leaching (PNL 1994)
- Mechanism of hot and cold sludge dissolution and solids formation to validate modeling (PNL 1994)
- Mixing of the tank contents adequate to maintain a uniform liquid composition throughout (Orme 1994)
- Durability of equipment internal to the DST, such as existing airlift circulators, thermocouple trees, drywells, and the mixing pumps to be added (Winkel 1989)
- Corrosion of the tanks' internal surfaces (PNL 1994 and Waters 1990b).

10.1.1 Enhanced Sludge Washing and Nonmelter Equipment Testing Issues

The following equipment is new or modified from previously used equipment at the Hanford Site. All of it would benefit from some level of radioactive testing:

- Transuranic (TRU) element monitor (Subrahmanyam 1989, Kupfer 1994, and Simons 1994); specific hot testing issues include the following:
 - Effect of neutron background count from local TRU elements on instrument performance
 - Effect of gamma radiation in the solution on performance
 - Degree and rate of TRU fouling (buildup) in the instrument requiring cleanout or replacement
- Sludge interface-level detector and corrosion and passivation probe (Kupfer 1994 and Simons 1994)
- Sludge sampler for 25-L amounts (Parazin 1993)
- Sludge mobilization (mixing) pumps (Waters 1990a, Waters 1990b, and Orme 1994)
- Modified decant pump (Winkler 1993)
- Decant pump discharge turbidimeter (measures suspended solids concentration) (Winkler 1993)

- Liquid-level monitor (Winkler 1993)
- Suspended solids, light-scattering tank profiler (Winkler 1993)
- Light duty in-tank articulated mechanical arm.

More details of selected issues may be found in Appendix B or in the references.

10.2 GENERIC VITRIFICATION ISSUES

The following represent the current generic vitrification issues for both LLW and HLW. These issues were developed from discussions with personnel and the noted references; the issues are expanded in Appendix C.

- Verification of waste simulant performance (similitude of hot to cold process) (Kupfer 1994 and May 1992)
- Waste feed composition uniformity (Randklev 1993)
- Feedback control and equipment development for the vitrification process
- Buildup of radioactive material in process (Herborn et al. 1993)
- Hot offgas emissions (May 1992)
- Final product form and shape
- Destruction of organics in the melter/incinerator (Miller et al. 1991 and May 1992)
- Secondary waste stream accumulation and disposal
- Development of product verification tests for disposal requirements.

10.3 SPECIFIC LOW-LEVEL WASTE VITRIFICATION ISSUES

The issue of final product quality sufficient to satisfy disposal requirements needs to be resolved (Kincaid et al. 1993). Details on this issue can be found in Appendix C.

10.4 SPECIFIC HIGH-LEVEL WASTE VITRIFICATION ISSUES

The following issues are specific to high-level waste vitrification:

- Possible plutonium or noble metals build up in the vitrification facility (Herborn et al. 1993 and May 1992)

- Final product quality to satisfy disposal requirements (Randklev 1993).

Details on the above vitrification issues can be found in Appendix C.

11.0 EVALUATION CRITERIA

The following are evaluation criteria applicable to all HLW and LLW vitrification and enhanced sludge processing. The more generic criteria were modified from those in WHC-EP-0616 (Boomer et al. 1993) and WHC-SD-W315-ES-001 (Parazin 1993).

- Requirements:
 - Meet existing federal and state regulatory requirements
 - Have more than 95% confidence that the process and equipment will operate as required to meet mission needs. This requirement is from the Washington State Department of Ecology (Ecology) requirement to have chemical analysis to the 95% confidence interval and because it was felt that the program needed high confidence that the disposal system would operate as required. It corresponds to no more than a 6-month delay in operation of a vitrification system because of technical problems.
- Needs:
 - Minimize worker exposure to ALARA
 - Minimize industrial safety risk
 - Minimize impact to Tri-Party Agreement (Ecology 1994) schedule
 - Maximize operability and reliability
 - Minimize design uncertainties
 - Maximize U.S. Department of Energy (DOE) and WHC order and requirement compliance.

Costs were not evaluated at this time.

An additional criterion for the evaluation of enhanced sludge washing is to maximize the quantity of problem melter components removed from the HLW to minimize the amount of waste to be processed in HLW vitrification.

The above-mentioned criteria were weighted as to importance. Alternatives were evaluated against the criteria and assigned a score. The weighted score is the product of the criteria weight and the criteria score. Generally, the highest weighted score indicates the best alternative.

12.0 ALTERNATIVES FOR RESOLUTION OF ISSUES

The options and alternatives are outlined below. The options are arranged (approximately) from simplest and least expensive to most complex and most expensive. The most promising combinations are discussed further.

The following are options for resolution of the issues:

1. Literature search
2. Cold laboratory testing
3. Computer modeling
4. Small, cold pilot plant
5. Testing in gamma irradiation facility
6. Large, cold pilot plant
7. Radioactive laboratory testing
8. Testing in existing DSTs
9. "Functional" radioactive pilot plant
10. Bench-scale radioactive pilot plant
11. Small, radioactive pilot plant
12. Large, radioactive pilot plant.

Each of the four areas requiring decisions (i.e., enhanced sludge washing, LLW and HLW vitrification, and equipment testing) used combinations of options (designated "alternatives") to determine an overall weighted score. The alternatives picked for further analysis were the ones that passed the requirements test (i.e., more than 95% confidence that they would not have major program impacts). In addition, the authors picked alternatives that they felt would be the most appropriate, including least costly and complex.

Because the purpose of this analysis is to identify the issues and provide information for making decisions on hot pilot plants, different types and sizes of hot pilot plants were included in decision analysis scenarios, as well as hot laboratory testing in place of hot pilots. In general, the minimum options in the alternatives that had a 95% or greater chance of success were those that incorporated significant amounts of cold-pilot testing and hot-laboratory testing. Where it was felt that large hot-pilot plants were not practical or reasonable, they were not evaluated.

A more detailed explanation of the options is in Appendix G.

13.0 ADVERSE CONSEQUENCE EVALUATION

The alternatives with the highest weighted score are evaluated for adverse consequences. This is an evaluation of the risk of the alternative. Items that the authors felt have the most influence on the risks of the alternatives are listed below:

- Cost of radioactive pilot plant
- Availability of hot cell space at the Hanford Site
- Type of melter to be used

- A combustion melter would have scaleup and scaledown concerns. The minimum melter size would probably be 5 ton/day but could be operated below full capacity (Appendix G).
 - The joule-heated melter could be operated at bench scale (Kupfer 1994).
- Change of regulations
 - Limited success of cold pilot operations.

Then final conclusions and recommendations are made.

14.0 DECISION ANALYSIS FOR RADIOACTIVE PILOT PLANT

1. Enhanced Sludge Washing

The following sets of options would meet or exceed the requirements. Appendix D lists the decision analysis matrix that evaluated the alternatives.

Alternative A, Radioactive Laboratory Testing--Options 1, 2, 3, 4, 5, and 7.

This alternative includes radioactive testing in the laboratory, but no pilot plant-scale radioactive testing. With the addition of both a cold pilot plant and gamma pit equipment testing, it should meet program guidelines within general rough order of magnitude estimate.

Alternative B, Testing in existing DSTs tanks--Options 1, 2, 3, 4, 7, 8, or alternative A, plus testing in existing DSTs.

The retrieval program is planning to retrieve two DSTs (101-AZ and 106-C) before 1997 (Appendix A). The contents of these tanks could be used to demonstrate (modified) enhanced sludge washing. Combined with radioactive laboratory testing this would be almost equivalent to a full-sized radioactive pilot plant test for each waste type tested.

Alternative C, Bench-scale radioactive pilot plant--Alternative B plus a bench-scale radioactive pilot plant (Option 10) on each major type of waste.

This would provide a more comprehensive assessment of enhanced sludge washing effectiveness on different waste types than would Alternative B.

Alternative D, Large radioactive pilot plant--Alternative C plus a larger scale radioactive pilot plant (Option 12) on selected problem (critical) waste types.

Larger scale pilots would reduce the risk of ineffective separations even further. This option will probably be over

the 1,000-kg limit and may not be permitted under WAC 173-303-071, "treatability Studies" (Ecology 1991).

Alternative B received the top score by a few points. Essentially, Alternatives B, C, and D received equal scores because they were close in point scores. Alternative A scored lower as a result of larger design uncertainties and operability and reliability concerns.

a. Adverse Consequences Evaluation

The factor that will make the difference in choosing between Alternatives B, C, and D is probably cost. Alternative B will cost much less than C and D because of the expense of setting up a bench-scale or larger radioactive pilot plant. Because of the limited consequences of enhanced sludge washing failure, it would be logical to choose Alternative B, testing in existing DSTs.

Availability of hot cell space is not a factor for Alternative B. A change of regulations probably will not influence this portion of the program because it does not have a closely regulated product. Other possible adverse impacts include the following.

- The composition of waste produced will affect the choice of the optimum melter type. Therefore, it is possible to have technical impacts by the incomplete separation of chemicals by enhanced sludge washing. These impacts are difficult to quantify at this point as a result of program uncertainties and limited process knowledge of the melters.
- Limited success of cold pilot operations or laboratory hot testing. If tests indicate limited success, they will influence the sizing of the HLW melter. The early establishment of in-tank tests should make this effect a manageable one.

The first two sets of retrieved tank waste are probably different from waste than would be found in other tanks and retrieval scenarios, but this would be an excellent and timely test of the equipment and the procedure effectiveness.

The risks associated with Alternative B appear to be modest and manageable. It is recommended that Alternative B be pursued at this time.

2. Low-Level Waste Melter System

a. Decision Analysis for Radioactive Pilot Plant

The following sets of the above options would meet or exceed requirements. All four alternative scenarios for the melter will include the following options to meet the requirement for 95% program confidence.

- Options 1, 2, 3, and 4 (Small, cold pilot) are needed because most melter technology is untested for continuous operation at relatively high throughput, such as 100 tons/day.

- Option 6 (Cold large pilot scale).
- Option 7 (Hot laboratory scale).

Numerical evaluations of the alternatives are listed in Appendix C. Alternatives are listed in order from least expensive to most expensive.

Alternative A, Cold Full Scale--Options 1, 2, 3, 4, 6, and 7.

This alternative jumps directly from small, cold pilot-scale to full-scale processing, with just the hot laboratory scale crucible melts.

Alternative B, Functional Hot Bench Scale--Options 1, 2, 3, 4, 6, 7, and 10.

This alternative incorporates functional testing of most parts of the vitrification process. The process would operate at a bench scale, to help verify the probable processing fate of the more important radioisotopes. It may not be possible or make sense to operate combustion melters at this scale.

Alternative C, Small Hot Pilot--Options 1, 2, 3, 4, 6, 7, and 11.

As in Alternative B, this alternative completes some cold, large-scale pilot work to obtain processing parameters. Hot work is conducted up to the minimum full pilot plant-scale to include the vast majority of the process equipment, with associated control equipment.

Processing options include operating the plant for extended periods at a reduced rate, operating for short periods at a maximum throughput or a combination of the two.

Alternative D, Large Hot Pilot--Options 1, 2, 3, 4, 6, 7, and 12.

This alternative completes the radioactive testing at a scale about 1/3 of full size. This would be an attempt to completely test the melter operation for short periods at high throughput with hot waste.

b. LLW Adverse Consequences Evaluation

Alternative A scored lower than the others because it only partly resolved two hot testing issues. The confidence in product quality was much increased. Confidence in verification of waste simulant performance was increased. All other issues were not significantly affected by hot laboratory testing. The two issues noted above would not be fully resolved. The probability and consequences of unresolved issues are significant in potential plant downtime to modify the vitrification process and significant probability that undesirable downtimes would be required.

The low rating of operability/reliability and the design needs for Alternative A indicates that there is a problem with not doing some

type of a hot pilot test. It is estimated that the probability of program success with alternative A (crucible melts) would be at or below the 95% confidence level.

Waste transport to the small and large pilot plants will be a major concern. The amount of waste needed to feed a minimum 5 ton/day unit is significant, even if it is only operated at 20% of capacity.

Alternatives B, C, and D differ little in their overall numerical evaluations. This means that there is either not enough information to determine the best alternative or that all alternatives are approximately equal.

The dose absorbed to operate hot pilots (ALARA) and industrial safety affects the decision evaluation the most. The longer time required for hot pilots could create a potential problem for adherence to schedules.

The challenge with evaluation of this technology is that there is not a good data base from which to draw, and the melter for the process has not been chosen. Process tests have been limited and alternate melters may or may not have the same concerns. For many melter systems Alternative A is not a good fit, and, in general, the lack of process experience drives hot testing to the maximum practical extent.

Timing, cost, and logistics will be major factors tending to forego a hot pilot. The large volume of product to be produced in 100 ton/day melters appears to drive a hot pilot to prove that a continuous melting process does work with LLW.

c. Test Conclusions

Clearly, the cold scaleup pilot route with hot crucible melts and its associated risks would be cheaper and faster to complete. There is an associated high risk with the lack of a continuous hot pilot plant.

Further investigations are warranted because a clear, best alternative is not identified at this point. More process knowledge and experience with the final selected vitrification system is needed to ensure success. Program risks are relatively large because there is a lack of information and experience with high capacity hot melter systems.

3. High-Level Waste Melter System

a. Decision Analysis for Radioactive Pilot Plant

The following alternative sets of the above options would meet or exceed the requirements. All three of these alternative scenarios for the HLW melter will include:

- Options 1, 2, 3, and 4 (Small cold pilot)
- Option 6 (Cold large pilot scale) except Alternative A

- Option 7 (Hot laboratory scale).

Alternative A, Cold, Full Scale, Hot Laboratory Scale--Options 1, 2, 3, 4, 6, and 7.

This plan jumps directly from small, cold pilot scale to full-scale processing with just the laboratory-scale verification (crucible melts) of the vitrified product.

Alternative B, Hot Bench--Options 1, 2, 3, 4, 6, 7, and 10.

This alternative incorporates functional testing of some parts of the process, but not all. This would be a continuous process at bench scale. It may not be possible or make sense to operate combustion melters at this scale.

Alternative C, Small Hot Pilot--Options 1, 2, 3, 4, 6, 7, and 11.

This alternative is more comprehensive than either Alternative A or B. It incorporates the cold, large-scale pilot work (Option 6) to obtain processing parameters. In addition, it extends the hot work up to a pilot scale for which it is possible to simulate almost all of the melter process, including realtime control equipment.

Large hot pilots were not evaluated for HLW because the small hot pilot is essentially equal to 1/4 scale of the full system. Thus, small and large hot pilots are close to equal and cannot be differentiated with this analysis at this time.

b. Adverse Consequences Evaluation

As in the LLW evaluation, Alternative A scored lower than others because it only partly resolved two hot testing issues. The issue of confidence in product quality was much increased. Confidence in verification of waste simulant performance was increased. All other issues were not significantly affected by hot laboratory testing. The two issues noted above would not be fully resolved. The probability and consequences of unresolved issues are significant in potential plant downtime to modify the vitrification process and significant probability that undesirable downtimes would be required. There are more and higher concentrations of radionuclides in the HLW than in LLW.

Numerically, Alternatives B and C are the same. The risk for Alternative B is greater than C. The hot bench test does not simulate the fate of the radionuclides, including the long-lived TRUs, in the process and its associated offgas and secondary waste streams.

Waste transport to the small and large pilot plants will be a major concern. Appendix H shows that the amount of waste needed to feed a minimum 5 ton/day unit is almost 10,000 gal of sludge, even if it is only operated at 20% of capacity. Bench-scale units would be much

easier to supply feed to, as noted in WHC-SD-WM-TA-138 (Kupfer 1994).

It is possible that the earlier Hanford Site or Savannah River experience with vitrification might have eliminated some of the potential risk. Melter choice is still a major factor in determining costs and which level of piloting is realistic. Melter choice is probably going to decide the size of pilot plant. Combustion processes cannot be downsized well and still retain similitude to the much larger process.

In spite of the negative ALARA and secondary waste factors associated with the upscaling of any hot HLW work, it is clear that small or bench hot pilot-scale work would be a better approach for the HLW effort. This is achieved partially by the elimination of any TRU criticality possibility and by the minimization of design and reliability uncertainties.

c. Test Conclusions

Hot pilot testing should be completed with associated large cold pilot testing as part of the HLW vitrification effort. There is a large uncertainty in feed requirements for the hot pilot because of melter selection uncertainties. More investigation is warranted on the size and cost of the hot pilot and on the melter alternatives.

4. Equipment and Instrumentation Testing

- a. Testing in Radioactive Pilot Plant for all analysis "instruments" shall be included under "equipment."

It was found from equipment installation at Tank SY-101 that most of the monitoring and control equipment that was installed in the tank failed after installation. This was caused by several factors, one of which was inadequate testing in the environment in which the equipment was expected to function. Therefore, greater emphasis is being placed on testing equipment in conditions in which it is expected to operate.

Nonmelter Process Equipment--Equipment testing was split into two separate evaluations. The first one envisions a radioactive pilot plant especially for nonmelter equipment testing. Because of the limited scope (and cost) of such a hot nonmelter pilot plant, the entire decision analysis process was not formalized but is summarized below.

Viable alternatives were limited. Cold testing needs alone were deemed not sufficient to meet the 95% confidence requirement for critical equipment, especially the TRU monitor. The description and adverse consequence analysis are combined in the following paragraphs:

- Full-scale cold testing plus DST tank testing would be possible but may not meet existing Nuclear Regulatory Commission (NRC), U.S. Environmental Protection Agency (EPA), and State

operability requirements. These methods would not easily meet existing DOE and WHC requirements for confinement, containment, and safety.

- **Full-scale cold testing plus hot bench scale testing** would not be appropriate for some of the equipment, such as the large TRU monitor. Scale down to bench scale is not practical.
- **Full-scale cold testing plus functional hot pilot plant** could be done in existing hot cells. The arrangement of equipment in the hot cell would be appropriate to include other equipment testing needs. The functional hot pilot plant would test a limited scope of selected equipment (up to full scale) using radioactive waste in controlled conditions. Smaller equipment previously identified (i.e., TRU monitor, sludge-level detector, corrosion monitor, and large sludge sampler) could be tested and demonstrated at this facility.

Some of the equipment (especially the TRU monitor) is going to be critical to prevent misroutings and to confirm feed specifications are met for TRU versus nonTRU (process control). It is important to the program that critical pieces of process equipment operate correctly. Other unforeseen equipment-testing needs also will surface in the future that will require equipment testing in radiation areas under process conditions.

For example, the TRU monitor probably could not be effectively tested using DST or hot bench scale because of the types of issues and the size of the equipment. This equipment and the associated facility utility requirements for a functional pilot plant are outlined in Appendix E.

Functional pilot plant costs are relatively low, quoted as 1.8 million dollars in a letter from R. D. Campbell to B. C. Landeene, dated August 26, 1993 (Campbell 1993). This included engineering, design, fabrication, materials, and installation but did not include regulatory and waste transport. It is apparent that the best alternative is a functional hot pilot plant equipped for equipment testing in nonmelter process.

Melter Equipment Testing--The second category of equipment testing is vitrification product testing and vitrification process control equipment. The need is to have enough information to implement process feedback control to the melter process. This information should be real time based on product quality. Real-time feedback control will allow the operators of the facility to correct for upset conditions and determine and correct trends. The result of feedback control is that the product will be more consistent and the process will run more consistently. The equipment to determine quality of the product will have to be semi- or nonintrusive to the process. This equipment would have to be installed in the process to provide real-time feedback. The feedback for product quality should be provided in minutes.

Product quality equipment would optimally be tested with the final hot radioactive vitrified product and associated process conditions to ensure that the equipment would be adequate in the application. This testing could involve a small-scale radioactive vitrification facility that had equipment and product testing capacity. New equipment that has not yet been fully envisioned may need to be developed and tested for HLW and LLW vitrification process feedback control systems. The equipment that may be required includes real-time product quality feedback analyzers. These analyzers might include refractive index, leach tests, infrared, and other features. The product quality testing equipment noted in Appendix E is a potential candidate for testing at such a pilot facility.

Alternatives for melter equipment testing include the following.

- Alternative A, cold pilot plant testing with irradiation testing (Options 1 through 7).

Alternative A would test the simulated vitrified product by cold testing in a cold pilot plant to establish operability. Equipment dependability would come from exposing the equipment to accelerated radiation testing in a gamma irradiation facility. Alternately a dose could be accumulated through exposure to the vitrified product during laboratory scale crucible testing.

- Alternative B, functional hot pilot plant (Options 1 through 7 and 9).

Alternative B would add to the testing of equipment by exposing the equipment to the functional equipment pilot plant used to test the nonmelter equipment. Some additional modifications to the functional pilot plant would be necessary, such as a heated container to simulate the vitrification process.

- Alternative C, a small radioactive vitrification pilot plant, with product testing capability (Options 1 through 7 and either Option 9 or 10).

Alternative C would allow equipment to be tested in the actual conditions of operation. The effects of radiation, heat, and remote operability would be combined to maximize equipment dependability and design. The size limit on the unit would be the smallest size that could be run to make acceptable product. Offsite testing is possible.

These alternatives were evaluated in Appendix F. Alternative C scored highest; Alternatives A and B were essentially equal. There is a difference between Alternative C and the others because of durability and design considerations.

b. Adverse Consequences Evaluation

The additional cost of adding equipment testing capability to a radioactive vitrification pilot plant may be significant. The

availability of onsite hot cell space will affect what can be tested at the Hanford Site and the cost of the testing.

The type of melter to be used will have an impact on the overall cost but may not be a major factor in equipment testing. Quality control testing equipment will be required for feedback control for LLW or HLW melter operation. Most of the quality control testing can be performed in cold or hot crucible tests. Final testing of the equipment requires the correct environment to ensure operability and dependability and to provide design feedback. To provide a limited environment in the testing facilities is, therefore, risky. If limited equipment testing is performed, the equipment will be prone to breakdown and will not necessarily predict vitrification product quality as needed. The testing combination of appropriate product, temperature, radiation type, and dose would be almost impossible to obtain in a nonmelter environment.

A change of regulations could affect the product quality requirements. These requirements will undoubtedly get more stringent as the HLW repository requirements are better defined. The LLW disposal requirements from the Grout Performance Assessment (Kincaid et al. 1993) are established and may or may not become more stringent. If product quality equipment fails during cold pilot operations, alternate equipment would have to be developed. This will not affect the hot pilot decision.

To ensure that the testing and the testing equipment are appropriate, process and product testing equipment should be a part of the first available radioactive vitrification pilot plant. This plant could be located offsite if an appropriate facility could be found. Product testing equipment will help establish durability, design, and operating parameters. Appendix E lists estimated space and utility requirements.

15.0 CONCLUSIONS AND RECOMMENDATIONS

Radioactive laboratory testing and testing in existing DSTs should be sufficient to meet enhanced sludge washing program needs and requirements. Pilot plant radioactive testing of enhanced sludge washing is not recommended.

It is recommended that further investigations and cost estimates be performed with regard to LLW vitrification hot pilots to determine if hot pilots are warranted. Associated risks to the LLW program are relatively large if some type of a hot pilot test is not performed. Development of a testing strategy should be pursued when more is known about the melter system. The testing strategy may be similar to that outlined in WHC-SD-HWV-ES-042 (May 1992).

High-level waste hot pilot plant testing should be performed with associated large cold pilot testing. It is recommended that hot pilot sizing costs and feed and utility requirements be explored further to determine the size of the hot pilot.

Nonmelter process equipment will be critical for process control and feedback. It is recommended that a functional hot pilot plant be established for equipment testing in a nonmelter process.

Disposal requirements will dictate that both the HLW and LLW vitrified product be tested to determine product quality, at least initially. It is recommended that process and product testing equipment be added to the first appropriate radioactive vitrification pilot plant to ensure that product testing is effective and the testing equipment is appropriate.

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APPENDIX A

SCHEDULES AND STATUS

ENHANCED SLUDGE WASHING

Tentative equipment testing schedules (Simons 1994) for the transuranic (TRU) waste monitor, interface-level detector, and corrosion monitor are as follows: Cold test in fiscal year (FY) 1996 and Hot test in FY 1997.

For the functional pilot plant equipment testing the 25-L sludge sampler needs to be on line before the hot test of the equipment. Total sludge required is at least 200 gal of 20 vol% solids. Also, see Appendix E for more functional (nonmelter) pilot plant needs.

Table A-1 lists the enhanced sludge washing draft schedule for aging waste tanks and the Tank 106-C waste schedule (provided by G. T. MacLean, February 28, 1994).

Table A-1. Pretreatment Schedule.

Task	Finish	Comments
Decant Tank 101-AZ supernate	July 1994	To nonaging waste double-shell tank
Add 1st wash solution to Tank 101-AZ	August 1994	From Tank 204-AR
Mix and settle Tank 101-AZ	December 1994	Project W-151
Decant Tank 102-AZ	April 1996	
Transfer Tank 101-AZ contents to Tank 102-AZ	July 1996	Project W-151
Retrieve Tank 106-C contents to Tank 1-2-AY	October 1996	Proposed date
Mix and settle Tank 102-AZ	February 1999	Project W-211

The draft schedule above may change.

LOW-LEVEL WASTE VITRIFICATION

Construction of a low-level waste (LLW) vitrification facility is scheduled to start in December 1997 and be completed in late 2003. The reference melter is to be chosen in June 1996. Design of the hot pilot plant equipment and hot test modifications should be completed by June 1996 and the test run and analysis completed by the start of construction of the LLW vitrification facility.

At least 8 months should be planned for laboratory analysis of results and inspection of the pilot plant after the pilot run is performed. It is assumed that the end of design coincides with the start of construction of the LLW vitrification facility. As pilot plant results are analyzed there may need to be design changes to the LLW facility. As reflected in the decision analysis, this is an extremely ambitious schedule.

HIGH-LEVEL WASTE VITRIFICATION

Construction of the high-level waste (HLW) vitrification facility is scheduled to start in June 2002, with a reference melter chosen in September 1998. Design of the hot pilot plant equipment and hot test modifications should be completed by September 1998 and the test run and analysis completed by start of construction of the HLW vitrification facility.

At least 10 months should be planned for laboratory analysis of results and inspection of the pilot plant after the pilot run is performed. It is assumed that the end of design coincides with the start of construction of the HLW vitrification facility. As pilot plant results are analyzed, design changes to the HLW facility may be required. The 18 months to complete the design, obtain regulatory approval, build, perform, and analyze results is tight, and it is complicated by the need to analyze for potential TRU buildup (criticality concerns) in the pilot plant. The experience gained from designing and building the LLW vitrification facility should be a positive factor.

Table A-2. Summary of Vitrification 1994 Status and Plans.

Reference Section*	Program Needs	Status of Cold Test Work Required	
		Before Actual	Hot Pilot-Scale Testing
7.0	LLW Vitrification		
7.4	Melter Evaluation:		
7.4.3	Identify Candidate Melters (WHC)		Done
7.4.4	Establish Melter Selection Process (WHC)		In Progress
7.4.5	Conduct Cold Melter Tests (WHC)		TBD
7.4.6	Analyze Cold Product/Testing (WHC)		TBD
7.4.7	Document Cold Melter Testing (WHC)		TBD
7.4.8	Candidate Melter Selection (Panel)		TBD
7.4.9	Conduct Cold and Hot Melter tests (Vendors)		TBD
7.4.10	Product Testing and Analysis (Panel)		TBD
6.0	HLW Vitrification (PNL)**		
6.10-17	Melter Equipment/Process Evaluation:		
6.10	Melter Performance Assessment		Done
6.11	Small-Scale Melter Testing		Delayed to FY 1995
6.12	Feed Preparation System Testing		In progress
6.13	Pilot-Scale Melter System Testing		Closed-out
6.14	Savannah River Test Center (SRTC) Integrated DWPF Melter System Testing		Closing-out
6.15	SRTC Stirred Melter System Evaluation		TBD
6.16	High-Temperature Melter System Evaluation		TBD
6.17	Cold Crucible Melter System Evaluation		TBD

* From the Tank Waste Remediation System FY 94 Technology Development Plan (January 5, 1994) (PNL 1994).

** Most work refers to Hanford Waste Vitrification Plant-may be changing rapidly

PROPOSED SCHEDULES FOR LLW AND HLW VITRIFICATION PILOT PLANT PROJECTS

These lists of assumptions were used to obtain estimates of when pilot plant test results would be available from LLW and HLW radioactive pilot plants. The proposed schedules presented in Figures A-1 and A-2 assume that these activities would be funded with project, not expense, monies. The schedules might be shortened somewhat by making them expense funded.

The LLW vitrification schedule shows that the Functional Design Criteria (FDC) and Conceptual Design Report (CDR) should be started as soon as possible to meet the Definitive Design startup near the Melter Determination point, as noted in the Tri-Party Agreement (Ecology 1994). The "Choose Melter" point in time is the most logical point for the start of the Definitive Design step.

These schedules were reviewed by G. Howden, R. A. Vandercook, W. J. Powell, and E. F. Riebling in May 1994. They still appear to represent the "best estimate" timeframe cases. Existing internal Westinghouse Hanford Company (WHC) schedules were not reviewed to determine if there were any prior plans for this subject.

LLW HOT PILOT PLANT SCHEDULE ASSUMPTIONS

1. The LLW pilot plant will not require delivery equipment times beyond one year. For example, shielding windows can take two years. This means that the facility would not be located at the Fuels and Materials Examination Facility (FMEF) main cell.
2. The LLW pilot plant is a lightly shielded facility, incorporating ^{137}Cs ion exchange feed pretreatment. The ^{137}Cs ion exchanger will be heavily shielded.
3. The feed to the LLW vitrification pilot will be supernatant, not sludge. It does not require concentration before melter input.
4. The feed may be transferred to the pilot facility by either existing pipelines or easily modified pipelines.
5. Readiness review and regulatory and safety requirements can be completed within a year of definitive design completion.
6. Only one type of radioactive waste is tested within this schedule. A variety of waste may have to be tested. That would lengthen the schedule.
7. Actual run time is from one to three months. Use three to six months to remove and inspect pilot equipment for radionuclides.
8. A cold pilot plant of the same size is required to be performed before the hot pilot.
9. A complete offgas scrubbing system is required.

10. The pilot plant is housed in an existing facility or is transportable and located in the field at the double-shell feed tank.

HLW HOT PILOT PLANT SCHEDULE ASSUMPTIONS

1. The HLW hot pilot would not require long equipment delivery times (beyond two years). For example, shielding windows could take two years.
2. The HLW pilot plant would be a heavily shielded facility that would not incorporate any ¹³⁷Cs ion exchange feed pretreatment.
3. The feed to the HLW vitrification pilot will be sludge and supernatant. It does not require any concentration before melter input.
4. The feed could be transferred to the pilot facility by large samplers, and the receiving capabilities could be installed in less than two years.
5. Readiness review and regulatory and safety requirements can be completed within two years of definitive design completion.
6. Only one type of radioactive waste is tested within this schedule. Different types of waste could be tested but that would lengthen the schedule.
7. Actual run time is from two to six weeks. Six to nine months would be used to remove and inspect the pilot facility for radionuclides.
8. A cold pilot plant of the same size is required to be performed before the hot pilot tests.
9. A complete offgas scrubbing system is required.
10. The melter is located in an existing shielded facility.

Figure A - 1
LLW Vitrification Pilot Plant Schedule

WHC-SD-WM-ES-317 REV 0

Figure A - 2
LLW Vitrification - Pilot Plant Schedule

WHC-SD-WM-ES-317 REV 0

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Figure A - 3
HLW Vitrification - Pilot Plant Schedule

WHC-SD-WM-ES-317 REV 0

A-8

△ TPA Milestone ○ Estimates
 TPA WDT Operations - Dec 2009

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APPENDIX B

ENHANCED SLUDGE WASHING

PROCESS TECHNOLOGY

Some compounds, including aluminum hydroxide and chromium (III) hydroxide, are amphoteric. The compounds are soluble at low pH because they form the soluble metal cation, and they are soluble at high pH because they form a soluble complex anion, such as aluminate. Adding sufficient free hydroxide will dissolve or "leach" the majority of the aluminum and most of the chromium, without dissolving radioactive compounds. The actual amount dissolved depends on the waste composition, as well as temperature, free hydroxide concentration, and leaching time.

Phosphate in insoluble phosphate compounds can sometimes be made water soluble by metathesis. This occurs when hydroxide ion replaces the phosphate ion in the insoluble compound, releasing the phosphate to the solution. This works well with bismuth phosphate but poorly with calcium, magnesium, or strontium phosphate. Thus, the phosphate associated with bismuth can be removed by caustic leaching.

The wastes that have sufficient amounts of aluminum, chromium, or phosphate to warrant treating by leaching should be grouped for processing with similar wastes. The maximum efficiency in leaching will be obtained when the specie being leached is at the maximum attainable concentration. This is because the equilibrium solution concentration is determined by the specie chemical activity not the amount in the insoluble phase.

Water washing of the sludge removes dissolved compounds from the interstitial liquid trapped within the sludge. Both leaching and washing of the sludge requires the ability to agitate or mix the sludge with the liquid in the tank. This will be accomplished with submerged mixing pumps. The development, construction, and installation of these pumps constitute the major costs as well as technical efforts for in-tank washing.

NEEDS AND ISSUES

The following information provides details of caustic wash issues.

Durability of internal tank equipment--The specification for mixing pumps is that they will be able to operate for 5,000 hours, intermittently, throughout a 10-year period. For wastes that require two stages of leaching, the pumps would operate for 1,776 hours per batch. This means that each pump would last for about three batches or 2.5 years. If the waste did not require leaching, only 336 hours of pump operation would be required per batch. For this case, a pump would be good for about 15 batches or 11 years. The actual duty required is somewhere in between.

Waters and Winkel (Winkel 1989) estimated that the airlift circulators would endure about 3,000 hours of mixing before fatigue would result in damage. This means the process life of a tank with airlift circulators is less than the life of a mixing pump. However, this is of concern only in the aging waste tanks (i.e., tank farms AY and AZ) because they are the only tanks

with such circulators. The tanks in farms AN and AW do not contain circulators.

Waters (Waters 1990a and 1990b) also has determined that existing thermocouple trees will have to be replaced and drywells will have to be strengthened. If this is done, the limit to the length of in-tank processing is the mixing pump life. The thermocouple trees may need to be replaced once during the course of processing the Hanford tank wastes.

Corrosion of tank internal surfaces--The corrosion concern stems from reports from Savannah River that corrosion was observed in laboratory coupons immersed in solutions similar to those that might be experienced at the Hanford Site during in-tank washing. Hydroxide and nitrite ion concentrations must be maintained at specified levels to prevent corrosion of the carbon steel tanks. Current tank farm specifications require that the hydroxide and nitrite ion concentrations be maintained at or above 0.01 g mol/L. The Savannah River results indicate that these concentrations may need to be higher for the wash solutions. Corrosion testing is currently being carried out by Pacific Northwest Laboratory (PNL), and a computer modeling of hydroxide depletion at the tank liquid surface is being performed by Westinghouse Hanford Company (WHC).

Process Development--Additional experimentation and computer modeling of caustic leaching of various tank waste is needed to better define the equilibrium conditions and the rate of dissolution of the leached species.

- Equipment Needs

- Interface-level detector: To determine the location of the settled solids to prevent the transfer of excess solids from the settling tank to the solids filtering equipment.
- TRU element monitor, corrosion, and passivation probe. For more information, see WHC-SD-WM-TA-138 (Kupfer 1994).
- Sludge sampler (25 L) (Parazin 1994).

APPENDIX C

EXPLANATION OF VITRIFICATION HOT PILOT-SCALE TESTING ISSUES

GENERIC VITRIFICATION HOT PILOT-SCALE PROCESS ISSUES

These issues are expected to be common to both the low-level waste (LLW) and high-level waste (HLW) glass melting processes.

1. Verify waste simulant performance (similitude of hot to cold process) (Kupfer 1994, May 1992, and Karnesky 1993)

The waste simulant performance data need to be verified on melter processing (e.g., rate, redox control, and foaming) using radioactive waste. The use of a waste simulant cannot really reproduce the actual waste crystal particle shape, hardness, size distributions, and reactivity of the radioactive waste.

Establish that the radioactive continuous melter system performs similar to the cold melter. The similitude of radioactive and nonradioactive vitrification operation at a small scale should be established to confirm small cold scaleup to full scale. Crucible melts using radioactive waste cannot establish similitude with continuous melting process.

These needs apply to the feed system to the melter, melter performance, product quality, and validation of property values predicted from empirical models. The amount and type of glass formers, slurry versus dry frit addition, and formulation boundaries may need to be proved during hot testing.

2. Waste feed uniformity (Randklev 1992)

The product waste form will have to be shown to meet disposal requirements with each different waste stream. There will probably be several waste streams in the feed for vitrification of LLW and HLW. The exact number and composition are unknown. It is the intent of the program to blend the waste to as uniform a composition as possible. However, plant equipment and schedule limitations will ensure significant feed variations.

Repository or State disposal requirements will probably demand a detailed waste-form qualification effort for each waste stream, as was done with the previous LLW form. Hot testing will have to be used to verify an acceptable product from each waste type before hot full-scale production. The hot test equipment could be expected to be used at least until the wastes were blended into a homogeneous feed. The need to identify and ensure an acceptable product from the incoming waste stream will undoubtedly decrease with time as the waste is blended and vitrification plant operating experience is obtained. The following subissues exist.

- The initial waste form physical and chemical property qualification tests require that the nominal product composition and reasonable expected variations be identified early on.

- The selection and development of several valid process control parameters are required to ensure that the vitrified product is compositionally within the determined operational band that will yield a quality product.
 - The radionuclide content of the product is required to be properly designated for disposal.
3. **Feedback control and equipment development for the vitrification melting process**

The *Chemical Engineers' Handbook* (Perry 1973) states the definition of control strategies:

Feedback control is when information about the controlled variable is fed back as the basis for control of a process variable. This feedback can be accomplished by a human operator (i.e., manual control) or by use of instruments (i.e., automatic control).

Feedforward control is when process disturbances are measured and compensated for without waiting for a change in the controlled variable to indicate that a disturbance has occurred. Feedforward control is useful where the final controlled variable cannot be measured... Many times a combination of feedback and feedforward control is used to produce a better product.

Product specifications generated from HLW or LLW disposal requirements will mean minimum requirements must be met for disposal. These product requirements will include product quality tests. Projected vitrification production rates require immediate feedback to the process to avoid offspec product. Real-time feedback control is necessary to meet these needs.

New instrumentation would have to be developed for a feedback process control approach to waste glass production. Such instrumentation would need to be tested to determine if it would be appropriate for the radioactive environment. The exact instrumentation needs are unknown. Equipment would have to be adopted for the remote microscopic examination of the hot product to check for bubbles, partially reacted (undissolved) batch, pieces of the melter wall bricks, and any other indicators of offspecification product.

In conjunction with feedback control, production will rely on batch weighing, product tank thermocouples, and radiation detectors to maintain the vitrification process within the operating control bands. This type of feedforward process control is what the commercial glass industry uses.

- a. Real-time process control feedback (minutes to hours)--If a process is to be controlled by product quality; immediate feedback is needed to make modifications in the process. Currently, instruments (other than visual) do not exist to do this in the glass industry. Equipment development would be necessary to establish these instruments.

- b. Longer time process control feedback (days)--Longer testing may be required to establish that the product does meet disposal requirements. This feedback could not be used for real-time process control.

4. Buildup of radioactive material in process (May 1992)

The fate of ^{129}I , ^{99}Tc , ^{106}Ru , ^{14}C , TRU, and ^{137}Cs and other radionuclides is needed to determine the feasibility, design, and operability of the process.

5. Hot offgas emissions (May 1992)

Emissions of specific radionuclides, such as ^{129}I , ^{99}Tc , ^{106}Ru , ^{14}C , TRU, and ^{137}Cs need to be quantified. Emissions of other nonradionuclides that might be changed because of the chemistry of the hot waste being different than anticipated. The design of radioactive gas scrubbing and cleaning equipment needs to be tested.

6. Final product form and shape

The form the product waste glass takes, such as annealed beebees, marbles, or golf balls. This may be limited by handling, packaging, disposal requirements, rework, or quality constraints. Resolution may require hot tests. This appears to be a secondary issue.

7. Destruction of organics in the melter/incinerator (Miller et al. 1991 and May 1992)

The Washington State Department of Ecology (Ecology) has noted that it expects to license the vitrification process as an incinerator under WAC 173-303. It is probable that a testing process needs to be completed to demonstrate that the process is capable of destroying or abating the organics to limit their release. Because complete quantification of organics in tanks has not been possible up to this time and organic destruction has not been demonstrated, it is a potential driver for a radioactive pilot plant.

8. Secondary waste stream accumulation and disposal

Secondary waste streams will require disposal, recycle, or reuse. Characterization of the waste streams are needed for determination of their ultimate fate. The radionuclide content of these streams will be a major segregation parameter. This appears to be a secondary issue for this program, but it also will affect other programs.

9. Development of product verification tests for onsite and offsite disposal requirements

Product verification testing will be performed to ensure acceptance of the waste product at the disposal facility. As requirements for acceptance at the HLW repository are not complete, it is not possible to establish the tests needed. The HLW repository requirements have been proposed as noted in WHC-EP-0522 (Randklev 1993) but have not been finalized. The Kincaid document (Kincaid et al. 1993) assumes a LLW waste form leach index of 6 (for a cement-based waste form) for onsite disposal.

Product tests will have to be developed to quantify the quality of the final radioactive product. Verification and validation of the new tests will require verification with radioactive vitrified product. The radioactive vitrified product has to be shown to meet disposal requirements or be recycled back to the melter (Orme 1994). Establishing and validating tests for the vitrified product are necessary as soon as possible for development of the vitrification system.

LOW-LEVEL WASTE VITRIFICATION ISSUES

1. **Final product quality to satisfy state and federal disposal requirements (Kincaid et al. 1993)**

In the Grout Part B permit document (WHC 1992), Ecology required hot product quality testing for the LLW form to establish that it met minimum product requirements. At least initially it was not acceptable to show that the plant operated within acceptable inlet parameters. The LLW vitrification product also will fall under this Ecology requirement.

Any mixed waste near-surface disposal site will require a minimum product quality for acceptance. An example is given in WHC-SD-WM-EE-004, Rev. 0, (Kincaid et al. 1993), which assumes a disposal product leach index of 6 for a cement-based waste form. A performance assessment (PA) is required for LLW disposal, as outlined in DOE Order 5820.2A (DOE 1988). This order also indicates that state and federal rules apply that cover groundwater contamination requirements, which means that Title 10, Code of Federal Regulations (CFR), Part 61 (NRC 1988), shall apply for LLW disposal. Title 10, CFR, Part 61, outlines additional disposal requirements.

HIGH-LEVEL WASTE VITRIFICATION ISSUES

1. **Plutonium or noble metals buildup in the vitrification facility (Herborn et al. 1993 and May 1992)**

The plutonium issue expressed in WHC-SD-HWV-PSAR-001 (Herborn et al. 1993) is "the potential for plutonium separation and accumulation in... the melter."

The HLW melter process could lead to plutonium precipitation, resulting in a criticality event. Herborn (Herborn et al. 1993) notes that separation of plutonium is not expected to occur, but the recommended method of establishing nonconcern is testing with actual waste solids. Separation of components does occur, as some types of joule-heated melters exhibit noble metal buildup and may tend to short circuit the melter.

This issue may require a hot test to establish that it is not a concern. It may be possible to conduct crucible tests to determine plutonium buildup. If crucible tests are not adequate, then this becomes a driver for a hot pilot plant.

2. Final product quality to satisfy state and federal disposal requirements (Randklev 1993)

Any disposal site will require a minimum product quality for acceptance. Hot testing is needed to establish that an acceptable product can be produced from the process with the actual hot waste feeds.

The NRC 10 CFR 60 applies to HLW disposal and requires that a PA be performed at the repository. It can be reasonably assumed that there will be waste form performance requirements associated with the repository PA. Product testing will be required to confirm that the waste form meets minimum requirements. There would be major program impacts if the vitrified product that was produced could not be disposed of because of its failure to meet the repository requirements. Therefore, hot testing is required early in the evaluation to establish that the process can make an acceptable product.

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APPENDIX D

**ENHANCED SLUDGE WASHING DECISION
EVALUATION OF ALTERNATIVES**

Table D-1. Enhanced Sludge Washing--Alternative A, Radioactive Laboratory Testing (Options 1, 2, 3, 4, 5, and 7).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	Minimizes work in radioactive laboratory and pilot; may cause exposure in full system to correct problems.	10	100.00
Minimize industrial safety risk.	7	One pilot to build; full-sized process may require field modifications.	8	56.00
Minimize impact to Tri-Party Agreement schedule.	3	Increased HLW and processing time if process failed.	9	27.00
Maximize operability and reliability.	8	Does not test process in actual tank situations; potential for equipment breakdowns is high.	6	48.00
Minimize design uncertainties.	7	Tests primarily on limited cold pilot-scale system; some radiation testing of equipment.	5	35.00
Maximize DOE and WHC order and requirement compliance.	2	Potential for field modifications and NCRs to full-sized process.	3	6.00
Maximize the amount of TRU and problem melter components removed from the HLW.	6	No process testing in field with waste; unknown if it will work on others.	3	18.00
Total Alternative				290.00

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

HLW = high-level waste.

NCR = nonconformance report.

TRU = transuranic.

WHC = Westinghouse Hanford Company.

Table D-2. Enhanced Sludge Washing--Alternative B, Testing in Existing Double-Shell Waste Tanks (Options 1, 2, 3, 4, 5, 7, and 8 or Alternative A Plus Testing in Existing Double-Shell Tanks).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	Some additional exposure with sample analysis at the laboratories and plant.	8	80.00
Minimize industrial safety risk.	7	More heavy equipment installation at DST.	8	56.00
Minimize impact to Tri-Party Agreement schedule.	3	Should not impact.	9	27.00
Maximize operability and reliability.	8	Test equipment in radiation areas; full testing with noncritical areas.	8	64.00
Minimize design uncertainties.	7	Equipment failure caught early; process failure possibility exists.	7	49.00
Maximize DOE and WHC order and requirement compliance.	2	May require some exemptions in setting up the equipment and tests; more likely to comply with full sized system.	5	10.00
Maximize the amount of TRU and problem melter components removed from the HLW.	6	Process proved for limited type of wastes.	7	42.00
Total Alternative				328.00

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

DST = double-shell tank.

HLW = high-level waste.

TRU = transuranic.

WHC = Westinghouse Hanford Company.

Table D-3. Enhanced Sludge Washing--Alternative C, Bench-Scale Radioactive Pilot Plant (Alternative B, Plus a Bench-Scale Radioactive Pilot Plant [Option 10] on Each Major Type of Waste).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted Score
Minimize worker exposure (ALARA).	10	Increased exposure from samples and D&D.	8	80.00
Minimize industrial safety risk.	7	One more pilot to set up.	7	49.00
Minimize impact to Tri-Party Agreement schedule.	3	Hot cell space limited; waste transport concern to set up.	5	15.00
Maximize operability and reliability.	8	Increases reliability of process.	8	64.00
Minimize design uncertainties.	7	Increases design parameters from further testing.	8	56.00
Maximize DOE and WHC order and requirement compliance.	2	Some exemptions may be required for hot pilot; more likely to meet full plant compliance requirements.	6	12.00
Maximize the amount of TRU and problem melter components removed from the HLW.	6	Increases assurance that the process will work as designed.	9	54.00
Total Alternative				330.00

ALARA = as low as reasonably achievable.

D&D = decontamination and decommissioning.

DOE = U.S. Department of Energy.

HLW = high-level waste.

TRU = transuranic.

WHC = Westinghouse Hanford Company.

Table D-4. Enhanced Sludge Washing--Alternative D, Large Radioactive Pilot Plant (Alternative C) Plus a Larger-Scale Radioactive Pilot Plant (Option 12) on Selected Problem (or Critical) Waste Types.

Needs	Weight (0-10)	Information	Score (0-10)	Weighted Score
Minimize worker exposure (ALARA).	10	Significant increase in exposure possible from samples and D&D activities.	5	50.00
Minimize industrial safety risk.	7		6	42.00
Minimize impact to Tri-Party Agreement schedule.	3	Significant impacts possible.	2	6.00
Maximize operability and reliability.	8		10	80.00
Minimize design uncertainties.	7		10	70.00
Maximize DOE and WHC order and requirement compliance.	2	May require significant continued exemptions to orders. May not be possible to permit (Ecology).	2	4.00
Maximize the amount of TRU and problem melter components removed from the HLW.	6		10	60.00
Total Alternative				312.00

ALARA = as low as reasonably achievable.

D&D = decontamination and decommissioning.

DOE = U.S. Department of Energy.

HLW = high-level waste.

TRU = transuranic.

WHC = Westinghouse Hanford Company.

Table D-5. Low-Level Waste Vitrification Decision Evaluation of Alternatives (Alternative A, Cold Pilot Plant [Options 1, 2, 3, 4, 6, and 7]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	Minimal hot laboratory and pilot work.	10	100
Minimize industrial safety risk.	7	Skips hot pilot; full size could require changes.	9	63
Minimize Tri-Party Agreement delays.	3	It pushes "full steam ahead."	8	24
Minimize design uncertainties.	10	There is a risk in direct upscaling an unproven device.	1	10
Maximize compliance with DOE and WHC requirements.	3	Only moderate chance of initial compliance.	5	15
Maximize reliability (fewest interruptions and replacements).	8	Direct full scaling of an unproven device is risky.	1	8
Total weighted score				220

NOTE: Cost has not been factored into any of these alternative evaluations. Detailed relative costs are not known at this time.

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-6. Low-Level Waste Vitrification Decision Evaluation
of Alternatives (Alternative B, Hot Bench Scale
[Options 1, 2, 3, 4, 6, 7, and 10]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	More hot work and on a larger scale.	7	70
Minimize industrial safety risk.	7	More larger-scale work.	7	49
Minimize Tri-Party Agreement delays.	3	Use bench-scale device to obtain some process information.	6	18
Minimize design uncertainties.	10	Some risk in using bench scale to obtain process information.	5	50
Maximize compliance with DOE and WHC requirements.	3	Increased work increases chances of complying.	7	21
Maximize reliability (fewest interruptions and replacements).	8	More knowledge should yield a more reliable process.	5	40
Total weighted score				248

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-7. Low-Level Waste Vitrification Decision Evaluation of Alternatives (Alternative C; Hot, Small Pilot [Options 1, 2, 3, 4, 6, 7, and 11]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	This does even more hot work.	5	50
Minimize industrial safety risk.	7	More larger-scale work.	5	35
Minimize Tri-Party Agreement delays.	3	More larger-scale hot work can only mean more delays.	4	12
Minimize design uncertainties.	10	Less risk because of use of larger scale.	7	70
Maximize compliance with DOE and WHC requirements.	3	Better chance of complying at the larger scale.	8	24
Maximize reliability (fewest interruptions and replacements).	8	More hot process information can only lead to greater reliability.	7	56
Total weighted score				247

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-8. Low-Level Waste Vitrification Decision Evaluation of Alternatives (Alternative D; Hot, Large Pilot [Options 1, 2, 3, 4, 6, 7, and 12]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	This does the most hot work and on the largest scale.	3	30
Minimize industrial safety risk.	7	More larger-scale work.	3	27
Minimize Tri-Party Agreement delays.	3	Most work means greater chance of more delays.	2	6
Minimize design uncertainties.	10	Largest scale reduces scaleup uncertainties.	9	90
Maximize compliance with DOE and WHC requirements.	3	Greatest chance of compliance. Cannot be treated as Treatability Study (Ecology)--too much waste processed.	9	27
Maximize reliability (fewest interruptions and replacements).	8	More hot work at near full scale with the melter does not gain much; final scaleup is not that large.	8	56
Total weighted score				236

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-9. High-Level Waste Vitrification Decision Evaluation of Alternatives (Alternative A; Cold, Full Scale with Hot Laboratory [Options 1, 2, 3, 4, 6, and 7]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	Minimal hot laboratory and pilot work.	10	100
Minimize industrial safety risk.	7	Skips stages.	9	63
Minimize Tri-Party Agreement delays.	3	It pushes "full steam ahead."	8	24
Minimize design uncertainties.	10	There is a risk in direct upscaling equipment not proven in the environment with real waste.	1	10
Maximize compliance with DOE and WHC requirements.	3	Only moderate chance of initial compliance.	5	15
Maximize reliability (fewest interruptions and replacements).	8	Direct upscaling of an unproven device is risky.	1	8
Total weighted score				220

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-10. High-Level Waste Vitrification Decision
Evaluation of Alternatives (Alternative B, Hot Bench Scale
[Options 1, 2, 3, 4, 7, and 10]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	More hot work and on a larger scale.	7	70
Minimize industrial safety risk.	7	More larger-scale work.	7	49
Minimize Tri-Party Agreement delays.	3	Use bench scale.	6	18
Minimize design uncertainties.	10	Significant risk in using hot bench scale to obtain process information.	5	50
Maximize compliance with DOE and WHC requirements.	3	Increased work increases chances of complying.	7	21
Maximize reliability (fewest interruptions and replacements).	8	More knowledge should yield a more reliable process.	5	40
Total weighted score				248

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

WHC = Westinghouse Hanford Company.

Table D-11. High-Level Waste Vitrification Decision
Evaluation of Alternatives (Alternative C; Hot, Small
Pilot [Options 1, 2, 3, 4, 6, 7, and 11]).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted score
Minimize worker exposure (ALARA).	10	This does even more hot work.	5	50
Minimize industrial safety risk.	7	More larger-scale work.	5	35
Minimize Tri-Party Agreement delays.	3	More larger-scale hot work can only mean more delays.	4	12
Minimize design uncertainties.	10	Less risk because of larger scale used.	7	70
Maximize compliance with DOE and WHC requirements.	3	Better chance of complying at the larger scale. May have Ecology permitting concerns.	8	24
Maximize reliability (fewest interruptions and replacements).	8	More hot process information can only lead to greater reliability.	7	56
Total weighted score				247

ALARA = as low as reasonably achievable

DOE = U.S. Department of Energy

WHC = Westinghouse Hanford Company.

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APPENDIX E

EQUIPMENT TESTING AND TEST REQUIREMENTS

This appendix outlines and describes equipment and equipment test requirements for radioactive pilot plant investigations. The most information exists on the proposed radioactive tests for the transuranic (TRU) monitor, the interface level detector (thermal dispersion probes), and the corrosion potential monitor.

Each of the three instrument systems has passed a series of cold laboratory evaluations establishing proof of principle. Final acceptance of these new control feature instruments requires that the testing be done at near full-scale, hot pilot conditions¹. Neutralized current acid waste (NCAW) has been the targeted waste, although the performance of this or similar equipment with other wastes would be beneficial.

The needs for process control as provided by the three instrument systems are discussed. Regarding the TRU Monitor, a method is required to ensure that the low-level waste (LLW) process streams destined for the proposed LLW Vitrification Plant are below the TRU limit. This will be 100 nCi/g or less, which translates to as low as 10 nCi/g TRU in the LLW headed to the LLW Vitrification feed tanks. For level detection, instrumentation is required to detect the liquid/sludge interface in the settling NCAW slurry to avoid sending excess solids (including TRU) to the polish filter.

Finally, for the corrosion monitor, a method is required to ensure that the washed solids destined to feed tanks for the High-Level Waste (HLW) Vitrification Plant meet, but do not significantly exceed, the tank corrosion limits.

Storage and feed capabilities are required, as well as view windows, to observe the clear-glass, level detection tank during testing. The design for the equipment to be tested is almost complete².

These instruments are crucial to the success of the LLW Vitrification Plant. The normal sampling and laboratory analysis cycle takes a minimum of 16 to 24 hours. This would interfere with throughput rates for sludge washing and solids filtering. These delays also could subject the ion exchange bed to prolonged TRU contamination and exposure while awaiting test results. Remote sampling procedures, the two-phase nature of the waste, and limitations on sample size to about 1 mL (unrepresentative of a large batch size) present further sampling problems. Therefore, sampling and analysis alone is not an adequate and timely process control method.

¹Flesher, D. J., 1991, *WESF Test Proposal: NCAW Process Control Pilot Tests*, WHC-SD-WM-TI-398, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

²Campbell, R. D., 1993, *TRU Monitor Pilot Plant, WESF Status*, (Letter NM-W-93-1815 to B. C. Landeene, August 26), Kaiser Engineers Hanford, Richland, Washington.

The online TRU monitor was developed to achieve a real-time measurement (i.e., minimum of 15 minutes) of the TRU content in the LLW. The monitor is backed up for a calibration and accuracy verification with the Delayed Neutron Analysis Activation System (DNAAS) in the laboratory, which has an 8 to 12 hour turnaround time³. During the Waste Encapsulation and Storage Facility (WESF) hot tests, samples will be taken and sent to the WHC 222-S Analytical Laboratory for analysis by the DNAAS. This will support development of the TRU monitor and the DNAAS itself.

The corrosion monitor is crucial to the success of the LLW and HLW Vitrification Plants. It will help to minimize the amount of sodium hydroxide for neutralizing LLW and HLW and subsequent glass production.

Nonmelter Pilot Plant Equipment and Facility Requirements--Separate settling, mix, and storage tanks are required for equipment testing. A large range of cold-to-hot levels of radioactive slurries are required to fully test the equipment, especially the TRU monitor. Finally, the liquid levels need to be observed visually in the settling tank for sludge-level measurement.

The TRU monitor has a 70-gal capacity and can tolerate a gamma radiation field internally and externally of about 3 Ci/L. The TRU monitor recirculation/transfer pump will operate within a range of 25 to 75 g/m. The neutron count signal from the TRU monitor will be sent to a computer along with a flow measurement to integrate the data to determine the TRU level.

As an example, most of the equipment could be located in Cell C of WESF. Three tanks will be required in the hot pilot test facility. Included will be a 235-gal storage/mix tank (100 in. high by 32 in. in diameter), a 38-gal glass settling tank, and a 15-gal head tank. The waste simulant needed would be about 200 gal of 20 vol% solids. Actual NCAW (about 1,500 gal of 20 vol% solids) could be stored in one portion of a baffled tank (e.g., Tank 39-5 in Cell 39 of B Plant) and be made available for transfer into the hot pilot test facility located in adjacent WESF.

The utilities needed for the facility will be deionized water, 440 V and 110 V electrical power, nitric acid for internal cleaning of the TRU monitor, and possibly low-pressure steam. Remote (manipulator) handling will be required, as well as remote crane operation, for equipment movement and remote operation of power tools.

Equipment to Monitor the Vitrification Product--The following are examples of potential equipment development needs for the monitoring of the vitrified product. Some or all of this equipment may need to undergo development for product-quality testing. This preliminary list is an example of the final monitors to be used. However, it would probably be necessary to environmentally test any of this type of equipment before installing it in a thermally hot, radioactive environment.

³Flesher, D. J., 1991, *WESF Test Proposal: NCAW Process Control Pilot Tests*, WHC-SD-WM-RPT-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

- Remote microscopic examination of vitrified samples for incompletely reacted batch materials, pieces of the glass melter wall brick, or gas bubbles.
- Remote scanning electron microscope (SEM) examination of vitrified samples for incompletely reacted batch materials.
- Remote density determination of known quench history vitrified samples to monitor glass product consistency and quality (may be existing).
- Remote refractive index measurements of known quench history of vitrified samples to monitor glass product consistency and quality.
- Remote X-ray examination to determine the percentage of crystallinity, hence, the degree of the amorphous character of the product.
- Remote X-ray fluorescence for vitrified product compositional consistency includes the following activities:
 - Crushing of glass samples
 - Leaching of the crushed samples
 - Electrochemical or inductively coupled plasma (ICP) analysis of leachate for the radioactive elements being immobilized.
- Remote viscosity of vitrified product as follows:
 - Equipment to draw fibers from a melted product sample
 - Elongation of the fibers in a small calibrated furnace to determine: (1) T_g (glass transformation temperature), (2) annealing temperature, (3) softening temperature, and (4) flow temperature.

Vitrification Pilot Plant Equipment Testing and Facility Requirements--The product quality and process control equipment that is needed for a pilot plant would take up a minimum amount of space. The melter pilot should have the capability of testing up to three product-quality instruments at a time. These instruments would be established in the cullet quench area. Because the actual instrumentation to be tested is not established at this time a best estimate of the size and type of utilities will be made. This estimate is rough order of magnitude (ROM) only.

Each instrument is assumed to take about 2 ft³ of floor space. Radiation shielding probably will be needed to protect the instrumentation when it is not operating; so weight is a consideration. Electrical connection of 110 V and low voltage (mv) control cable will be required. Space and equipment to remotely install and remove a instrumentation package of at least 1 ft x 2 ft x 5 ft will be needed. Cooling water of about 1 gal/min may be required. A decontamination facility for the instrumentation would be appropriate.

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APPENDIX F

VITRIFICATION EQUIPMENT TESTING DECISION MATRIX

Table F-1. Alternative A, Cold Pilot Plant Testing with Irradiation Testing (Options 1 through 7).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted Score
Minimize worker exposure (ALARA).	10	Minimizes work in radioactive laboratory and pilot; may cause exposure in full system to correct problems.	9	90.00
Minimize industrial safety risk.	7	One pilot to build; full-sized process may require field modifications.	8	56.00
Minimize impact to Tri-Party Agreement schedule.	3	Minimum equipment; increased HLW volume and processing time if process failed.	9	27.00
Maximize operability and reliability.	8	Does not test process in actual conditions; potential for equipment breakdowns (moderate to high).	2	16.00
Minimize design uncertainties.	7	Tests primarily on limited cold pilot-scale system; some radiation testing of equipment.	3	21.00
Maximize DOE and WHC order and requirement compliance.	2	Potential for significant hot modifications and NCRs to full-sized process.	3	6.00
Total				216.00

ALARA = as low as reasonably achievable
 DOE = U.S. Department of Energy.
 HLW = high-level waste.
 NCR = Nonconformance report.
 WHC = Westinghouse Hanford Company.

Table F-2. Alternative B, Functional Hot Pilot Plant
(nonmelter pilot) (Options 1 through 7 and 12).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted Score
Minimize worker exposure (ALARA).	10	Increased work in radioactive laboratory and pilot; may cause exposure in full system to correct problems.	8	80.00
Minimize industrial safety risk.	7	One pilot to build; functional pilot assumed needed (small impact). Full-sized process may require field modifications.	7	49.00
Minimize impact to Tri-Party Agreement schedule.	3	Minimum equipment; increased HLW volume and processing time if process failed.	8	24.00
Maximize operability and reliability.	8	Does not test process in actual conditions; potential for equipment breakdowns (moderate).	4	32.00
Minimize design uncertainties.	7	Tests primarily on limited cold pilot-scale system; some radiation testing of equipment.	4	28.00
Maximize DOE and WHC order and requirement compliance.	2	Generally requirement met; potential for unanticipated hot modifications and NCRs to full-sized process.	7	14.00
Total				227.00

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

HLW = high-level waste.

NCR = Nonconformance Report.

WHC = Westinghouse Hanford Company.

Table F-3. Alternative C, A Small Radioactive Vitrification Pilot Plant with Product Testing Capability (Options 1 Through 7 and Either Option 9 or 10).

Needs	Weight (0-10)	Information	Score (0-10)	Weighted Score
Minimize worker exposure (ALARA).	10	Doubles dose in radioactive laboratory and pilot; limits exposure in full systems.	5	50.00
Minimize industrial safety risk.	7	Two pilots to build (cold and hot); full-sized process may not require field modifications.	5	35.00
Minimize impact to Tri-Party Agreement (TPA) schedule.	3	Minor impact to TPA if equipment testing is added to hot pilot; significant impact if it causes hot pilot to be built--Process failure unlikely.	5	15.00
Maximize operability and reliability.	8	Tests equipment in actual conditions; potential for equipment breakdown (low).	9	72.00
Minimize design uncertainties.	7	Proves design in actual conditions; minimum design corrections in full-scale system.	9	63.00
Maximize DOE and WHC order and requirement compliance.	2	Requirement usually met; Potential for temporary exemptions for pilot testing; low probability of exemptions during full process.	8	16.00
Total				251.00

ALARA = as low as reasonably achievable.

DOE = U.S. Department of Energy.

HLW = high-level waste.

NCR = Nonconformance Report.

WHC = Westinghouse Hanford Company.

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APPENDIX G

EXPLANATION OF OPTIONS

1. Literature search is self explanatory.
2. Cold laboratory testing includes investigations involving waste simulant and laboratory-scale nonradioactive testing. Mixing in beakers and crucible melting of simulants are examples.
3. Computer modeling includes simulation of the process using scientific principles and testing results to predict how well the process will work.
4. Small, cold pilot plant is a unit in the 1/3-to 1/1,000-ratio range that uses waste simulant and scale equipment to simulate the process.
5. Testing in Pacific Northwest Laboratory (PNL) gamma irradiation facility. This facility uses high gamma radiation dose rate sources (^{60}Co) located in a water pool for shielding. The maximum sized access tube located in the pool is 6 in. in diameter.
6. Large cold pilot plant is a 1/3- to full-scale unit that uses essentially all the equipment and controls of the full-sized hot unit.
7. Radioactive laboratory testing includes real radioactive waste used in laboratory equipment to make products and establish basic processes.
8. Testing in existing double-shell waste tanks includes either inserting equipment into the tank or pumping waste solution up to the equipment to test equipment or process.
9. "Functional" hot pilot plant tests only critical portions of the process, not the entire process. It may be set up for one or several specific testing tasks. This document assumes it makes use of radioactive waste. The plant is normally limited in its scope and much smaller and less expensive than a full-sized unit.
10. Bench-scale radioactive pilot plant is a limited pilot unit that may use some scaled process equipment to establish certain critical parameters. It uses radioactive feed to the pilot plant. Not all of the equipment is scaled down from that which will be used in the process. Usually, this would fit in a small hot cell or a hood. Some melting systems may not be able to be scaled down to this size.
11. Small radioactive pilot plant uses a majority of the scaled-down process equipment used in a full-sized plant. Radioactive waste is used as a feed. A small pilot plant is usually 1/3 to 1/100 scale of the full-sized unit.
12. Large radioactive pilot plant can be 1/3- to full-scale and uses radioactive waste as the feed. The equipment is normally the same type envisioned for the full-scale unit (with modifications to make it more flexible than the full unit).

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APPENDIX H

REQUIREMENTS FOR VITRIFICATION SPACE AND UTILITIES

Unless noted otherwise, the following utility and space requirements are the authors best estimates for a worst-case 15-ton/day combustion-fired melter.

The fossil-fuel-fired cyclonic melter (FFFCM) was used as the worst case for both low-level waste (LLW) and high-level waste (HLW) vitrification hot cell space analysis. This melter represents a worst-case scenario for the hot pilot plant evaluation because of the large size (5 ton/day) of the smallest pilot plant unit. Other melters, such as the Joule-heated variety, can be scaled down to much smaller sized units for bench scale and small pilot plant (Kupfer 1994).

The FFFCM would vitrify relatively large amounts of waste and would not fall inside the 1,000-kg limit allowed on waste treatability study feed required by WAC 173-303-071. This would allow significantly reduced permitting requirements.

The requirements given below will change somewhat as more is understood about the process and how the process is controlled.

Typical power consumption and utilities listed below are from a Vortec Corporation letter, dated March 22, 1994:

Natural gas.....	4 million Btu/hour
City water.....	20 gal/min
Cooling water.....	100 gal/min
480 V.....	40 kW
280 V.....	20 kW
100 psi compressed air.....	25 scfm

Decontamination equipment will be required, including acid solutions, and sodium hydroxide and sodium nitrate solutions in the 100 to 1,000 gal recirculating volume. Remote operation of equipment will require a minimum 20-ton-capacity crane and two pairs of 50-lb-capacity remote manipulators; at least two shielded windows to the process, one to observe the melter and one to observe the offgas system. Several radiation-resistant cameras also will be required. Laboratory facilities will be required, either at the pilot facility or nearby, to facilitate chemical analysis of waste, radionuclides, and quality control of the product. A computerized data collection and control system will be required as well.

FACILITY SIZE

An example of a large pilot facility is the Vortec Corporation sketch B-EGT110892 (Figure H-1), which gives the layout study of a 20- to 30-ton/day unit. This sketch gives overall room dimensions of 60 ft by 26 ft by 45 ft high. The unit includes glass canister transfer equipment and the basic melter. It does not include offgas equipment. It also does not show solids or waste input equipment or heat recuperators.

During telephone discussions with Vortec Corporation president, J. G. Hnat, on March 21, 1994, he noted that the 15-ton/day pilot unit normally has a 20 ft by 30 ft floor space requirement, with a 15 ft by 30 ft potential floor space requirement.

The smallest area that could fit a 5- to 10-ton/day unit probably would be 6 ft by 8 ft, but this would leave little room for equipment modifications and no room for full-sized glass canisters or heat recuperators. The height of the unit is normally 25 to 30 ft, which leaves little excess room for equipment movement. More overhead and floor space would be very desirable.

The Vortec Corporation has not operated a 5- to 10-ton/day pilot unit, so all the small-sized unit volume estimates are tentative. It is strongly recommended that further study be undertaken to better determine this information. Scaledown to 5 ton/day is not necessarily a linear extrapolation from the above-mentioned information, and combustion process scaleup and -down is not well understood in many cases.

Other utility requirements are best estimates by the authors. They are rough order of magnitude only and should be confirmed with more investigation. The following estimates are based on NCAW from aging waste tanks, and a 5-ton/day feed to the melter; total operation time would be about 5 days on hot waste and 5 days on waste simulant:

- Air conditioning (4 million Btu/hour)
- Unloading/transfer facilities for 50,000 gal of radioactive waste, consisting of 30,000 gal of settled sludge
- Two decant/feed tanks with mixing capacity for 50,000 gal of waste
- Two holding/feed tanks with mixing capacity for 50,000 gal of simulant.

The four tanks should have chemical addition capacity, primarily sodium hydroxide and water for the waste tanks. A full range of chemical addition is needed for the waste simulant tanks, sodium nitrate, sodium nitrite, and sodium hydroxide are the main ones. About 20 different chemicals are needed to make up the more than 50,000 gal of waste simulant.

The authors estimate that the melter might be operated at about 20% of capacity to reduce hot waste requirements. If this can be accomplished, it would reduce the above hot waste requirements accordingly.

Figure H-1. Vortec Corporation Sketch EGT110892.

OFFGAS SYSTEM

The offgas system will probably take at least as much space as the melter equipment. Generally, the radiation shielding requirements will be less than that of the melter. The following offgas scrubbing equipment will need to be included in the scrubbing train (listed in the order in which it occurs downstream from the melter):

1. Quench tower (i.e., water chiller and recycle loop, including a mixing tank and transfer system for solids handling)
2. Venturi scrubber with water wash (from quench water)
3. Solids separator and closed-loop heat exchanger (i.e., chiller)
4. Metal high-efficiency particulate air (HEPA) filter bank with filter wash
5. Blower (fan)
6. Heater (400 °C) and SO₂ absorber (copper oxide bed)
7. Heater (500 °C) and NO_x Catalytic reactor
8. Chiller and HEPA filter
9. Offgas sampler and release point.

Items 1 through 3 need to be in a highly shielded containment area. The quench tower may have to be as close to the melter as possible to simulate (scaleup) particulate drop out from the full-sized melter. Item 4 could be in a restricted (contaminated) area with personnel access. Items 5 through 9 could be in a radiation area. No appreciable dose should be apparent in the limited run time available.

VORTEL CORPORATION
LAYOUT STUDY
DOE HWVP FACILITY
20 TO 30 TON PER DAY UNIT
DRWN: E.G. TAKACH 11-30-92
SCALE: 1/8" = 1'-0"

SHEET NO. 8-EGT110B92

ELEVATION A-A

NOTE: RESERVOIR CAPACITY = 1 HOUR OF GLASS PRODUCTION.

* FLUE LENGTH TO BE DETERMINED BY BUILDING ARRANGEMENT

**COMMERCIAL 15 TON/DAY CMS
SEPARATOR - RESERVOIR OUTLINE**

SKETCH No. B-EGT033192

03/23/02

A	B	C	D	E	F	G	H	I	J	K	L	Weight
14' 9"	15' 0"	-	40"	46"	-	24"	28"	8"	10"	-	24"	3250 lbs

Radiation Recuperator - Parallel Flow

OUTLINE DRAWING - BELTRAN ASSOC. INC.
WET ELECTROSTATIC PRECIPITATOR MPL.BTP-6X6

SKETCH NO. B-ELT120791

PETC III
LAYOUT STUDY OF WET
ELECTROSTATIC PRECIPITATOR
DRAWN: E.G.TAKACH 12.11.91
SCALE: 1/4" = 1'-0"

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