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Sludge Treatment Alternatives Analysis

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Abstract: This sludge treatment alternative analysis (STAA) evaluates alternatives for the treatment and disposition of sludge from the K East and K West Basins. The sludge must be removed from the basins as part of an interim remedial action conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The results of this STAA will be incorporated into a focused feasibility study prepared to support the CERCLA process and will be used to support selection of an appropriate treatment and disposition pathway for the sludge.

The analysis focused on the evaluation of six alternatives; baseline chemical process, modified chemical process, grinding/milling process, direct vitrification, calcination, and grouting. The alternatives were evaluated against a set of criteria and ranked according to composite scores. The results of the analysis reflect the scope of the analysis and the conditions currently imposed on the sludge disposition activities.

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SLUDGE TREATMENT ALTERNATIVES ANALYSIS

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April, 1999

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EXECUTIVE SUMMARY

This sludge treatment alternative analysis (STAA) evaluates alternatives for the treatment and disposition of sludge from the K East (KE) and K West (KW) Basins. The sludge must be removed from the basins as part of an interim remedial action conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The results of this STAA will be incorporated into a focused feasibility study prepared to support the CERCLA process and will be used to support selection of an appropriate treatment and disposition pathway for the sludge.

The sludge is highly radioactive because it derives in part from the degradation of spent nuclear fuel (SNF). Because of this, early evaluations of sludge disposition concluded that the sludge could best be managed by storing it with other highly radioactive wastes in the Hanford double-shell tanks (DST) and managing it under the Tank Waste Remediation System (TWRS). When sludge characterization data became available, it was determined that the sludge would require substantial treatment prior to being added to a DST to address concerns regarding criticality control, reactive metals, flammable gas, and polychlorinated biphenyls (PCBs). A chemical treatment process was developed that would ensure that the treated sludge would meet DST criteria. This chemical treatment process became the baseline for the SNF Project.

As the chemical treatment system has been developed more fully, it has become clear that the baseline treatment process will be more complex and more costly than originally scoped. These changes are significant enough to warrant a reevaluation of whether the baseline process should remain the preferred treatment and disposition option. Additionally, during Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) negotiations, the Department of Energy, Richland Operations Office, (RL) committed to a reevaluation of treatment and disposition options for the K Basins sludge to determine if the baseline process is still preferred given the complexity and cost. This alternatives study is part of the deliverable for this commitment.

Certain features of the SNF Program and the sludge constrain sludge management and disposal, regardless of the technology used. These constraining features were critical in developing viable alternatives and include the following:

- The sludge must be removed from the basins beginning no later than July 2004 and ending no later than August 2005 to meet milestones established in the Tri-Party Agreement. This study assumed that removal of sludge from the basins and treatment occurs within this 13-month window.

- The sludge contains a significant quantity of uranium and plutonium, so treatment must assure nuclear criticality safety.

- The sludge will be designated as either a TRU waste or a HLW. A final determination has not been made. Sludge or fractions thereof designated as TRU waste or HLW cannot be disposed at the Hanford Site, but rather must be disposed at the WIPP or at the national geologic repository, respectively.

- The sludge contains reactive and potentially pyrophoric and corrosive metals and metal hydrides, primarily uranium and a zirconium alloy. Treatment must address reactivity, pyrophoricity, and potential for corrosivity.

- The sludge generates hydrogen gas. The generation, accumulation, and release of hydrogen gas must be controlled.

- It is assumed that the sludge contains TCLP metals at concentrations that cause the sludge to be designated as a mixed waste, thus the sludge must be managed in accordance with the state Dangerous Waste Regulations.

- The sludge is designated as a PCB remediation waste and is regulated under TSCA. Neither TWRS nor the national geologic repository can accept TSCA-regulated waste. A risk-based approach that requires PCB treatment is used to exit TSCA regulation.

- The sludge removed from the basins will not be homogenous. Sludge characteristics vary depending on source (e.g., floor sludge is significantly different from canister sludge) and a treatment system or systems must be sufficiently robust to handle the range of characteristics in different feed streams.

A value engineering workshop attended by Hanford program representatives, DOE-RL, and the Environmental Protection Agency (EPA) was conducted to identify potential treatment and disposition options and issues, including options other than DST storage and TWRS management. Options identified in the workshop formed the starting point for identifying alternatives evaluated in the STAA.

The alternatives evaluation initially focused on the segregation strategy defined at the alternatives selection meeting. The segregation strategy was based on utilizing different disposition paths for the low-activity streams (i.e., low TRU streams consisting of floor and pit sludge) and the high-activity streams (high TRU streams consisting of canister and fuel wash sludge). The key disposition option identified for the low-activity streams was precluded due to the requirement for excessive dilution to produce a non-TRU waste form suitable for ERDF disposal. Additionally, the complexity of the sludge eliminated the "one-step process" located within the Basins option for the high-activity streams. Therefore, the treatment selections were adapted to a process robust enough to deal with the full spectrum of the feed stream envelopes.

Six sludge disposition options, including the baseline chemical process, for the K Basins sludge were evaluated. These six alternatives involve size segregation and/or size reduction process

steps to meet treatment, storage, or disposal criteria. Apart from the baseline chemical and grinding/milling options, the other alternatives involve segregation of the sludge in the basin prior to treatment for the separate processing and disposition of the organic ion exchange resin (OIER) beads, materials less than 250 μm (feed type A) and materials greater than 250 μm (feed type B). The OIER are delivered as a segregated batch for grouting in the facility. In the baseline chemical option, comparable segregation of the OIER occurs at the treatment facility as the first step in the process and is then combined with the insoluble solids for eventual grouting. The alternatives assume the OIER and insoluble solids would be treated to meet the disposal criteria at the ERDF. If, however, the ERDF criteria cannot be met, the grouted waste would be disposed at the WIPP or another offsite disposal facility as appropriate for the waste designation. No segregation steps prior to treatment are required for the grinding/milling alternative. The six alternatives considered are:

Baseline chemical: The Baseline Chemical Alternative would treat the sludge by separation of the OIER prior to dissolution, dissolving the fuel constituents in nitric acid, separating the insoluble material, adding neutron absorbers for criticality safety, reacting the solution with caustic to co-precipitate the uranium and plutonium, and neutralize the solution. PCB treatment would be achieved by a combination of volatilization and separation of undissolved solids. The undissolved solids and the ion exchange media would be treated to reduce the transuranic (TRU) and ^{137}Cs content, stabilized in a grout matrix, and transferred to the Environmental Restoration Disposal Facility (ERDF) for disposal. The treated slurry would be transferred to a DST for eventual processing with other Hanford tank waste at the planned vitrification facility. The LAW and HLW produced would then be disposed in Land Disposal facilities and at the geologic repository, respectively.

Modified Chemical: The Modified Chemical Alternative would treat the sludge by grouting the OIER, dissolving the sludge (feed types A and B) in nitric acid, separating the undissolved solids and grouting, adding neutron absorbers for criticality safety, reacting the solution with caustic to co-precipitate the uranium and plutonium, and neutralize the solution. PCB treatment would be achieved by a combination of volatilization and separation of undissolved solids. Compared to the baseline process, use of polishing filters and leaching of resins/undissolved solids were eliminated. Elimination of the leaching step simplifies the process but produces a larger volume of secondary waste. The treated slurry would be transferred to a DST for eventual processing with other Hanford tank waste at the planned vitrification facility. The LAW and HLW produced would then be disposed in Land Disposal facilities and at the geologic repository, respectively. The solidified OIER and undissolved solids are disposed of at the ERDF.

Grinding/milling: The Grinding/Milling Alternative would treat the sludge by reducing the sludge particle size through fracturing/mechanical abrasion and accompanying oxidation reactions of any metallic uranium in water. Treatment would include, grinding the sludge (including OIER) to oxidize metallic uranium and reduce particle size, recycle or separate oversize material, adding neutron absorbers and chemical adjustment of the slurry. The oversize material and OIER would be solidified and disposed of at the ERDF. PCB treatment would be

achieved primarily by adsorption of the PCBs onto the polyurethane liner of the grinder. The treated slurry would be transferred to a DST for eventual processing with other Hanford tank waste at the planned vitrification facility. The LAW and HLW produced would then be disposed in Land Disposal facilities and at the geologic repository, respectively.

Direct Vitrification: The Direct Vitrification Alternative would treat the sludge by grouting the OIER, delivering type A feed directly to a melter feed tank, dissolving type B feed in nitric acid, removing undissolved material for grouting, feeding dissolver solution to a melter feed tank, sugar denitration of the acidic solution, and glass former additions. Glass would be poured directly into 3m high stainless steel canisters of the type used by DWPF. The remote-handled glass canisters would be placed in modular storage units for interim storage at the CWC and ultimately disposed in the geologic repository. Oversize material separated from the dissolver solution would be washed with nitric acid, rinsed and then grouted into drums for disposal at the ERDF. PCBs would be volatilized or destroyed during treatment. This option was evaluated assuming a borosilicate waste glass formulation melted in a low-temperature joule-heated inconel electrode refractory lined melter. However, an evaluation of various melter technologies would be required to select the most appropriate technology for the application.

Calcination: The Calcination Alternative would treat the sludge by grouting the OIER, delivering type A feed directly to a calciner feed tank, dissolving type B feed in nitric acid, removing undissolved material for grouting, feeding the dissolver solution to the calciner feed tank. PCBs would be volatilized or destroyed during treatment. The calciner would be a continuous rotary calciner. The calcine material would be packaged into 1 gallon cans and placed into a 21-can shielded overpack (contact handled package) for interim storage at CWC and ultimate disposal at WIPP. Oversize material separated from the dissolver solution would be washed with nitric acid, rinsed and then grouted into drums for disposal at the ERDF.

Grouting: The Grouting Alternative implements the same segregation of sludge in the basin as previously described. However in this alternative, the OEIR beads would be combined with the materials passing the 250 μm screen to form type A feed to the facility. Feed Type A would be subjected to a hot water oxidation step to oxidize any small metal particles. Feed type B would be delivered to a screen in an argon-inerted cell where the water used for transfer would be drained, the particles calcined in batch furnaces, and the calcine pneumatically transferred to the grout feed tanks located in an adjacent nitrogen-inerted cell. The slurry in the feed tanks would be sampled, analyzed and then delivered to a mixing tank where the sludge would be mixed with grout formers and pumped into remote-handled (RH) canisters to meet the WIPP waste acceptance criteria. The PCB concentrations in the final waste form would be less than 50 ppm. The filled RH-canisters would be sent to the CWC for interim storage then shipped to the WIPP for final disposal.

Table ES-1 summarizes some of the main features of the different alternatives

Table ES-1: Fact Sheet for the Alternatives

	Alternative 1 - Baseline	Alternative 2 - Modified Chemical	Alternative 3 - Grinding/Milling	Alternative 4 - Vitrification	Alternative 5 - Calcination	Alternative 6 - Grouting
Volume of As-Settled Sludge	50 m3	50 m3	50 m3	50 m3	50 m3	50 m3
Process Steps Involved (number)	11 - 12	7	5	14	7	6
Solids Transfers at controlled rate (number)	4 - 5	2	1	1	1	0
Solids Transfers at uncontrolled rate (number)	5 - 6	4	4	2	2	3
Waste Form	Slurry	Slurry	Slurry	Glass	Calcine	Grout
Assumed waste classification	Mixed TRU	Mixed TRU	Mixed TRU	HLW	RH- TRU	RH- TRU
Waste Volume After Treatment	1620 m3 slurry	1525 m3 slurry	1208 m3 slurry	27 m3 of waste glass	16 m3 of calcine	315 m3 of grout
# Waste Packages	NA	NA	NA	46 (3 m)	4039 (1-gal cans)	364 (RH Canisters)
# Shipments to Interim Storage	203 shipments - TWRS (8 m3 cask)	191 shipments- TWRS (8 m3 cask)	175 shipments -TWRS (7 m3 cask)	13 shipments - CWC (11 NUHOMS 2 Standalone casks)	64 shipments - CWC (192 Overpacks, 3 Overpacks/truck)	364 shipments- CWC
# Secondary Waste Packages	7 liners - NonTRU 46 drums - NonTRU 3 drums - TRU	1784 drums - NonTRU	104 drums - nonTRU	189 drums - NonTRU	189 drums- NonTRU	0
# Shipments for secondary waste packages	18 shipments - ERDF 1 shipment - CWC	595 shipments - ERDF	35 shipments - ERDF	63 shipments - ERDF	63 shipments -ERDF	---
Total volume - land-based disposal facility	LAW - 571 m3 NonTRU - 44 m3 TRU - 1 m3	LAW - 468 m3 NonTRU - 371 m3	LAW - 69 m3 NonTRU - 22 m3	HLW - 46 m3 NonTRU - 40 m3	TRU - 90 m3 NonTRU - 40 m3	TRU - 364 m3 (RH)

The current SNF Project baseline includes the assumption that the sludge treatment process would be performed within the CVDF. During the performance of this study, a separate siting study (currently in draft form) developed information that indicates the CVDF may not be suitable for this service. The key reason is that the CVDF does not have adequate shielding, and the existing floor slab cannot support the weight of the required shielding.

Discussions with SNF Operations and Engineering staff were held which concluded that there was insufficient space in the basins for all options with the possible exception of grinding. For the grinding option, a portion of the fuel and racks would need to be removed to make room for installation. In addition, the grinders would need to be installed through roof penetrations due to the inadequate capacity of the monorail system. Construction at the site to prepare for the grinding/milling process would impact scheduled operations in removing fuel and debris from the basin resulting in a delayed schedule. For this reason, processing in the basin was not pursued. However, it is believed that the initial screening and elutriation operation can fit within the basin and this was added to several of the options to reduce hot cell space in the processing facility. Based on these conclusions, a newly-constructed, shielded facility was assumed for evaluating all processes. The ultimate decision on selecting the processing location will be made in the siting study.

Detailed information was developed for each of the alternatives. This information entails; consideration of the technologies necessary for the implementation of the process steps, development of process flow sheets designed to meet process and disposition constraints, preliminary hazard analysis for each process, preliminary lay-out of stand-alone processing facility requirements, maintenance requirements, and parametric life-cycle cost estimates (i.e., equipment, procurement, construction, transportation, interim storage, and final disposal).

Once the alternatives were fully developed, each alternative was assessed with respect to evaluation criteria. Using the CERCLA evaluation process as a starting point, six criteria were identified against which the alternatives were evaluated. A consensus process involving Numatec Hanford Company (NHC), Fluor Daniel Hanford (FDH), DOE-RL and EPA was used to develop these criteria and assign the weighting factors. The criteria and weighting factors were:

- Reduction in toxicity, mobility, and volume through treatment (5%)
- Short-term effectiveness (10%)
- Near-term implementability (30%)
- Long-term implementability (5%)
- Near-term cost (40%)
- Long-term cost (10%)

The score for each criterion was multiplied by the weighting factor to arrive at a composite score for ranking the alternatives. The ranking order, from highest to lowest, resulting from this analysis is: 1-Modified Chemical, 2-Calcination, 3-Baseline Chemical, and 4-Grouting, 5-Direct Vitrification, and 6-Grinding/Milling. The results of the analysis, as shown in Table ES-2, show that the scores for the top four alternatives differ by less than15 percent.

Table ES-2: Evaluation of the Sludge Alternatives

WT Factor		Baseline	Mod. Chem	Grind/Mill	Vitrification	Calcination	Grout
5	**Toxicity Reduction**						
	Waste Form	1	1	1	10	5	9
	Final Land-Fill Volume	1	1	9	10	7	3
	SCORE	1	1	5	10	6	6
10	**Short-Term Effectiveness**						
	Risk to Public and Environment						
	Process Control	10	10	1	5	8	3
	Upset Severity	10	10	1	7	7	5
	Release Potential	7	7	10	1	3	5
	Risk to Worker						
	Dose from Transports	3	3	4	10	9	6
	Dose from Maintenance	1	3	8	8	10	6
	SCORE	6	7	5	6	7	5
30	**Near-Term Implementability**						
	Tech. Maturity	9	10	1	4	5	7
	Tech. Feasibility						
	complexity	6	8	3	1	5	7
	reliability	8	8	9	5	6	6
	maintainability	7	10	1	3	5	5
	Flexibility/Robustness	7	10	5	1	7	8
	Programatic Risks	5	6	4	9	9	7
	Regulatory Risks	10	7	1	10	7	7
	SCORE	7	8	3	5	6	7
5	**Long-Term Implementability** SCORE	10	10	10	6	3	3
40	**Near-Term Costs** SCORE	5	5	1	1	5	4
10	**Long-Term Cost** SCORE	1	2	5	3	7	5
	TOTAL SCORES	535	585	305	360	565	515

The ranking for the Baseline and Modified Chemical Alternatives score higher in near-term implementability due to higher scores for technical maturity and feasibility. Part of this score is due to the fact that laboratory tests using actual and simulated K Basins sludge have demonstrated that chemical treatment could meet the applicable DST and ERDF waste acceptance criteria. Additionally, similar chemical treatment processes have been used extensively to process like materials at the Hanford site. Calcination and grouting were also highly rated and score competitively with the modified chemical option. Calcination and grouting have not been tested using actual K Basin sludge and therefore more extensive development work compared to the chemical process may be required. It is also uncertain whether all of the calcined or grouted sludge could be disposed at the WIPP because of uncertainty about the radioactive designation (TRU waste versus HLW). Reworking solidified sludge would be technically difficult. It would be technically feasible to rework calcined sludge, but there would be an impact on long-term cost. There is an additional uncertainty as to whether a dispersible particulate waste, such as calcined sludge, could be transported to WIPP. Vitrification was assessed to be the most complex process of all the alternatives and difficult to implement due to the variation in sludge composition. Vitrification also as the added uncertainty of the repository accepting all of the glass waste product as HLW. While grinding/milling would provide a relatively simple process for the treatment of sand, OIER, and oxides it has not yet been demonstrated to be capable of safely and successfully reducing irradiated uranium to meet the TWRS acceptance criteria. In the absence of an experience base with this option, uncertainties in design (e.g., processing rates and logistics); safety (e.g., hydrogen generation, criticality), and uncertainty in whether further treatment to reduce PCB concentrations are required, resulted in a low near-term implementability score for this alternative. If test data were obtained for processing and reaction rates, and particle size distributions the grinding score may improve considerably.

The chemical processes also rank higher because of low near-term costs and partly because of the low weighting on long-term costs. As a result, substantial costs associated with processing and disposing an increased volume of LAW glass due to the sodium sent to TWRS, are weighted lighter than near-term costs. In addition, the TWRS interim storage options are aided by the conclusion that when blending with a high zirconium tank sludge there is no cost impact to HLW vitrification or disposal. Calcination and grouting again score competitively with the chemical processes. Life-cycle costs for these options are the lowest of all alternatives. Vitrification scored lower due to high costs associated with expected higher costs for equipment and safety documentation. Significant costs are also expected for the waste form qualification for a stand-alone facility producing a unique glass from K Basin sludge. The ranking for grinding/milling was also low due to high near-term costs associated with testing and development, and safety documentation. Long-term costs, however, are reduced substantially over the chemical processes because of the decrease in sodium volume to TWRS.

The selected weighting factors make the final ranking most sensitive to the scores for near-term implementability and near-term cost. A sensitivity analysis indicates that moderate changes in the weighting factors and/or individual category scores would cause the ranking to favor calcination or grouting indicating there is little distinction between the rankings for calcination,

chemical processes, and grouting. Significant changes in weightings and/or category scores would be needed to promote vitrification or grinding/milling to the highest scored alternative.

The following presents key conclusions of the evaluation.

- Complexity of the sludge feed streams precludes a "one-step," in-basin process for treatment of the high-activity sludge (i.e., high TRU streams consisting of canister and fuel wash sludge). Key variables include; significant quantity of cesium, uranium and plutonium, and relatively large pieces (6350-micron) of metallic uranium and zircalloy cladding. The TRU content of the sludge precludes a simple, cost-effective disposition path to ERDF for the low-activity streams (i.e., low TRU streams consisting of floor and pit sludge).

- Treatment of the sludge requires processing in a heavily shielded area within a Hazard Category II nuclear facility. This requirement and the need to remove sludge from the basins by August 2005 (determines scale of facility), are key drivers in the site selection process for the sludge treatment facility and led to the assumption of a newly-constructed facility for the sludge treatment system.

- All of the alternatives, with the possible exception of the grinding/milling option, have the potential of providing an appropriate treatment and disposition pathway for the K Basins sludge. However, given the current set of regulatory and safety constraints and requirements, it was concluded that a chemical process has the greatest likelihood of success as a single treatment process for all five sludge feed streams. The other alternatives, while viable, do not provide major advantages in terms of technical viability, cost or schedule when evaluated against a modified chemical process.

- Parametric cost numbers based on the process descriptions and preliminary layouts indicate that the costs, when assuming a newly-constructed facility, exceed the baseline budget. If the siting study (which is currently in progress) identifies an existing processing location, the results of this study would need to be reviewed. Conversely, if the siting study determines that a new facility is required, the budget and schedule for sludge treatment would need to be reexamined.

- Both the design/construct schedule (approximately five years for design and construction of the processing facility) and the assumed operating window are viewed as extremely aggressive, therefore, all of the alternatives could impact the schedule.

Based on the preceding summary, a reasonable path forward approach for consideration is to initiate a high-level review of the current set of policies, requirements, and constraints to identify disposition options unconstrained by current regulations and requirements, and/or beyond the scope of this evaluation. Additionally, review other programs to identify potential integration opportunities. The rational for this approach is all of the alternatives selected for evaluation have significant uncertainties and associated risks in completing design, construction, startup and

operations of a treatment system to process the entire volume of sludge per the current Tri-Party Agreement milestones. Some uncertainties are contingent on the currently imposed constraints and requirements. Additionally, near-term funding requirements would need to be increased to expedite definitive design activities for a single treatment process option. Increased funding would not support the objective of maintaining consistency with the current budget requirements.

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LIST OF TERMS

ARARs	Applicable or relevant and appropriate requirement
B&W	B&W Hanford, Company
BHI	Bechtel Hanford, Incorporated
BIO	Basis for Interim Operations
BTU	British Thermal Unit
CERCLA	*Comprehensive Environmental Response, Compensation and Liability Act of 1980*
CFR	*Code of Federal Regulations*
CH	Contact-handled
CRWMS	Civilian Radioactive Waste Management System
CSB	Canister Storage Building
CSER	Criticality Safety Evaluation Report
CVDF	Cold Vacuum Drying Facility
CWC	Central Waste Complex
DCRT	Double contained receiver tank
D&D	Decontamination and decommissioning
DESH	DE&S Hanford, Inc.
DST	Double-shell tank
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
Ecology	Washington State Department of Ecology
EM	DOE Office of Environmental Management
EPA	Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
FDH	Fluor Daniel Hanford, Inc.
FDNW	Fluor Daniel Northwest, Inc.
FFS	Focused Feasibility Study
FGE	Fissile gram equivalent
HLW	High-level waste
ISB	Interim Storage Basis
ISO	International standards organization
IWTS	Integrated water treatment system
KE	K East
KW	K West
LAW	Low-activity waste
MCO	Multi-canister overpacks
MOU	Memorandum of Understanding
MYPP	Multi-year program plan
NCAW	Neutralized cladding acid waste
NCRW	Neutralized cladding recovery waste
NOC	Notice of Construction

NRC	Nuclear Regulatory Commission
OIER	Organic ion exchange resin
ORNL	Oak Ridge National Laboratory
PCB	Polychlorinated biphenyl
PFP	Plutonium Finishing Plant
PHMC	Project Hanford Management Contractor
PNNL	Pacific Northwest National Laboratory
RCRA	*Resource Conservation and Recovery Act of 1976*
RH	Remote-handled
RL	Department of Energy, Richland Operations Office
ROD	Record of Decision
SAIC	Scientific Application International Corporation
SAR	Safety analysis report
SARP	Safety analysis report for packaging
SFD	Spent Fuel Division
SNF	Spent Nuclear Fuel
SNFP	Spent Nuclear Fuel Project
SpG	Specific gravity
SRS	Savannah River Site, Aiken, SC
STAA	Sludge Treatment Alternative Analysis
TAG	Technical Assistance Group
TDOP	Ten-drum overpack
TPA	Tri-Party Agreement (*Hanford Federal Facility Agreement and Consent Order)*
TRU	Transuranic
TSCA	*Toxic Substances Control Act*
TWRS	Tank Waste Remediation System
TWRS-P	TWRS Privatization Project
WAPS	Waste acceptance preliminary specifications
WDD	Waste Disposal Division
WHC	Westinghouse Hanford Company
WIPP	Waste Isolation Pilot Plant
WSPS	Waste stream profile sheets

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SLUDGE TREATMENT ALTERNATIVES ANALYSIS

1.0 INTRODUCTION

The K East (KE) and K West (KW) fuel storage basins at the 100 K Area of the Hanford Nuclear Reservation contain sludge on the floor, in the pits, and inside fuel storage canisters. The sludge is a complex mixture of metallic uranium, uranium oxides and hydrides, plutonium, fission products, zirconium cladding, ion exchange media (organic and inorganic), corrosion products from the steel structures in the basins, sand from outside the buildings, and material from the degradation of the structural concrete forming the basins. These components are not uniformly distributed throughout the basin. There are three distinct sludge types (1) floor/pit sludge, (2) canister sludge, and (3) fuel wash sludge. The decision to dispose of this sludge separately from the fuel elements stored in the basins was made.

Selection of the baseline sludge disposition path was based on a thorough decision process (Hatch 1997). The recommended (baseline) sludge disposition path is chemical pretreatment of the sludge at the 100 K Area Treatment under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). This is to be followed by interim storage using existing Tank Waste Remediation System (TWRS) double-shell tanks (DST) and permanent treatment at the planned Phase II vitrification facilities at a later date. Chemical processing was deemed necessary because:

- The sludge does not presently meet Tank Farm criticality requirements;
- Potentially reactive fuel particles in the sludge would violate the Tank Farm safety analysis criteria defined in the Basis for Interim Operation (BIO); and
- Designation of the sludge as a Toxic Substances Control Act (TSCA) waste due to polychlorinated biphenyl (PCB) components would introduce new and costly regulatory constraints on the Tank Farm storage and disposal system.

The pre-conceptual design for the selected pre-treatment process was developed using a modular compact processing approach (Chang 1997). The baseline assumed this skid-mounted equipment could be located in the Cold Vacuum Drying Facility (CVDF) and estimated the cost to implement the pre-treatment alternative at $36.5 million (Hatch 1997).

Following approval of this recommendation by the U.S. Department of Energy, Richland Operations Office, (RL), (Wagoner 1997), Fluor Daniel Hanford (FDH) prepared change control documentation to incorporate the necessary additional work scope (e.g., sludge testing; Sellers 1997) to ensure that the pretreatment process would successfully meet TWRS waste acceptance criteria and eliminate all safety issues. In FY 1998, engineering studies and laboratory testing were carried out to further define the sludge treatment process in terms of TWRS waste acceptance and the process flowsheet. This effort supported Performance Agreement SNF 3.1.1, Complete Sludge Pretreatment Process Selection, and was submitted to FDH in August 1998 (Miller 1998).

Treatment of the sludge in a manner that is safe and capable of meeting TWRS acceptance criteria involves the following issues:

- particle size (e.g., up to 6350 μm diameter in sludge)
- transfer of high density particles (up to 19 g/cc)
- protection of workers and public from exposure to the large volume of high activity material (up to 36,332 Ci/m^3 ^{137}Cs)
- control of criticality
- safe handling and treatment of pyrophoric materials
- processing of potentially reactive organic resin beads
- control of fine-sized uranium particles

However, pretreatment of the sludge is complicated by differences in the physical, chemical, and radiological differences of the sludge in the three streams, and the resulting issues involved in safely processing, transferring, and storing the sludge. As a result, the baseline chemical treatment process designed to treat the sludge to meet TWRS acceptance criteria, would be more complex and potentially more costly than originally scoped.

These changes are significant enough to warrant a reevaluation of whether the baseline process should remain the preferred treatment and disposal option. Additionally, during the Tri-Party Agreement negotiations, DOE-SNF committed to a reevaluation of the treatment/disposal options for the K Basin sludge to determine if the baseline option is still the preferred alternative given the complexity and perceived high cost. This alternatives study is part of the deliverable for this commitment.

The Environmental Protection Agency (EPA), Ecology, and DOE will use the information presented in this study to support completion of a focused feasibility study (FFS) and as the basis for selecting a sludge disposition alternative for start of conceptual design. The preferred alternative will be presented for public review and comment in a proposed plan. The EPA will select the disposition alternative in a Record of Decision (ROD) for the K Basin interim remedial action.

2.0 OBJECTIVES AND SCOPE

The primary purpose of this effort was to evaluate alternatives for the disposition of the K Basin sludge, and provide justification for selection of an alternative treatment/disposition process or for reaffirming the baseline disposition as the preferred option (i.e., chemical treatment followed by interim storage in a double-shell tank with ultimate disposal at the repository via the TWRS phase II vitrification plant. Additionally, the implications of modifying requirements and other factors that significantly affect decisions in the selection process are addressed. These requirements include the waste acceptance criteria established by the TWRS for safe storage of the sludge, and restrictions and requirements imposed by the PCB components and TSCA Disposal Amendments.

2.1 SCOPE

The scope of this study was primarily limited to those requirements and alternatives recommended by stakeholders in a meeting held 9/24 - 25/98 (Miller and Pearce1998). At this meeting, stakeholders identified candidate treatment technologies and disposition options to be evaluated for the K Basin sludge. Key representatives from SNF, TWRS, DOE-RL and EPA were also challenged to identify waste acceptance criteria that could potentially be altered.

Evaluation of the alternative sludge treatment/disposition options involved an array of activities resulting in the identification of the optimal disposition strategies for the K Basin sludge in terms of cost, scope, and schedule. These activities involved the evaluation of waste storage, treatment, and disposal options in the context of cost, scope, and schedule, and requirements associated with environmental regulations, safety, and protection of worker and public health. The key activities in this effort included the following:

- Define the design requirements and capabilities of the alternative treatment technologies
- Assess the viability of treatment designs in the context of interim and/or final storage acceptance criteria
- Define the assumptions and screening/decision criteria to be used in evaluating the alternatives
- Initial screening (down selection) of alternatives against set of screening criteria
- Develop a pre-conceptual study level description of the alternatives
- Evaluate the alternatives individually against the decision criteria
- Evaluate viable alternatives against one another by applying weighted decision criteria to each alternative
- Investigate waste acceptance criteria that could be potentially altered or further evaluated to reduce complexity and cost of treatment
- Recommend options that best satisfy the evaluation criteria.

Evaluation of the alternatives investigated in this study was based on design information using the best available literature, engineering and vendor studies. Laboratory proof-of-principle tests were not included in the scope of this study.

This evaluation included consideration of life-cycle impacts of utilizing various approaches for dispositioning the K Basin sludge. Accordingly, the evaluation considered the potential impacts of alternative approaches to treatment, interim storage, and final disposal of the treated sludge. The evaluation does not address alternatives for sludge collection and removal from the basins. Potential modifications to requirements imposed by outside agencies, waste acceptance criteria established by the ERDF, WIPP, or geologic repository was also not included within the scope of this evaluation.

2.2 REQUIREMENT ISSUES

Two of the most important requirements in this study initially were the TWRS waste acceptance requirements for criticality control and those associated with constraints imposed by TSCA regulation of wastes containing PCBs. In the September 1998 meeting, it was pointed out that a sensitivity

analysis was performed by a team of off-site criticality experts to identify conservatism of criticality assumptions used by TWRS.

The current TWRS acceptance criteria established for the purpose of criticality control include strict limits on waste characteristics such as particle size. This study includes a review of the TWRS criticality safety criteria based on a sensitivity analysis and feedback from off-site experts on the approach currently used for development of the criticality safety evaluation report (CSER) for transfer and storage of the sludge in a DST.

The disposition options for the sludge were initially restricted by issues related to the presence of PCBs in the sludge at levels potentially exceeding regulatory (TSCA) limits. Recent changes in the regulation of wastes containing PCBs have impacted some of these restrictions. EPA's interim guidelines, for the purpose of this evaluation, focuses on regulating the PCB levels of the sludge after, rather than before, treatment, and prior to transport to another facility. This development has important implications on the disposition strategies, on costs, and even on the extent of TSCA regulation. This study addresses options for resolving the PCB issue based on the 40 CFR 761.61 provision for the risk-based management of PCBs.

3.0 PREVIOUS ANALYSES OF SLUDGE DISPOSITION OPTIONS

Over the last four years, much effort has been expended in evaluating the handling, management and disposition of the K Basin sludge.

In 1994, an evaluation of potential disposition alternatives and the impact of related regulatory and permit requirements was made by a team comprised of Westinghouse Hanford Company (WHC), Pacific Northwest National Laboratory (PNNL), and Scientific Application International Corporation (SAIC). The assessment showed that the disposition path is dependent on the classification of the sludge (i.e., as SNF, radioactive waste, or mixed waste) and that the floor sludge and canister sludge should be considered separately. A recommendation for classifying K Basin sludges was submitted to DOE in 1995 (Fulton 1995a). The recommendation is 1) to manage the sludge as SNF while in the K Basins, 2) once the sludge is removed from the basin, it should be managed as a waste consistent with characterization results, and 3) sludge remaining in the multi-canister overpacks (MCOs) should continue to be managed as SNF. DOE concurred with the sludge classification approach and requested that sludge disposition consider the option of desludging the canisters as the in-situ desludging offered potential savings in project costs (Hansen 1995a).

Studies were completed on the alternatives for sludge treatment options in January 1995 (PNL 1995). As a further input to help validate the recommended path forward, an independent review team was assembled which reviewed technical consistency of the path forward with existing Hanford infrastructure, and viability of the path from a strategic management perspective (Fulton 1995b). The evaluation included; 1) grouting and vitrification treatment processes for sludge classified as waste, 2) calcining and drying treatment processes for sludge classified as SNF, 3) waste disposal paths available at Hanford and 4) whether to continue to manage the sludge as fuel or to disposition it as waste. The recommended plan was to classify the bulk sludges (floor and pit) as waste upon removal

from the basins. Final disposition of the bulk sludges included two options: transferring the sludges to the Hanford double shell tanks or placing the sludge into a form appropriate for solid waste storage and/or disposal. Fuel canister desludging, if required for stabilization, would add additional material to the bulk sludge waste stream. DOE approved this strategy as the baseline disposition path June 1995, with the request for resubmission of a definitive sludge disposition strategy (Hansen 1995b).

At the time this evaluation was conducted, sludge characterization data was limited to a few samples of KE Basin sludge. Therefore, the next major step in establishing the actual disposition path was characterization. Parallel to the characterization process, ongoing studies collected additional data associated with solid waste and tank farm disposal. In late 1995, budget constraints led to the decision to realign the disposal options in a serial path rather than parallel paths and proceed at risk with the TWRS disposal option. This approach was baselined in the FY 1996 RL approved Multi-Year Program Plan (MYPP).

In April 1996, characterization data was available for the floor and pit sludge (Makenas et al. 1996). This data was used to establish waste stream profile sheets (WSPS) which were used by TWRS to perform the waste compatibility assessment. The assessment compared compositions of the sludge waste, receiver tank (AW-105) contents, and transfer conditions to TWRS operations, safety and environmental acceptance criteria.

In May 1996, TWRS and SNFP signed a Memorandum of Understanding (MOU) to describe the process for determining acceptability of K Basins sludge into the TWRS DST system (Fulton 1996). This MOU directed that survey of alternative storage locations for the K Basins sludge be conducted, anticipating its use as feed for Phase I Privatization. A two-day workshop identified a list of fifty-three potential options that were further refined to a short list of six options (NCAW tank, NCRW tank, Iso tanks, shielded container, rail car, upgrade K Basins) focused on sludge storage. The survey confirmed the choice of a Neutralized Cladding Removal Waste (NCRW) DST as the preferred K Basins sludge storage location. The key selection factors were schedule and cost drivers. Any alternate storage would have to satisfy all the confinement, safety, monitoring, transfer, permitting, and documentation requirements currently satisfied through the use of DST. It was also determined that the K Basins sludge does not meet the Privatization Envelope D Feed Specification without some blending (Truax and Gerber 1996).

Because of the unique characteristics of the KE Basin sludge (for example, high percentage of solids, large particles, and quantities of PCBs exceeding TSCA limits) disposal issues outside those normally considered by TWRS for waste receipt and storage were identified. Analysis of safety, waste compatibility, retrievability, transport, and immobilization aspects identified a number of issues that require adjustment of sludge characteristics prior to acceptance of the K Basin sludge into the DST system. These issues resulted in a list of 17 items requiring action or resolution for tank farms to receive the waste (Bacon 1996). A major effort was initiated in Fiscal Year 1997 to resolve or identify action plans for closing out the technical and safety issues identified by the waste compatibility report. Evaluation of the key issues established that pre-treatment of basin sludge would be required prior to tank storage to ensure safety and vitrification process performance. Pre-treatment processes must be performed to control sludge particle size, waste stream pH, neutron absorber characteristics, chemical

compatibility with current tank contents, and the presence of uranium metal or uranium hydride particles (i.e., pyrophoric materials) [Carothers et. al. 1997].

Additional characterization campaigns were conducted for KE canister sludge and KW canister sludge. The results of these campaigns were available in September 1997 (Makenas et al. 1997) and February 1998 (Makenas et al. 1998). Waste stream profile sheets were prepared for both sludge materials and submitted to TWRS for performance of waste compatibility assessments. A technical evaluation of KE Basin canister sludge was performed to determine waste acceptance into the DST system. This evaluation was issued as a precursor to the waste compatibility assessment since chemical treatment is required prior to waste acceptance. The issues identified in the KE Basin floor and pit sludge compatibility assessment are applicable to KE canister sludge as well. K West Basin canister sludge was evaluated for acceptance into the DST system. No additional issues were identified that are specific to the KW canister sludge. This resulted in no new requirements being placed on the sludge treatment system by tank farms (Gmyrek 1997).

In March 1997, Flour Daniel Hanford, Inc. (FDH) recommended vitrification of the sludge through TWRS, and consideration of additional options (unrestricted use of AW-105, restricted use of AW-105, newly-constructed tanks and non-TWRS alternatives) to resolve the regulatory and environmental concerns associated with PCBs, as well as resolution of various technical and safety issues (Hatch 1997). The study conducted provides a preconceptual design package including preconceptual designs and cost estimates for temporary sludge storage tanks (McLean 1997). Two tank options were evaluated for the critically safe tank system. One system assumed the K Basin sludge was pre-treated and assumed double contained receiver tanks (DCRT) for sludge storage. The second system assumed the sludge had minimal pretreatment (i.e., hot water oxidation) and assumed "critically safe" tanks for storage. These tanks have geometric configurations that minimize the risk of a criticality. Additionally, several non-TWRS disposition alternatives were evaluated for life-cycle costs and impacts associated with disposal of K Basins sludge (CH2M Hill1997). Two categories of alternatives were evaluated. The first category considered adding PCB treatment at the 100-K Area, at the T Plant, or at a new facility. The second category considered solidification via modification/restart of the Grout Facility, modification of T Plant, or construction of a new facility.

The recommended approach from this evaluation was chemical pretreatment, followed by interim storage and treatment using the existing TWRS DST and the Phase II privatization facilities. A risk-based decision analysis was utilized to support formulation of this recommendation. The evaluation indicated that the recommended alternative scored highest in both cost and schedule. All non-TWRS alternatives had major disadvantages that precluded feasibility or drove costs far beyond TWRS alternatives.

The preceding studies led to the selection of the baseline process involving treatment of the sludge for storage in a DST, vitrification via the phase II high-level treatment plant and disposal at the national geologic repository. Acceptance of this recommendation was granted by RL in August 1997 (Wagoner 1997).

4.0 PROCESS FEED STREAMS DESCRIPTIONS

The K East (KE) and K West (KW) fuel storage basins at the 100 K Area of the Hanford Site contain sludge on the floor, in pits, and inside fuel storage cansiters. Sludge on the floor and in the pits of the KE Basin is a mix of fuel corrosion products (containing fission and activation products), small fuel fragments (irradiated metallic uranium and zirconium cladding), iron and aluminum oxide, concrete grit, sand, dirt, and biological debris. The large quantity of fuel corrosion products in the KE Basin floor and pit sludge is a result of the open tops, and in some cases open-screened bottoms, of the fuel storage canisters. Because the SNF stored in the KW Basin was placed in closed containers before storage, corrosion products were retained within the canisters therefore the sludge buildup in the KW Basin contains smaller volume of fuel corrosion products. The small quantity of sludge on the floor of the KW Basin appears to consist primarily of dust and sediment; the floor sludge is not expected to contain significant amounts of fuel corrosion products because the KW Basin canisters have closed tops and bottoms. Only one of the pits (North Loadout Pit) in the KW Basin contains a significant amount of sludge and is likely to consist of a mix of sand and fuel corrosion products. Sludge in the KE and KW Basin fuel storage canisters consists primarily of fuel corrosion products.

The sludge in the basins is commingled with SNF and is not considered a waste; however, when the sludge is separated from the SNF and removed from the basins, it will be designated and managed as a waste (Wagoner 1996). For the purposes of differentiating SNF and debris from sludge, any material less than or equal to 0.64 cm (0.25 in.) in diameter is defined as sludge.

The total nominal volume of as-settled sludge in the KE and KW Basins combined is estimated to be 50.6 m^3 (13,000 gallons). There will be five distinct feed streams to the sludge treatment process--two from the KE Basin and three from the KW Basin. The five sludge feed streams as defined in Pearce et. al. (1998) are:

- KE1-- This stream consists of sludge (less than or equal to 6350 μm in diameter) retrieved from the various KE Basin pits and floor areas. This stream also will include canister and fuel wash sludge component particles less than or equal to 250 μm in diameter. Interim storage for process stream KE1 is in the KE Basin Weasel Pit. Contains more insoluble material than uranium.

- KE2-- This stream consists of sludge [less than or equal to 6350 μm (0.25 in.) and greater than 250 μm in diameter] collected from the canister removal and fuel wash activities. Interim storage for process stream KE2 is in IWTS Knockout Pots. Contains a high percentage of uranium and little iron or insoluble material

- KW1--This stream consists of sludge [less than or equal to 6350 μm (0.25 in.) in diameter] retrieved from the various KW Basin pit and floor areas. An interim storage location for process stream KW1 currently is not planned. Contains mostly insoluble material.

- KW2--This stream consists of sludge [less than or equal to 6350 μm (0.25 in.) and greater than 500 μm in diameter] collected from the canister removal and fuel wash activities. Interim storage for process stream KW2 is in IWTS Knockout Pots. Contains a high percentage of uranium and little iron or insoluble material

- KW3-- This stream consists of sludge [less than or equal to 500 μm in diameter] collected from the IWTS Knockout Pot filter system. Interim storage for process stream KW3 is in settler tanks. Contains a high percentage of uranium and little iron or insoluble material

Key characteristics of the K Basins sludge, based on data provided in Pearce et. al. (1998), is provided below and in Table 4-1. Tables 4-2 and 4-3 provide nominal inventories for KE Basin and KW Basin process feed streams, respectively.

- PCBs up to 140 ppm (as-settled basis) in floor/pit sludges
- Dangerous waste constituents: toxicity characteristic heavy metals
- Pyrophoric materials in the form of metallic uranium and zirconium, and uranium hydrides
- Organic ion exchange resin (OIER)
- Dirt, windblown silica, grafoil
- Primary particle sizes ranging from sub-micron to 6350 μm diameter

Table 4-1. Sludge Waste Stream Characteristics

	KE1	KE2	KW1	KW2	KW3
Volume (m3)	41.4	2.37	4.67	0.199	1.878
Mass (kg)	23382	3909	1784	1635	3586
Beta-gamma (Ci)	13907	11404	284	14195	13981
TRU (Ci)	1008	1076	40	452	933
U (kg)	2615	2819	87	1467	2206
Pu (kg)	8	10	< 1	5	9

Table 4-2. Nominal Inventory for KE Basin Process Feed Streams.

		Stream KE1			Stream KE2			
	Units		Stream KE1 Composition in total kg			Stream KE2 Composition in total kg		
As-settled Sludge Solid Content (g dry solids/cm3 as-settled sludge)	g/cm^3	0.564			1.655			
As-settled Sludge Density	g/cm^3	1.403			2.359			
Volume of Sludge	m^3	41.459			2.369			
As-settled Sludge Chemical Composition								
U	g/cm^3	0.001166	48.345		0.637703	1,510.603		
UO_2	g/cm^3	0.039209	1,625.558		0.384911	911.785		
U_3O_7	g/cm^3	0.028711	1,190.347		0.202970	480.799		
$UO_4 \cdot 4H_2O$	g/cm^3	0.000990	41.061		-	-		
UH_3	g/cm^3	0.001920	79.593		0.038189	90.463		
$Al(OH)_3$	g/cm^3	0.006358	263.589		0.143847	340.749		
Al_2O_3	g/cm^3	0.041651	1,726.804		-	-		
FeO(OH)	g/cm^3	0.192012	7,960.648		0.091262	216.182		
SiO_2	g/cm^3	0.154610	6,409.987		0.069935	165.664		
CaO	g/cm^3	0.006824	282.917		0.001348	3.193		
CO_2	g/cm^3	0.004996	207.140		0.006278	14.873		
C	g/cm^3	0.000655	27.163		0.001941	4.599		
Sum of Other Compounds	g/cm^3	0.037669	1,561.739		0.014023	33.218		
Miscellaneous solids								
PCB	g/cm^3	0.000108	4.465		0.000001	0.004		
OIER	g/cm^3	0.029395	1,218.692		0.014397	34.103		
Zeolite	g/cm^3	0.017818	738.740		-	-		
Zircalloy 2	g/cm^3	-	-		0.043569	103.207		
Grafoil	g/cm^3	-	-		-	-		
Dry solid - radionuclide content								
^{238}Pu and $^{239/240}$Pu	g/cm^3	0.000195	8.084		0.004316	10.225		
^{238}Pu and $^{239/240}$Pu	µCi/g	18.79			127.47			
^{241}Am	µCi/g	24.29			147.94			
^{137}Cs	µCi/g	302.79			1,374.21			
$^{89/90}$Sr	µCi/g	284.46			1,541.42			
Uranium composition								
U	kg		2614.96			2,819.18		
^{233}U	mass%	0.0000			0.0004			
^{234}U	mass%	0.0064			0.0081			
^{235}U	mass%	0.6361			0.6769			
^{236}U	mass%	0.0658			0.0718			
^{238}U	mass%	99.29			99.24			

Table 4-3. Nominal Inventory for KW Basin Process Feed Streams

		Stream KW1			Stream KW2			Stream KW3	
	Units		Stream KW1 Composition in total kg			Stream KW2 Composition in total kg			Stream KW3 Composition in total kg
As-settled Sludge Solid Content (g dry solids/cm3 as-settled sludge)	g/cm^3	0.382			8.242			1.915	
As-settled Sludge Density	g/cm^3	1.292			8.549			2.582	
Volume of Sludge	m^3	4.67			0.199			1.878	
As-settled Sludge Chemical Composition									
U	g/cm^3	0.000187	0.871995		7.374676	1,464.425		0.035401	66.498
UO_2	g/cm^3	0.010487	48.975756		-	-		0.835274	1,569.000
U_3O_7	g/cm^3	0.010695	49.944728		-	-		0.368587	692.363
$UO_4 \cdot 4H_2O$	g/cm^3	0	0		-	-		0.004785	8.988
UH_3	g/cm^3	0	0		-	-		0.082877	155.678
$Al(OH)_3$	g/cm^3	0	0		-	-		0.215869	405.494
Al_2O_3	g/cm^3	0.020981	97.980113		-	-		-	-
FeO(OH)	g/cm^3	0.069370	323.957757		-	-		0.179110	336.445
SiO_2	g/cm^3	0.255239	1191.967215		-	-		0.059759	108.361
CaO	g/cm^3	0.004117	19.225854		-	-		0.000986	1.853
CO_2	g/cm^3	0.001190	5.557143		-	-		0.001557	2.924
S	g/cm^3	0.000194	0.908042		-	-		0.001570	2.949
Sum of Other Compounds	g/cm^3	0.009626	44.955227		0.042141	8.368		0.124142	237.0
Miscellaneous solids									
PCB	g/cm^3	0	0		-	-		0.000008	0.015
DIER	g/cm^3	0	0		-	-		-	-
Zeolite	g/cm^3	0	0		-	-		-	-
Zircalloy 2	g/cm^3	0	0		0.519739	103.207		-	-
Grafoil	g/cm^3	0	0		0.279611	55.524		-	-
Dry solid - radionuclide content									
^{238}Pu and $^{239/240}Pu$	g/cm^3	0.000068	0.318071		0.026116	5.186		0.004931	9.262
^{238}Pu and $^{239/240}Pu$	µCi/g	11.57			152.41			145.38	
^{241}Am	µCi/g	10.97			124.25			114.87	
^{137}Cs	µCi/g	96.62			4,881.41			1,637.75	
^{90}Sr	µCi/g	62.64			3,800.71			2,260.13	
Uranium composition									
U	kg		87.24			1464.42			2,207.77
^{233}U	mass%	-			-			-	
^{234}U	mass%	0.00668			0.00690			0.00584	
^{235}U	mass%	0.6794			0.78000			0.78828	
^{236}U	mass%	0.0726			0.09900			0.09250	
^{238}U	mass%	99.2424			99.11000			99.14212	

5.0 REQUIREMENTS, CONSTRAINTS, AND ASSUMPTIONS

Requirements, constraints, and assumptions are used to formulate alternate concepts. Since all viable options must be capable of complying with the requirements and constraints, the lists provided in sections 5.1 and 5.2 were used as a screening tool to eliminate some concepts from consideration.

5.1 REQUIREMENTS

Requirements are internally (under purview of PHMC contract) derived criteria. If sufficient justification is developed (e.g., program cost minimization, re-analysis, schedule improvement, etc.), these criteria can be modified. This section provides discussion of the results of challenging the TWRS waste acceptance criteria (section 5.1.1) and the PCB regulatory strategy (section 5.1.2). Section 5.1.3 provides discussion of general requirements.

5.1.1 TWRS Waste Acceptance Criteria Challenged

The TWRS criticality limits represent standard criticality safety assumptions and, with the exception of particle size, do not afford much opportunity for reducing conservatism. Review of the sensitivity analysis and feedback from off-site experts on approach that is currently being used for development of the CSER found that the analysis is not overly conservative and recommended that a 0.10 administrative margin (not 0.05) be used for criticality calculations of K Basins sludge in the Hanford waste tanks. The standards specify that a larger margin is required if validating experiments, close to the case being evaluated, have not been done. Runs have currently only been done on aqueous solutions and none with solutions containing iron. The review also verified that the calculations are correct.

The particle size issue, however, leading to the assumption of a threefold increase in the plutonium concentration may be examined more closely. Because transfer of K Basin sludge to tank farms is several years away, an opportunity presents itself for confirming the suspected plutonium behavior by laboratory analyses. If it can be shown that plutonium does not preferentially segregate, the particle size limit of 10 • m could potentially be increased.
Decreasing the particle restrictions for criticality could reduce quantity of iron to be added thus decreasing volume of slurry to be transferred to TWRS (fewer shipments decreases transport costs). Unit operation steps for the chemical processes would not be affected, as the sludge would still be required to meet the pyrophoric limit.

For purposes of this study, it is assumed that the waste acceptance criteria established by TWRS are valid and must be met. Examining the TWRS criteria requires further analysis and is outside the planned scope of this document.

5.1.2 PCB Regulatory Strategy Challenged

The current PCB regulatory path requires treatment of the sludge to the point that it is no longer TSCA-regulated or less than 2 ppm solids (and 0.5 ppb liquids) before it is moved to another facility. Investigation of provisions now allowed by 40 CFR 761.61 led to the following assumptions used in

this study for alternatives other than the baseline. The baseline chemical alternative has been developed to achieve the TSCA treatment limits (of 2ppm in the solids and 0.5 ppb in liquids) and therefore, does not rely on modification of the PCB strategy.

RL and SNFP intend to use the risk-based approach allowed by the TSCA Disposal Amendments to address the PCBs. EPA endorses the use of the risk-based approach for the sludge. There are two basic components to the risk-based approach. The most critical component is a demonstration that, without any treatment, the total mass of PCBs in the sludge is so low that they do not present a risk to human health or environment. The second component is a requirement to incorporate into the sludge treatment system a process or technology that removes or destroys PCBs. The selection of a process or technology can be based on general PCB guidance and literature. Process testing with actual or simulated K Basins sludge for purpose of demonstrating that PCBs will be removed or destroyed will not be required. Furthermore, there will be no specific performance standards for sludge treatment relative to PCBs, nor will there be a requirement to sample and analyze for PCBs after treatment. The off-gas, however, would have to be treated to ensure that emissions contain less than 10 $\mu m/m^3$ PCBs.

Work with the downstream waste management facilities to modify their waste acceptance criteria to receive the sludge as a TSCA-regulated waste has not been pursued and therefore, the risk-based approach discussed previously is assumed to be the new PCB regulatory strategy (Gerber 1999).

5.1.3 General Requirements

The following general requirements must be satisfied for all alternatives:

- Contaminated Sludge: The treatment system must be capable of handling K Basin sludge feed streams with the characteristics specified in Pearce et al. (1998).

- PCB Emissions Requirement: The sludge treatment offgas system must limit emissions to 10 micrograms per cubic meter (Boomer et al. 1988).

- TSCA Disposal Requirements: Specific performance standards for sludge treatment relative to PCBs are not required, nor is there a requirement to sample and analyze for PCBs after treatment. The treatment process only has to indicate that PCBs can be "reduced."

- Interim Storage Acceptance Criteria: The alternative must produce a product which meets the applicable interim storage acceptance criteria. Table 5-1 summarizes the requirements for the interim storage locations (DST, CWC).

- Storage Availability: The interim storage facility shall support the scheduled operation of the sludge treatment system. Sludge removal/treatment begins July 2004 (TPA milestone).

- Storage Capacity: The interim storage facility must be capable of providing interim storage for the waste volumes produced.

- Final Disposal: All waste streams (primary and secondary) must have a well-defined disposition path from treatment to final disposal and meet the applicable acceptance criteria. Section 5-2 summarizes the constraints imposed by the final disposal facilities (ERDF, WIPP, and geologic repository).

- Safety: An alternative must ensure nuclear and operational safety. The K Basins sludge contains plutonium, metallic uranium and uranium hydrides, and radioactive fission products. In addition, the sludge contains some organic resin. These properties will require addressing criticality, pyrophoricity, gas generation and retention, metal-water reactions, and reactive organic constituents.

Table 5-1. Interim Storage Requirements

Sludge Characteristic	Tank Waste Remediation System (TWRS) Tank 241-AW-105 (Carothers et al. 1997)	Central Waste Complex (CWC) (FDH 1998)
Corrosion	Nitrite and hydroxide concentrations as specified in Lockheed Martin Hanford Corporation (1996)	Waste compatible with container
Criticality	pH>8 Particle size < 10 μm[1] U235 < 0.84 wt% and Iron/Pu > 353	Fissile material limited to 177 Pu-239 fissile gram equivalents (FGE)/55-gallon drum and Class C limits; Greater than Class C with DOE approval
Energetics	No separable organic layer; exotherms/endotherms < 1.0	No requirement specified
Flammable gas	Eliminate non-radiolytic gas generation; specific gravity (SpG) x solids depth < 148 (solids < 379 m^3)	Radiolytic gas generation must be controlled
Heat generation	<70,000 British thermal units (BTU)/hr (commingled with DST contents)	< 3.5 watts/m^3 or ensure integrity of container
Particle size	Less than 177 microns (for retrieval/mobilization)	No requirement specified
Pyrophoric material	Eliminate reactive materials in sludge	Radioactive pyrophorics < 1%; non-radioactive pyrophorics prohibited
RCRA-regulated metals	Specific waste codes acceptable	Specific waste codes acceptable
TSCA-regulated material	Prohibited, unless there is a formal determination that TSCA regulations do not apply *and* [PCB] < 50 ppm	Acceptable for non-TRU waste; requires DOE approval for TRU waste because of WIPP limits

[1] A Criticality Safety Evaluation Report (CSER) will establish the definitive criticality criteria. Currently the draft CSER specifies a particle size of less than 10 microns, therefore this is the limit assumed in this report rather than the 50 micron limit specified in Carothers et. al. (1997).

Table 5-2. Constraints Imposed By Final Disposal Facilities

Sludge Characteristic	Final Disposal Facilities Waste Acceptance Criteria		
	National Geologic Repository (DOE 1996a)	Waste Isolation Pilot Plant RH-TRU (DOE 1996b)	Environmental Restoration Disposal Facility (BHI 1998)
Particle Size	Particulate materials must be incorporated into encapsulating matrix.	Not specified by WIPP (transport limit of 1-4 mm)	Not applicable
Pyrophoric constituents	Shall not be in an amount that compromises repository objectives.	Radionuclide pyrophorics: <1% Non-radionuclide pyrophorics prohibited	Prohibited
Flammable Gas	No combustible waste forms or explosive materials	Flammable VOCs ≤500 ppm in headspace	≤ 10% organic/ carbonaceous material
Heat Generation	1500 Watt/canister	<300 Watts/canister	Not specified
Fissile Material	Pu < 2500 g/m^3	< 325 FGE/RH-cask 200 FGE/Pipe overpack	<100 nCi/g TRU activity and < Class C limits
Dose Rate	Gamma <100,000 rem/hr per canister Neutron < 10 rem/hr per canister	≤1000 rem/hr per canister ≤200 mrem/hr per cask	
TRU Alpha Activity	Accepted if Nuclear Regulatory Commission (NRC) determines geologic disposal appropriate	Accepted (non-TRU waste specifically prohibited) ≤ 23 Ci/L total activity	Prohibited
High Level Waste	Accepted	Prohibited	Prohibited
RCRA-Regulated Waste	Prohibited	Accepted for specific waste codes	Accepted with appropriate treatment
TSCA/PCB-Regulated Waste	No criterion defined	< 50 ppm PCBs	Solids containing PCBs accepted

5.2 CONSTRAINTS

Constraints are externally imposed criteria. In limited instances, modification to or waiver from constraints might be possible, but such an occurrence requires negotiation with external agencies. Regardless of justification, institutional impediments could prevent implementation of an otherwise attractive idea.

- BHI-00139 (BHI 1998): The ERDF is designed to accept waste generated as a result of CERCLA actions. It can accept low-level radioactive waste, dangerous/hazardous waste, hazardous substances, and low-level mixed waste. It cannot accept TRU waste or liquid wastes.

- DOE/EM-0093, EM-WAPS (DOE 1996a): Waste form Producers are required to meet the technical specifications for vitrified high level waste (HLW) to ensure acceptance into the Civilian Radioactive Waste Management System (CRWMS).

- DOE/WIPP-069 (DOE 1996b): Participating DOE TRU Waste Generator/Storage Sites are required to meet the criteria and requirements for contact-handled (CH) and remote-handled (RH) defense TRU waste forms to ensure safe handling, transportation, and disposal in the WIPP.

- EPA/540/G-89/004 (EPA 1988): Applicable or relevant and appropriate requirements (ARARs) must be met or waived for actions conducted under the CERCLA. Only the substantive (versus administrative) provisions of ARARs must be met for those actions conducted entirely onsite (CERCLA Sec. 121(d)(2)). Such onsite actions are exempted from obtaining federal, State of Washington, and local permits (CERCLA Sec. 121(e)(1)).

5.3 COMMON ASSUMPTIONS

To evaluate the alternatives, several assumptions were made based on the best information available, applications of a similar technology, or engineering judgement. Assumptions common to several of the alternatives are identified in this section. Assumptions that are unique to a specific alternative are included in the appropriate alternative's description. The assumptions used in this study are as follows:

- Removal of the sludge from the K Basins will be conducted under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), therefore, environmental permits (except for an NOC license) will not be required.

- The KE Basin floor and pit sludge have been designated TSCA waste based on characterization samples with PCB concentrations greater than 50 ppm (TSCA limit). The KE and KW Basins canister/fuel wash sludge are non-TSCA waste based on characterization samples with PCB concentrations below TSCA regulated limits (i.e., 50 ppm) (Pearce et. al.1998).

- The KW Basin floor/pit sludge is expected to be non-TSCA waste based on process knowledge.
- DOE has determined that the sludge will be managed as a waste rather than as SNF when it is removed from the basins (Wagoner 1996).
- The sludge transfer mechanisms being evaluated for the chemical baseline process are assumed applicable for the alternatives.
- All treatment systems are sized such that the throughput rate meets a 13-month processing window.
- The treatment facility must be capable of supporting start of sludge Operational Readiness Review (April 2004).
- The treatment facility shall be designed to include remote operation and handling of waste packages.
- TWRS does not require new tanks to store treated K Basin sludge
- Worker exposures will be within limits set by regulatory/DOE requirements

6.0 IDENTIFICATION AND INITIAL SCREENING OF ALTERNATIVES

In the following sections, the different alternatives for sludge disposition (i.e., pretreatment, interim storage and final disposal) are discussed and screened. The alternatives were generated by brainstorming and are documented in Miller and Pearce (1998). The alternatives generated at the brainstorming meeting primarily centered around segregating the sludges into low-activity streams (floor and pit sludge) which have a low TRU concentration fraction and high-activity streams (canister and fuel wash sludge) which have a high TRU concentration fraction. The interest in segregating the streams was the expectation that a simple, relatively inexpensive process, could be developed for treating the bulk sludge (floor and pit sludge accounts for 73 wt% of the total sludge in the basins) and a less complex (less equipment, smaller treatment facility, decreased processing times, and so forth) process could be identified for the smaller mass of high-activity sludge. The alternatives brainstormed were thought to be one-step processes that could potentially be located in the Basins, thus eliminating need for new infrastructure. It was acknowledged that this may not be possible and therefore, new infrastructure could be the main driver for cost in all cases.

Additionally, if the final disposal site identified for the low-activity streams has less stringent PCB requirements (i.e., solids containing PCBs accepted at the ERDF), this could alleviate the regulatory constraints imposed on the baseline treatment option. The high-activity streams are non-TSCA waste, therefore the processing steps for treating the PCBs could be eliminated and thereby further simplifying the treatment process for the high-activity sludge streams. The segregation approach would disposition the low-activity streams using a different treatment, interim storage, and disposal

path than that identified for the high-activity streams. To define the alternatives for the segregated streams, a disposition option for the low-activity streams would be paired with a disposition option for the high-activity streams.

Alternatives were also generated for sludge disposition paths which would not require segregation of the sludge streams. For these alternatives, all of the sludge streams would be dispositioned through a common treatment (for example, grouting, calcination, vitrification), interim storage, and disposal path. Following is the list of options generated for disposition paths that rely on segregating the K Basin sludge streams and those which do not rely on segregation:

Segregation Options:

- low activity streams→grouting→ERDF
- low activity streams→grouting→CWC→WIPP
- high activity streams→modified chemical→TWRS-P[2]/DST storage→TWRS-P Treatment→Repository
- high activity streams→grinding/milling→TWRS-P/DST storage→TWRS-P Treatment→Repository
- high activity streams→hot water oxidation→TWRS-P/DST storage→TWRS-P Treatment→Repository
- high activity streams→vitrification (frit)→TWRS-P/DST storage→TWRS-P Treatment→Repository
- high activity streams→vitrification→CSB/CWC storage→Repository
- high activity streams→calcination→TWRS-P/DST storage→TWRS-P Treatment→Repository
- high activity streams-→calcination→CSB/CWC storage→Repository

Non-segregation Options:

- mixed high/low streams→grouting→CWC→WIPP
- high/low streams→TWRS-P storage→TWRS-P Treatment→Repository
- high/low streams→pretreatment→TWRS-P/DST storage→TWRS-P Treatment→Repository
- high/low streams→pretreatment→CSB/CWC storage→Repository/WIPP

The first step in the evaluation process was to assess whether an alternative would meet the applicable constraints and requirements (as defined in Section 5.0 of this report) and if they did not to screen them from further consideration. Section 6.1 provides the conclusions of the screening process and Section 6.2 provides a list of the alternatives to be considered further.

[2] TWRS Privatization Project (TWRS-P). Refers to those options sending treated or untreated sludge to the TWRS Phase I Treatment Facility.

6.1 SCREENED ALTERNATIVES

6.1.1 Grouting to ERDF

This is not a viable alternative, as it does not meet the constraints established in Section 5. This option considers solidification of the low-activity sludge streams, only, in a cementitious grout and then disposal of the grouted waste form at the ERDF. Assuming the final grout density is 1.76 g/cm^3 (i.e., no aggregate), and the as-settled sludge is slurried 1:1 by volume with water to enable transfer, the increase in volume would need to be a factor of 25 to 65 to reach 100 nCi/g. There is no technical or regulatory reason to use such a high ratio of additive; solidification could be achieved at much lower ratios. This option was dropped from further consideration because it will not meet the ERDF waste acceptance criteria for a non-TRU waste without high additive ratios. The addition of additive solely for the purpose of making the final waste form non-TRU is inconsistent with current DOE and regulator policy. The detailed analysis of this option is provided in Appendix A.

6.1.2 Treated Sludge to TWRS Phase I Treatment Facility Option

This is potentially a viable alternative but will not be considered further because a comparative evaluation of this alternative against the others cannot be made due to inadequate information available at the time of this study. This option included treating the sludge before sending the high-activity sludge to the TWRS Phase I Treatment Facility for interim storage or direct feed to the vitrification plant. The most technically feasible approach for this option would be construction of a new facility for receipt and transfer of sludge. The sludge would be transferred as a slurry via a dedicated pipeline from the new facility to the TWRS Phase I Treatment Facility vitrification plant. Therefore, if the treated sludge resulted in a calcined or glass (frit material) waste form, the waste would have to be re-wetted. To fully evaluate this option the following issues need to be resolved: design and cost of new facility, negotiation change with privatization contractor, schedule impacts, definition of acceptance criteria for all possible waste forms (liquid, calcine, frit).

6.1.3 Untreated Sludge to TWRS Phase I Treatment Facility

This is potentially a viable alternative but will not be considered further in this study because the assumption of relaxed acceptance criteria for storage of untreated sludge in a new TWRS Phase I Treatment Facility storage tank will not be verified within the timeframe required for completion of this analysis. This alternative was envisioned to send untreated sludge to a TWRS Phase I Treatment Facility storage tank and allow the TWRS Phase I Treatment Facility to treat the sludge for direct feed to a melter. If evaluation of the need for additional tanks within the Waste Disposal Division (WDD) program indicates that additional tank capacity is required, consideration of the K Basin sludge in design of those tanks could be advantageous. The new tank criteria could be more flexible depending on the design (could be designed to be geometrically favorable for criticality prevention) and capabilities of the new tank (mixing system that could mitigate flammable gas concerns). Additionally, a possible cost advantage could be realized by building a reusable facility run by one organization. A study on need for additional tank space is being conducted for the TWRS Phase I Treatment Facility however, it does not include consideration of the K Basin sludge. The acceptance

criteria for interim storage in a new tank have not been established (a safety analysis for the TWRS Phase I Treatment Facility storage tank is required). This option is eliminated from further consideration in this study because treatment would be required.

6.1.4 Hot Water Oxidation

In this alternative, the sludge is treated by oxidation of metals and metal hydrides in water at elevated temperatures followed by interim storage in an existing DST. Final disposal would be at the geologic repository via the Phase II high-level waste melter. The reaction time to oxidize a 6350 μm uranium particle in water at 100°C is estimated to be 2557 hours (107 days). If each batch of sludge (215 total) is processed for this period, the number of oxidation tanks operating in parallel to meet the 13-month processing window is excessive. However, by segregating the sludge into several size fractions the number of tanks required is greatly reduced (14 total).

Compared to the nitric acid flowsheet the hot water oxidation with grinding option would replace screening/elutriation, two dissolvers, a centrifuge and polishing filter with screening, 14 hot water oxidation tanks, a grinder and hydrocyclone separator. It is expected that the hot water oxidation process would involve additional complexity in demonstrating compliance with TWRS size specifications. The hot water oxidation would reduce the amount of sodium sent to TWRS (no need to neutralize nitric acid with NaOH) resulting in a long-term savings in LAW glass volume. In addition, the hot water oxidation process would have a lower volume of secondary sludge waste to dispose. These savings would be partially offset by the additional sodium introduced during caustic sludge washing in the DST due to the additional solids sent to TWRS (ground sand, zeolite, OIER).

The hot water oxidation option was discounted for further evaluation because it was judged that the 7-fold increase in oxidation tanks compared to dissolvers would increase the hot cell size and increase the initial facility cost. There does not appear to be any significant benefit to offset the higher initial cost. In the evaluation, near term costs are weighted 4 times higher than long term costs so that if the alternative were evaluated, it is unlikely that the savings would be sufficient to offset the higher initial cost. Hot water oxidation, considered alone, was screened from further consideration. However, the approach was used within the *grouting → CWC → WIPP* alternative to oxidize the metallic uranium particles in the fine solids fraction prior to grouting. Detailed analysis of this option is provided in Appendix B.

6.2 ALTERNATIVES TO BE EVALUATED

The non-segregation strategy where all of the sludge streams are processed using the same disposition path for treatment, storage, and final disposal was carried forward. The six alternatives considered for further evaluation are as follows:

- baseline chemical→DST storage→TWRS-P Treatment→Repository
- modified chemical→DST storage→TWRS-P Treatment→Repository
- grinding/milling→DST storage→TWRS-P Treatment→Repository
- vitrification→CWC storage→WIPP/Repository
- calcination→CWC storage→WIPP/Repository
- grouting→CWC storage→WIPP

7.0 DESCRIPTION OF ALTERNATIVES FOR REEVALUATION

For each alternative, the following tasks were performed to support the evaluation process:

- A process flow sheet was developed to meet the applicable constraints and requirements of the downstream waste management facilities (i.e., TWRS, ERDF, the repository, and WIPP).
- Technologies necessary for the implementation of the process steps were selected
- A preliminary hazard analysis was performed for each of the alternatives
- Maintenance concepts were defined and a preliminary layout of the processing facility was developed.
- Parametric cost information associated with the treatment facility, transport to interim storage, final treatment and final disposal was evaluated. Costs were considered for the entire life cycle of each sludge disposition alternative.

The alternatives are described in Sections 7.4 through 7.9. The descriptions of the alternatives are based on the present understanding of the chemistry and physics of the K Basins sludge and currently available information on treatment technologies and waste management facility acceptance criteria.

7.1 SLUDGE TREATMENT FACILITY

This study assumed the treatment system would be in a standalone facility located on the Hanford Site (most likely in the 100 or 200 Area). At the outset of this study two locations were being considered, the CVDF and the basin proper. Preliminary information from a site selection study (currently underway) which evaluates locations to be considered for the baseline sludge treatment system and discussions with K Basin personnel have indicated that neither the CVDF nor the Basin proper may be suitable. This section provides rational for the assumption of a standalone facility. Determination of the exact location of the treatment facility is outside the planned scope of this study.

7.1.1 Cold Vacuum Drying Facility

The baseline assumes the sludge treatment process will be located in the CVDF. This assumption is based on an early pre-conceptual concept that placed the chemical treatment process equipment on skids. Preliminary dose rate and shielding calculations indicate that a hot cell is required to provide shielding (~75 cm of concrete) for remote operation of the main processing vessels (Westra 1998). It is questionable whether the concrete base mat under the CVDF bays is thick enough to support the required hot cell. There are other challenges to building the sludge treatment facility in the CVDF such as space limitations, safety analysis report (SAR) impacts, ventilation upgrades, safety envelope for dispersible materials, sludge transportation and so forth. These will be covered in detail in a site selection study that is currently underway.

Additionally, the sludge transportation study that is currently in progress for the baseline chemical option indicates that a standalone facility may be preferable to the CVDF or required. The preliminary conclusions of the sludge transportation study indicate that sludge transportation costs might be minimized by locating the sludge treatment facility near the AW tank farm (in the 200 E Area) or closer to the basins (within ¼ mile).

7.1.2 Basin Proper

Locating the sludge treatment process as described in the other alternatives (vitrification, grinding/milling, grouting and calcination) in one or both of the basins was discussed with K Basin Operations. Discussion with personnel from K Basin Operations to determine if any of the other alternatives could be located in the Basin, thus precluding construction of a new facility, indicate the available real estate is not adequate to support placement of any of the treatment processes, with the exception of the grinding/milling alternative, within the basin proper.

A grinder sized to process sludge at the estimated rate to meet a 13-month processing window is physically too large to fit in the basin and would have to be located under water. The grinder could be located in the East Bay but only after a portion of the fuel and racks are removed. Further, the existing crane, which services the East Bay, does not have the capacity to lift the grinder. In order to get the machine into the basin, a hole would have to be cut into the roof, and the equipment lowered through the hole into the East Bay. The grinder would be skid mounted, eliminating the need to bolt the grinder to the basin floor. The monorail would be used to move the grinder under water to the other side of the bay making room for the second grinder. Construction at the site to prepare for the grinding/milling process would impact scheduled operations in removing fuel and debris from the basin resulting in a delayed schedule.

7.2 COMMON PROCESS CONSIDERATIONS

7.2.1 Sludge Segregation

All of the options, except baseline chemical and grinding/milling, assume a sludge segregation step is

performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the OIER. This separation results in two to three separate feed types (type A, type B, and OIER) being delivered to the treatment facility. The OIER are delivered as a segregated batch for grouting in the facility in the modified chemical, vitrification, and calcination processes. Type A feed consists of particles <250μm (majority of KE1 and nearly all of KW1 and KW3) while type B feed consists of particles >250μm (KW2 and KE2 along with the oversize material from KE1). In the grouting alternative, the OIER are recombined with type A feed prior to delivery to the treatment facility.

Sludge segregation for the baseline chemical alternative is assumed to take place in the treatment facility, this assumption was not changed as the intent of this alternatives study was to investigate ways to simplify and reduce cost. The elutriation and screening steps are moved to the basin to eliminate equipment which otherwise would need to be placed in a hot cell. This provides the opportunity to minimize expensive hot cell space. The reason the OIER beads are separated is to avoid contacting them with nitric acid in the dissolver. Nitrated resin if allowed to dry out could undergo an energetic reaction that could pose a safety issue. In the grouting alternative, the OIER beads are separated to avoid combustion of organics, soot in the offgas and corrosion of metallic parts in the calciner. Additionally, separating the beads prevents the potential for the beads to become a sticky mass in the calciner.

The grinding/milling alternative does not implement the sludge segregation step in the basins because it does not have safety concerns with nitrated beads. Furthermore, TWRS has indicated that the volume of OIER estimated in the sludge would be acceptable for storage in AW-105 (Erlandson 1999).

7.2.2 Transfer Method

The method for transferring the sludge materials to the treatment facility and within the process was assumed to be by slurry transfer. For the high-density fuel pieces (up to 6350 μm at a density of 19 g/cc) this means of transfer has not been demonstrated and may prove to be nonviable. Testing and demonstration will be necessary to validate the current process (slurry transfer) or investigate alternate methods (sorting in the basin or treatment facility).

7.2.3 Grouting of Insoluble Solids and OIER

All of the alternatives, with the exception of the Grouting Alternative, remove the oversize materials and OIER and grout for disposal at ERDF. The baseline chemical process would remove the TRU constituents during the leaching process such that the TRU waste limit of 100 nCi/gram would be meet. In the other processes, it is assumed that the OIER and insoluble solids, after slurried to12 wt% solids and grouted would be suitable for ERDF disposal. If the material turns out to be TRU, a nitric acid rinse (to reduce the TRU levels) prior to grouting could be included or the material could be disposed at the WIPP.

7.3 COMMON SAFETY CONSIDERATIONS

Several fundamental characteristics of the sludge to be processed impose safety considerations for any process. Specifically these are; high radiation which will require heavy shielding (approximately 75 cm of concrete) and remote operation, criticality prevention measures, hydrogen mitigation features for vessels upstream from the oxidation process, and features to preclude pyrophoric reaction of metallic uranium.

Unshielded exposures for some of the feed streams have been calculated in excess of 4,000 R/hr. All of the processes will be housed in remotely operated hot cells. The design philosophy varies slightly between the alternatives, but a lightly shielded or unshielded primary process system is not an option for consideration.

Included in the sludge are approximately 10,000 kilograms of enriched uranium and 30 kilograms of plutonium. These fissile materials are not uniformly distributed through the sludge, but are found in higher concentrations in some of the feed streams than others. The principal means to deal with this issue is limiting the amount of sludge in the process to less than one third of a minimum critical mass.

Hydrogen generated as the result of uranium oxidation will be monitored and diluted to less than the lower flammability limit in all vessels upstream from the oxidation unit operation. In some instances, inert atmospheres will be used. To preclude pyrophoric reactions, the sludge will be kept covered by an excess of water, or will be exposed to the cell atmosphere only in inerted cells.

7.4 ALTERNATIVE 1 – BASELINE CHEMICAL

The baseline chemical dissolution alternative treats the sludge by dissolving the fuel constituents in nitric acid, separating the insoluble material, adding neutron absorbers for criticality safety, and reacting the solution with caustic to co-precipitate the uranium and plutonium. A truck will transport the resulting slurry to an underground storage tank (currently identified as 241-AW-105). The undissolved solids and the ion exchange media separated before the dissolver will be treated to reduce the TRU and ^{137}Cs content, stabilized in a grout matrix, and transferred to the ERDF for disposal.

The following sections provide summary information for the baseline chemical alternative. Detailed description and analysis is provided in Appendix C.

7.4.1 Process Flow Logic

The baseline chemical treatment process includes the following operations:

- Pumping the sludge from the transport container into the lag storage tank where it will be held until it can be moved on through the process
- Sieving the sludge on a screen to remove the organic resin beads, grafoil, and some inorganic ion exchange media followed by separation of the resin from larger and denser sludge particles in an elutriation column
- Transfer larger and denser sludge particles to the dissolver

- Dissolving the sludge in nitric acid by continuously feeding a batch of sludge into 6 M HNO_3 at 95°C
- Physically separating residual solids (mostly zirconium, sand, dirt, and the remaining inorganic ion exchange media) from the solution in a centrifuge followed by a polishing filter
- Adding iron and/or depleted uranium as a neutron absorber to the nitric solution
- Precipitating the acid solution using a sodium hydroxide solution
- Chemically adjusting the solution using sodium nitrite
- Leaching the organic resin beads to remove absorbed TRU constituents
- Leaching the insoluble solids to remove absorbed TRU constituents
- Combining and stabilizing the resin beads and insoluble solids (sand, zircaloy, grafoil, and zeolite) in a grout matrix.

A block flow diagram is shown in Appendix C.

7.4.2 Safety Considerations

The primary safety considerations associated with the baseline chemical alternative include the following:

- Dose to worker for maintenance of pumps and valves
- Reaction rate control in the dissolver
- Handling of leached OIER

7.4.3 Transportation and Interim Storage

The baseline chemical process will generate about 1620 m^3 of waste slurry that will be transported to 241-AW-105 in an 8 m^3 transport cask and offloaded at a newly constructed Sludge Receiving station. It will require approximately 203 shipments to transfer all of the sludge to the DST.

The process will also generate about 34 m^3 of grouted waste (7 liners) that will be transported to ERDF for disposal. There will also be 49 waste drums (55-gallon) generated for disposal of filter cartridges. Forty-six of the filter cartridges will be grouted in drums sent to ERDF, one will be TRU waste that will be interim stored at CWC until sent to WIPP for final disposal, and two filter cartridges will be TRU waste containing PCBs at concentrations > 50ppm. These two filters will be stored in drums on-site with other "like-waste" until a final disposal path is determined.

7.4.4 Final Disposal

No additional glass canisters from the high level waste (HLW) will be produced as a result of blending the treated K Basin sludge with AW-105 (Taylor 1999). There will however, be an increase in the amount of glass produced from the low activity waste due to the dissolved sodium (152,346 kg) in the treated sludge sent to AW-105 plus the sodium (7,392 kg) used to caustic leach the sludge by TWRS prior to delivery to the vitrification vendor. This quantity of sodium results in approximately 571 m^3 of low-activity waste (LAW) (Taylor 1999).

At some future date, one to three waste drums will be shipped to the WIPP for final disposal.

7.4.5 Open Issues

- The total volume of solids in the sludge waste stream sent to Tank Farms after chemical treatment may exceed 100,000 gallons (allocated space). Some of the waste may need to be sent to AW-103 as well as to AW-105.

7.4.6 Advantages

The key advantages of the baseline chemical alternative are as follows:

- This process utilizes mature technology and processes. Key chemical process steps have been demonstrated in small-scale laboratory experiments using actual K Basin sludge.
- Process control and safety control technology is mature and well established.
- Engineering studies and laboratory testing of the baseline treatment process indicate it would be sufficient to meet TWRS safety and operational criteria for AW-105.

7.4.7 Disadvantages

The key disadvantages of the baseline chemical alternative are:

- Numerous process steps are needed.
- Requires a significant number of shipments (203) to the TWRS. Poses potential risk to schedule.
- Product verification for TWRS waste streams requires sample and analysis of every batch.
- Generates a large volume of waste (616 m^3) that requires landfill disposal (note: volume does not include D& D).

7.5 ALTERNATIVE 2 – MODIFIED CHEMICAL

The modified chemical dissolution alternative treats the sludge by segregating sludge in the basin, dissolving type A and type B feeds in nitric acid, separating the insoluble material, adding neutron absorbers for criticality safety, and reacting the solution with caustic to co-precipitate the uranium and plutonium. The modified chemical dissolution alternative is a modification of the baseline chemical process and is predicated on the assumptions that enhancements to the baseline process could be realized by use of the PCB megarule and use of maximum permissible grout volume increases (i.e., up to 10 times per EPA suggestion). These assumptions resulted in the following changes to the baseline process; 1) eliminated polishing filters, 2) replaced centrifuge with less expensive solid/liquid separation method, 3) eliminated buffer tank, and 4) eliminated use of resin bead and insoluble solids leaching steps and associated chemicals.

The modified chemical process produces a slurry which meets the waste acceptance criteria established by TWRS. The resulting slurry will be transferred to an underground storage tank (currently identified as 241-AW-105) for interim storage. Final treatment will be via the Phase II high-level melter with subsequent transport to the national geologic repository for final disposal. The undissolved solids will be grouted to meet the ERDF waste acceptance criteria for final disposal.

The following section provides summary information for the modified chemical alternative. Detailed description and analysis is provided in Appendix D.

7.5.1 Process Flow Logic

The modified chemical treatment process includes the following operations:

- Feed type discrimination in the basin
- Pumping the sludge (type A and B feeds) from the transport container into the lag storage tank where it will be held until it can be moved on through the process.
- Transfer type A and type B feed to the dissolver
- Dissolving the sludge in nitric acid by continuously feeding a batch of sludge into 6 M HNO_3 at 95°C
- Physically separating residual solids (mostly zirconium, sand, dirt, and the remaining inorganic ion exchange media) from the solution
- Adding iron and/or depleted uranium as a neutron absorber to the nitric acid solution
- Precipitating the acid solution using caustic solution
- Chemically adjusting the solution using sodium nitrite
- Delivering the resin beads directly to the insoluble solids holding tank
- Combining and stabilizing the resin beads and insoluble solids (sand, zircaloy, grafoil, and zeolite) in a grout matrix.

A block flow diagram is shown in Appendix D.

7.5.2 Safety Considerations

The primary safety considerations associated with the modified chemical alternative include the following:

- Dose to worker for maintenance of pumps and valves
- Reaction rate control in the dissolver

7.5.3 Transportation and Interim Storage

This treatment process will generate about 1525 m^3 of waste slurry that will be transported to 241-AW-105 in a 8 m^3 transport cask and offloaded at a newly constructed Sludge Receiving station. It will require approximately 191 shipments to transfer all of the sludge to the DST.

This process will also generate about 371 m^3 of grouted waste (1784 Contact Handled [CH]-nonTRU drums) from insoluble solids that will be transported to ERDF for disposal. For the analysis it is assumed that 3 drums can be placed onto each truck shipment, therefore, it will require approximately 595 shipments to transfer the waste to the ERDF.

7.5.4 Final Disposal

No additional glass logs from the high activity waste will be produced as a result of blending the treated K Basin sludge with AW-105. There will however, be an increase in the amount of glass produced from the low activity waste due to the dissolved sodium (123,000 kg) in the treated sludge sent to AW-105 plus the sodium (7863 kg) used to caustic leach the sludge by TWRS prior to delivery to the vitrification vendor. This quantity of sodium results in approximately 468 m^3 of LAW (see Appendix I).

7.5.5 Open Issue

- The total volume of solids in the sludge waste stream sent to Tank Farms after chemical treatment may exceed 100,000 gallons (allocated space). Some of the waste may need to be sent to AW-103 as well as to AW-105.
- Interface agreement with K Basins on locating elutriation columns in the Basins.

7.5.6 Advantages

The key advantages of the modified chemical alternative are as follows:

- This process utilizes mature technology and processes. Key chemical process steps have been demonstrated in small-scale laboratory experiments using actual K Basin sludge.
- Process and safety control technology is mature and well established.
- Engineering studies and laboratory testing of the baseline treatment process indicate it would successfully meet TWRS safety and operational criteria for AW-105.
- Has fewer process steps than the baseline process, thus reducing complexity issues associated with the baseline chemical alternative.

7.5.7 Disadvantages

The key disadvantages of the modified chemical alternative are:

- Generates a large volume of waste (~839 m^3; does not include D&D volumes) that requires landfill disposal.
- Requires a large number of slurry shipments (~191) to TWRS in a short period of time (13-months).
- Product verification for TWRS waste streams requires sample and analysis of every batch

7.6 ALTERNATIVE 3 -- GRINDING/MILLING

The grinding/milling alternative being discussed here reduces sludge particle size through fracturing/mechanical abrasion and accompanying oxidation reactions of the metallic uranium in water. This process treats the sludge materials to produce a slurry that meets TWRS waste acceptance criteria for interim storage in an underground tank (currently identified as 241-AW-105). Subsequent treatment would be via the Phase II high-level melter for final disposal to the national geologic repository. Oversized solids (e.g., zirconium cladding), surviving the grinding process, would be stabilized in a grout matrix and transferred to ERDF for disposal.

Particle size reduction by milling was originally examined to determine if commercially available technologies could be used for processing K Basin sludge to meet the TWRS waste acceptance criteria (Precechtel and Packer 1997). Technologies considered included hammer mills, an impact type shredder, a grinding/dispersing system, and a tooth mill grinder. That evaluation concluded there was insufficient experience and confidence in existing size reduction processes to reduce the particle size of the K Basin sludge to less than 177 μm. In particular, there was no relevant experience involving the processing of uranium metal. A subsequent study evaluated the use of high-energy vibratory milling for processing K Basin sludge (Precechtel and Turnbaugh 1998). This technology had been not considered in the previous particle size reduction study. Precechtel and Turnbaugh (1998) concluded that high-energy milling could potentially offer cost, schedule, safety, and feasibility advantages over the baseline nitric acid dissolution process. However, they also concluded that further evaluation, as provided in this study, was necessary to address assumptions and uncertainties associated with the process.

Literature studies do not provide evidence that irradiated uranium can be size reduced by grinding/milling. Moreover, a typical industrial approach for the production of small metal particles is to convert the metals to the hydride form, grind, then dehydride the ground material back to metal. Evaluation of this process, therefore, considered only the oxidation reaction mechanism.

The following sections provide summary information for the grinding/milling alternative. Detailed description and analysis is provided in Appendix E.

7.6.1 Process Flow Logic

The grinding/milling process includes the following process steps:

- Sludge transfer from transport container to lag storage vessel
- Sludge transfer to grinder
- Sludge grinding
- Separating solids by particle size to allow only 10 μm or less particles to go to the adjustment tank and returning larger particles to the grinder
- Addition of neutron absorbers as required
- Adjusting the slurry by addition of sodium hydroxide and sodium nitrite
- Separation of cladding solids greater than 1000 μm to be grouted

- Grouting of separated solids
- Transfer of the sludge to TWRS

A block flow diagram is shown in Appendix E.

7.6.2 Safety Considerations

The primary safety considerations associated with the grinding/milling alternative include the following:

- Hydrogen generation in the grinding/milling machine
- Reaction rate control in the grinding/milling machine
- Criticality management of recycling large particles in grinding/milling machine

7.6.3 Transportation and Interim Storage

This treatment process will generate approximately 1208 m^3 of waste slurry that will be transported to 241-AW-105 in a 7 m^3 transport cask and offloaded at a newly constructed Sludge Receiving Station. It will require approximately 175 shipments to transfer all of the sludge to the DST.

This process will also generate approximately 22 m^3 (104 drums of CH-nonTRU waste) of grouted waste that will be transported to ERDF for disposal. For the analysis it is assumed that 3 drums can be placed onto each truck shipment, therefore, 35 shipments will be required to transfer the waste to the ERDF.

7.6.4 Final Disposal

No additional glass canisters from the high activity waste will be produced as a result of blending the treated K Basin sludge with AW-105. There will, however, be an increase in the amount of glass produced from the low activity waste resulting from the dissolved sodium (5903 kg) in the treated sludge sent to AW-105 plus the sodium (13,311 kg) used to caustic leach the sludge by TWRS prior to delivery to the vitrification vendor. This quantity of sodium results in approximately 69 m^3 of LAW (see Appendix I).

7.6.5 Open Issues

- Ability to meet the TWRS waste acceptance criteria for particle size, pyrophoricity, and PCBs.
- Ability to monitor and control uranium-water reactions
- Ability to meet the 13-month processing window if the rate is not accelerated by fracturing
- Determine particle separation/classification for achieving a particle size cut at 10 μm
- Generally, vibratory grinders are used for the reduction of particles less than 1000 μm. If the sludge contains a substantial quantity of particles between 1000 μm and 6350 μm, longer processing times may be necessary to fracture these larger particles

7.6.6 Advantages

The key advantages of the grinding/milling alternative (if demonstrated to work through additional development) are as follows:

- Relatively simple process with few process steps
- Equipment requirements are moderate
- Can process silica, corrosion products, rocks from ~ 250 μm to less than 10 μm in about 2 hrs (given a homogeneous feed)
- Wide range of grinding machine sizes commercially available.

7.6.7 Disadvantages

The key disadvantages of the grinding/milling alternative are:

- Little or no previous experience in radioactive environment
- Generally used to process feed that is less than 1000 μm
- Product verification for TWRS waste streams requires sample and analysis of every batch.
- Vibrations may create maintenance challenges
- Large number of transfers of slurry sent to TWRS (175 shipments)

7.7 ALTERNATIVE 4 -- VITRIFICATION

The vitrification alternative treats the sludge by segregating the sludge in the basins, delivering OIER beads directly to grouting and type A feed directly to a melter feed tank. Type B feed is delivered first to a dissolver feed tank then fed to a dissolver. Undissolved material leaving the dissolver is removed on a 250 μm screen and the remaining solution and fine solids sent to a melter feed tank. The option is evaluated assuming a borosilicate waste glass formulation melted in a low-temperature (1150 C) joule-heated inconel electrode refractory lined melter. However, an evaluation of various melter technologies would be required to select the most appropriate technology for the application. Glass is poured directly into 3m high stainless steel canisters of the type used by Defense Waste Processng Facility (DWPF). The remote-handled glass canisters would be placed in modular storage units for interim storage at the CWC and ultimately disposed in the geologic repository. Oversize material separated from the dissolver solution is washed with nitric acid, rinsed and then grouted into drums for disposal at the ERDF.

The following sections provide summary information for the vitrification alternative. Detailed description and analysis is provided in Appendix F.

7.7.1 Process Flow Logic

The vitrification process includes the following process steps:

- Feed type discrimination in basin
- Type B feed:
  - Transfer to dissolver feed tank
  - Dissolve sludge in nitric acid by continuously feeding a batch of sludge into 6 M HNO_3 at 95 C.
  - Sieve the insoluble residues
  - Sugar denitration at 100 C, to decrease the nitrate content below 1 M
  - Sample solution
  - Redox adjustment and glass former addition
  - Feed solution to the melter
- Type A feed:
  - Transfer to melter feed tank and evaporate water to obtain a 500 g/l slurry
  - Sampling of solution
  - Redox adjustment and glass former additions
  - Feed solution to the melter
- Wash insoluble residue then grout
- Deliver OIER directly to grout mixing tank and grout as separate stream
- Intermittent pouring of glass into 3-m glass canisters
- Weld glass canisters and decontaminate external surface

A block flow diagram is shown in Appendix F.

7.7.2 Safety Considerations

The primary safety considerations associated with the vitrification alternative include the following:

- Control of the dissolver
- Control of the sugar denitration operation
- Potential for contamination spread to cell environment due to upset condition in the melter
- Controls (administrative) to avoid mixing type A feed and type B feed that have been through the dissolver

7.7.3 Transportation and Interim Storage

Vitrification will generate approximately (46) 3-meter canisters of HLW glass and (189 CH drums) 35 m^3 of grouted waste that will be disposed of at the ERDF. It will require approximately 13 shipments to transfer the 3-meter canisters to the CWC for storage and 63 shipments to transfer the drums to ERDF.

7.7.4 Final Disposal

At some future date, the 46 HLW glass canisters would be shipped to the geologic repository for final disposal.

7.7.5 Open Issues

- Assumptions used for canister filling assume that the 2500 g/m^3 limit on Pu for the repository satisfies criticality concerns with the glass canisters.
- Can the condensate be transferred into the transport package and sent to basin water treatment system?
- Sludge may contain noble metals. The total quantity needs to be estimated so design of melter can deal with it.
- Waste designation of sludge as HLW or TRU
- Interface agreement with K Basins on locating elutriation columns in the Basins
- Optimize storage package for storing glass canisters on Hanford site.

7.7.6 Advantages

The key advantages of the vitrification alternative are as follows:

- Organic contaminants (i.e., PCBs) are removed or destroyed
- Produces a very stable waste form
- Good waste loadings may be achievable resulting in a low volume of waste product
- Waste form does not generate hydrogen
- Mature and demonstrated technology

7.7.7 Disadvantages

The key disadvantages of the vitrification alternative are:

- Requires off-site approval of the waste form (complex interfaces) and creates an additional waste stream from the Hanford Site that needs to be qualified
- Rework of an off specification canister of glass is difficult
- The process uses high temperatures (1150 C) and is relatively complex
- Offgases are generated, requiring treatment (volatilization of radionuclides - additional complexity)
- Frequent feed analysis is required to control glass composition.

7.8 ALTERNATIVE 5 - CALCINATION

The calcination alternative treats the sludge by segregating the sludge in the basins, delivering OIER beads directly to grouting and type A feed directly to a calciner feed tank. Type B feed is delivered to a dissolver feed tank then to a dissolver. Undissolved material leaving the dissolver is removed on a

250μm screen and the dissolver solution sent to the calciner feed tank. Calcine material is packaged into 1 gallon cans and placed into a 21-can shielded overpack which allows the package to be contact handled. After interim storage at CWC, the 21-can overpack is then placed in a ten-drum overpack (TDOP) and placed in a TRUPACT-II for shipment to WIPP. Oversize material separated from the dissolver solution is washed with nitric acid, rinsed and then grouted into drums for disposal at the ERDF.

The following sections provide summary information for the calcination alternative. Detailed description and analysis is provided in Appendix G.

7.8.1 Process Flow Logic

The calcination process includes the following process steps:

- Feed type discrimination in basin
- Feed type B:
  - Transfer to a dissolver feed tank
  - Dissolve sludge in nitric acid by continuously feeding a batch of sludge into 6 M HNO_3 at 95 C.
  - Sieve the insoluble residues
  - Feed calciner at constant flowrate of about 75 l/h
- Feed type A:
  - Transfer to calciner feed tank
  - Feed agitated slurry to calciner at a constant flowrate of about 75 l/h
- Wash insoluble residue then grout
- Deliver OIER directly to grout mixing tank and grout as separate stream
- Solid stream at exit of calciner:
  - Collect calcine in filling bin (approximately 80 liters/bin)
  - Transfer into one-gallon can

A block flow diagram is shown in Appendix G.

7.8.2 Safety Considerations

The primary safety considerations associated with the calcination alternative include the following:

- Criticality management of the calcine material
- Reaction rate control in the dissolver
- Reaction rate control in the calciner (assure complete reaction while avoiding hot spots)

7.8.3 Transportation and Interim Storage

Calcination will generate approximately (190) 21-can overpacks of RH TRU waste and (189 CH drums) 35 m^3 of grouted waste that will be transported to the ERDF for disposal. For the analysis it is

assumed that three overpacks can be shipped at a time, therefore, it will require approximately 64 shipments to transfer the 21-can overpacks. Sixty-three (63) shipments are required to transfer the CH drums to the ERDF.

Once the shielded overpack is loaded with 21 one-gallon cans and closed up the package should be a contact-handled package. For shipment to CWC it is intended that the shielded overpack would itself be overpacked in a TDOP and the TDOP shipped to the CWC.

7.8.4 Final Disposal

For shipment to WIPP it is intended that the shielded overpack would itself be overpacked in a TDOP and the TDOP shipped in a TRUPACT-II shipping cask. The package arrangement would need to be approved by the NRC prior to shipment of the material to WIPP.

7.8.5 Open Issues

- Dry storage environment may be needed. Potential for water to diffuse into the containers then combine with oxides to form hydrates and result in hydrogen generation requires investigation.
- Waste designation of K Basin sludge as TRU or HLW
- NRC approval of non-standard waste package
- Interface agreement with K Basins Engineering/Operations on locating elutriation columns in the Basins.

7.8.6 Advantages

The key advantages of the calcination alternative are as follows:

- Mature technology and simple process
- There is minimal need for up front sampling and analytical work on feed material
- One gallon cans can be rearranged in overpacks at a later date to meet FGE or other limits
- Waste volume of product is minimized
- Product is readily reworked at a later date if needed (i.e. made into glass, grout or other)
- Overpacking 1-gallon cans eliminates the need for decontamination

7.8.7 Disadvantages

The key disadvantages of the calcination alternative are:

- The product is dispersible
- Large quantity of 1 gallon cans requiring individual handling

7.9 ALTERNATIVE 6 – GROUTING

The grouting alternative treats the sludge by segregating the sludge in the basins and delivering two types of feed to the treatment facility. Type A feed is delivered directly to the grout feed tank. Type B feed is delivered to a 250 μm screen in an argon-inerted cell where the water used for transfer is drained, the particles are calcined in batch furnaces, and the calcine pneumatically transferred to the grout feed tanks located in an adjacent nitrogen-inerted cell. The feed tanks are maintained at 100°C for 102 hours to oxidize any metallic content passing the 250 μm screen. The slurry in feed tanks is sampled, analyzed and then delivered to a mixing tank where the sludge is mixed with grout formers and pumped into RH-canisters to meet the WIPP waste acceptance criteria. The filled RH-canisters are sent to the CWC for interim storage then shipped to the WIPP for final disposal.

The following sections provide summary information for the grouting alternative. Detailed description and analysis is provided in Appendix H.

7.9.1 Process Flow Logic

The grouting process includes the following process steps:

- Feed type discrimination in the basin
- Type B feed:
    - Transfer from transport container to 250 μm screen
    - Remove free water then transfer particles to trays (~ 12 kg/batch)
    - Load trays into furnace and subject to following heat treatment:
        - Drying at 100 C
        - Dehydride at 400 C
        - Oxidize at 500 C
    - Remove calcine material from tray and transfer to feed tank for sampling and subsequent grouting
- Type A feed:
    - Transfer from transport container to grout feed tank
    - Age at 100 C for 100 hours to fully oxidize the small metallic particles
    - Sample slurry then mix with grout formers

A block flow diagram is shown in Appendix H.

7.9.2 Safety Considerations

The primary safety considerations associated with the grouting alternative include the following:

- Oxidation rate control in furnace
- Handling of dry dispersible solids
- Handling of metallic uranium particles prior to calcination
- Criticality management of calcine materials

7.9.3 Transportation and Interim Storage

The grouted canisters produced will be remote-handled packages. Although remote-handled material has been accepted at CWC in the past, CWC does not routinely accept remote-handled material. Special arrangements would be needed for storage of the remote-handled canisters (~364 total). For purposes of the current study it is assumed that the canisters are placed into a vented steel overpacks that provides shielding to contact dose levels. The overpacks would then be stored at CWC. For this analysis it is assumed that 1 RH-overpack can be shipped at a time, therefore, 364 shipment will be required to transport all of the overpacks to CWC.

7.9.4 Final Disposal

Transport of the RH canisters of grout to WIPP will occur in the NuPac-72B cask at some unspecified future date.

7.9.5 Open Issues

- Waste designation of K Basin sludge as HLW or TRU
- WIPP acceptance of sludge waste steam and/or grout product
- Optimize the waste package

7.9.6 Advantages

The key advantages of the grouting alternative are as follows:

- Well established and accepted technology
- Minimal equipment required which reduces size of cell
- Minimal energy input for type A feed (bulk of material)
- Simple process with minimal maintenance requirements
- No gases generated by stabilization process

7.9.7 Disadvantages

The key disadvantages of the grouting alternative are:

- If the waste form fails to meet criteria, reprocessing is difficult
- Water content in grout matrix results in hydrogen generation from radiolysis
- Flushing of mixing vessel is required after each batch
- Batch calcining process requires an argon-inerted cell to prevent uranium ignition when handling sludge solids
- Loading and unloading of calciner trays is operator intensive

7.10 FACT SHEET

Table 7-1 provides summary of data developed for the alternatives.

Table 7-1. Fact Sheet for Sludge Alternatives

	Alternative 1 - Baseline	Alternative 2 - Modified Chemical	Alternative 3 - Grinding/Milling	Alternative 4 - Vitrification	Alternative 5 - Calcination	Alternative 6 - Grouting
Volume of As-Settled Sludge	50 m3	50 m3	50 m3	50 m3	50 m3	50 m3
Process Steps Involved (number)	11 - 12	7	5	14	7	6
Solids Transfers at controlled rate (number)	4 - 5	2	1	1	1	0
Solids Transfers at uncontrolled rate (number)	5 - 6	4	4	2	2	3
Waste Form	Slurry	Slurry	Slurry	Glass	Calcine	Grout
Assumed waste classification	Mixed TRU	Mixed TRU	Mixed TRU	HLW	RH- TRU	RH- TRU
Waste Volume After Treatment	1620 m3 slurry	1525 m3 slurry	1208 m3 slurry	27 m3 of waste glass	16 m3 of calcine	315 m3 of grout
# Waste Packages	NA	NA	NA	46 (3 m)	4039 (1-gal cans)	364 (RH Canisters)
# Shipments to Interim Storage	203 shipments - TWRS (8 m3 cask)	191 shipments- TWRS (8 m3 cask)	175 shipments -TWRS (7 m3 cask)	13 shipments - CWC (11 NUHOMS 2 Standalone casks)	64 shipments - CWC (192 Overpacks, 3 Overpacks/truck)	364 shipments- CWC
# Secondary Waste Packages	7 liners - NonTRU 46 drums - NonTRU 3 drums - TRU	1784 drums - NonTRU	104 drums - nonTRU	189 drums - NonTRU	189 drums- NonTRU	0
# Shipments for secondary waste packages	18 shipments - ERDF 1 shipment - CWC	595 shipments - ERDF	35 shipments - ERDF	63 shipments - ERDF	63 shipments -ERDF	---
Total volume - land-based disposal facility	LAW - 571 m3 NonTRU - 44 m3 TRU - 1 m3	LAW - 468 m3 NonTRU - 371 m3	LAW - 69 m3 NonTRU - 22 m3	HLW - 46 m3 NonTRU - 40 m3	TRU - 90 m3 NonTRU - 40 m3	TRU - 364 m3 (RH)

8.0 EVALUATION CRITERIA

This section describes the decision criteria that provide a means to facilitate objective assessment and selection of the various technologies that are candidates for use in the treatment, interim storage and ultimate disposal of K Basins sludge. The nine evaluation criteria specified by CERCLA to evaluate remedial action alternatives provide the basis for the criteria to be used in this evaluation. These criteria were chosen because 1) treatment of the K Basin sludge is being conducted under the CERCLA as an interim remedial action and 2) they encompass broad evaluation areas of concern for sludge treatment and disposal. The nine CERCLA evaluation criteria are:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance.

The first two criteria (overall protection of human health and the environment, and compliance with ARARs) are threshold criteria. Alternatives that do not protect human health and the environment or do not comply with ARARs do not meet statutory requirements and are eliminated from further consideration in this study. Compliance with ARARs is effectively evaluated in the cost criterion as processes that require significant expenditures to meet ARARs will have increased costs. The third criterion (long-term effectiveness and permanence) addresses the results of a remedial action in terms of risks that remain at the site after the remedial objectives are met. All of the alternatives would be very effective in the long term as the sludge and the treatment process equipment would be removed from the basins and transferred to facilities that are more protective, thereby eliminating the potential for future releases from the basin. State of Washington acceptance will be further evaluated following the State of Washington's review of the FFS. Community acceptance will be further evaluated after public review of the proposed plan.

The other four CERCLA criteria (reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost) provide a means for differentiating between the alternatives. It should be noted that for the purposes of this assessment, a candidate technology includes all of the activities and operations involved to completely process the waste through to final form, including burial.

These criteria were agreed to by a team composed of representatives from NHC (Sludge Treatment engineers, Safety, Project Management), DOE-RL (TWRS, SFD, TAG), FDH

(Regulatory, Project Direction), B&W (Sludge Treatment Design Authority), DE&SH (Operations) and EPA. The team agreed that the results from applying the criteria should not be considered an end-all answer. Rather, application of the criteria should provide information and a perspective from which to further evaluate options and ultimately select the preferred option (Parker 1999).

8.1 REDUCTION IN TOXICITY, MOBILITY, AND VOLUME THROUGH TREATMENT

This criterion addresses the degree to which a remedial alternative uses treatment to reduce the toxicity, mobility, or volume of hazardous substances. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media. The evaluation focuses on volume of waste (primary and secondary, only) requiring landfill, mobility of waste sent to interim storage (highest scores will be given to solid waste forms, lowest scores to liquid waste forms), and reduction in toxicity.

8.2 SHORT-TERM EFFECTIVENESS

The short-term effectiveness criterion is concerned with the effects of the alternative on human health and the environment during its construction and implementation phases of a remedial action. All alternatives must furnish a basic degree of public, worker and environmental protection. However, some alternatives may inherently provide a greater degree of protection or risk reduction.

Short-term human health impacts are closely related to the duration of exposure to hazardous wastes and risks associated with removal of wastes. Typically, the greater the exposure time, the greater the risk. As low as reasonably achievable (ALARA) guidelines will be practiced during implementation of the remedial action to minimize worker risks. The following factors are considered for each alternative:

Risk to the Public and Environment: This attribute considers the complexity of the safety controls required for preventing accidents from the chemical reactions occurring in the process, consequence of off-normal event (upset severity), and potential for airborne releases. Complexity of safety-related process control, upset severity and release potential provide a subjective measure of the degree of protection or risk reduction. An alternative which requires simple controls to operate, has upset conditions that would result in minimal consequences and generates few emissions would receive highest scores.

Risk to Worker: This attribute considers dose to worker by assessing potential for exposure from transports (larger number of shipments or longer load/unload times increases exposure potential), and exposure from maintenance activities (contact maintenance presents more opportunities for

exposure than remote maintenance). Alternatives with smaller number of shipments and capabilities for remote maintenance would receive highest scores.

8.3 IMPLEMENTABILITY

This evaluation criterion assesses the technical and administrative feasibility of implementing an alternative and the availability of the equipment and services required during implementation. Each alternative will be evaluated on a near-term (treatment to interim storage emplacement) and a long-term (interim storage to final disposal emplacement) basis.

8.3.1 Near-Term Implementability

Near-term implementability considered the following factors:

Technical Maturity - such as the uncertainties related to technologies. This parameter considers the development status of each candidate technology in terms of its maturity regarding actual demonstration and application with actual K Basin sludge or similar materials. If a process is mature and currently operating or had been operating it is reasonable to assume that it can be implemented quickly and effectively. Conversely, if a process exists only as a concept study it is unlikely to be readily implemented in a short period. Maturity also considers the probability of the technology to provide a system that meets the sludge treatment requirements on a continuous basis.

Technical Feasibility - such as the likelihood of technical difficulties in constructing and operating the alternative and the likelihood of delays due to technical problems. It also considers the complexity of implementing the technology in the operating environment, the reliability of the technology to provide a system that minimizes equipment failures and thus reduces plant downtime, and the maintenance requirements viewed from the perspective of relative ease of fixing potential equipment failures.

Flexibility/Robustness - such as the ability of the system to handle the wide variability of the constituents to be treated. Processes which are capable of accepting a wide variation in feed material and intermediate products which provide opportunities for relatively easy rework (should final product specifications change) will be considered more flexible and robust than processes which must be more tightly controlled.

Administrative Feasibility - such as the ability to coordinate activities with other offices (i.e., Sludge Retrieval, CSB, CWC, TWRS, WDD) and agencies (i.e., WIPP, geologic repository) and the risks associated with meeting the TPA milestones (programmatic risk). This attribute also considers the potential for regulatory constraints (regulatory risk) to develop (i.e., perceived difficulty of obtaining the necessary regulatory approvals and permits (i.e., air permits) to allow implementation of the option.)

8.3.2 Long-Term Implementability

The criterion, long-term implementability, considered the likelihood of obtaining a memorandum of understanding with the final disposal facility, potential of adding to a facility's current burden of orphan waste (not desirable), and perceived ability of accepting facility's management of the waste until final disposal (i.e., will the waste be treatable in the accepting facility, are new risks introduced to producing compliant waste forms, are accepting facilities costs impacted for processing, storage, disposal.)

8.4 COST

This criterion considers the cost of implementing a remedial alternative, including capital costs, operation and maintenance, and monitoring costs. The cost criterion is presented so as to differentiate costs attributable to near-term activities (activities associated with treatment and emplacement of the sludge product in interim storage) and those attributable to far-term activities (activities associated with removal from interim storage and emplacement of the sludge product in final disposal facility).

The cost estimates for the purposes of this alternative analysis are prepared from information that was available at the time the alternative study was prepared. The actual cost of the project will depend on additional information gained during the conceptual design phase, the final scope and design of the selected alternative, the schedule of implementation, the competitive market conditions, and other variables.

9.0 COMPARITIVE EVALUATION OF ALTERNATIVES

Several evaluation criteria are used to assess the alternatives against one other. The evaluation method established for this study was intended to identify applicable and feasible treatment and disposal systems, rank them according to their relative advantages across several key attributes. This evaluation process should thus indicate which treatment and disposal systems appear to provide greater benefits than other competing systems. For this purpose, a method that provides a format for developing decision criteria, listing alternatives, and weighing the alternatives against the decision criteria and against each other was used. The method is commonly referred to as the Kepner-Tregoe method.

Weighting factors were assigned to each decision criteria (described in Section 8.0) by a team composed of representatives from NHC (Sludge Treatment engineers, Safety, Project Management), DOE-RL (TWRS, SFD, TAG), FDH (Regulatory, Project Direction), B&W (Sludge Treatment Design Authority), DE&SH (Operations) and EPA (Parker 1999).

The alternatives were scored for each of the decision criteria (scores were also assigned to sub-attributes which were then averaged to give a final score for the decision criteria), except Near Term Cost and Long Term Cost. Scores assigned to the alternatives ranged from 1 to 10 (1=lowest, 10=highest). Multiplication of the decision criterion weighting factors times the assigned scores yielded net scores for each alternative. Net scores obtained in this way were then ranked and evaluated.

9.1 ALTERNATIVE ANALYSIS SUMMARY

The criteria weights and assigned scores for the sludge disposition alternatives are shown in Table 9-1. The total scores ranged from 305 for grinding/milling to 585 for modified chemical.

Table 9-1. Sludge Alternatives Performance Scores

WT Factor		Baseline	Mod. Chem	Grind/Mill	Vitrification	Calcination	Grout
5	Toxicity Reduction						
	Waste Form	1	1	1	10	5	9
	Final Land-Fill Volume	1	1	9	10	7	3
	SCORE	1	1	5	10	6	6
10	Short-Term Effectiveness						
	Risk to Public and Environment						
	Process Control	10	10	1	5	8	3
	Upset Severity	10	10	1	7	7	5
	Release Potential	7	7	10	1	3	5
	Risk to Worker						
	Dose from Transports	3	3	4	10	9	6
	Dose from Maintenance	1	3	8	8	10	6
	SCORE	6	7	5	6	7	5
30	Near-Term Implementability						
	Tech. Maturity	9	10	1	4	5	7
	Tech. Feasibility						
	complexity	6	8	3	1	5	7
	reliability	8	8	9	5	6	6
	maintainability	7	10	1	3	5	5
	Flexibility/Robustness	7	10	5	1	7	8
	Programatic Risks	5	6	4	9	9	7
	Regulatory Risks	10	7	1	10	7	7
	SCORE	7	8	3	5	6	7
5	Long-Term Implementability SCORE	10	10	10	6	3	3
40	Near-Term Costs SCORE	5	5	1	1	5	4
10	Long-Term Cost SCORE	1	2	5	3	7	5
	TOTAL SCORES	535	585	305	360	565	515

9.2 REDUCTION IN TOXICITY, MOBILITY, AND VOLUME THROUGH TREATMENT

All of the alternatives would oxidize uranium metals and hydrides, thus reducing the risk associated with reactive metals. All of the alternatives would also provide some degree of treatment for PCBs, by either removing the PCBs from the sludge through volatilization or immobilizing the PCBs. Only vitrification and grouting would reduce the mobility of heavy metals and radionuclides as part of the CERCLA action. Heavy metals and radionuclides eventually would be immobilized by the other alternatives (baseline, modified chemical, and grinding/milling), but this would be accomplished outside the CERCLA action. The exception would be the calcination alternative.

The scores assigned to each of the alternatives for this criterion were based on the final landfill volumes and mobility of the interim stored waste form from the standpoint of toxicity, the alternatives were judged comparable. Vitrification received the highest performance score because it generates a low volume of waste and has the most stable waste form. Calcination has a less stable waste form than vitrification therefore it rates lower than vitrification. It rates higher than the chemical and grinding/milling alternatives because it has a small volume (comparable to vitrification) and a dispersible form. Grouting has a more stable form than calcination but generates a much higher volume. The average score (mobility plus volume) for grouting resulted in the same score as calcination. Grinding/milling received a slightly lower score because it has an interim storage waste form which is not as stable as vitrification, calcination or grouting. It scored higher than the chemical processes because it generates a smaller volume of waste going to final landfill. Baseline chemical and modified chemical both received lowest scores because of the large volume of waste generated and the interim waste form is a slurry.

9.3 SHORT-TERM EFFECTIVENESS

9.3.1 Risk to Public and Environment

Complexity of Safety-Related Process Control: It is currently assumed that criticality control is accomplished using a mass limit applied on a per-batch basis. All processes would have controls for filling the transport cask with a batch of sludge for shipment to the facility. In addition, all processes will require hydrogen monitoring and purging of the plenum spaces of tanks containing sludge which have not yet been fully oxidized. Finally, all options except grinding/milling and grouting perform an elutriation to avoid feeding OIER beads to a dissolver. However, since these controls are common to all alternatives, these are not discriminating criteria between options.

The modified chemical and baseline chemical processes require process control of the dissolver temperature to prevent a run-away reaction. Exothermic reactions occurring when sludge is added to the dissolver may cause the dissolver to exceed the 95°C set point. Temperature in the

dissolver is controlled by reducing or halting sludge addition, increasing cooling flow, and if necessary, adding water from a drown tank situated above the dissolver. The acid strength is controlled based on the conductivity of the solution. In addition to the dissolver, the baseline chemical and modified chemical processes require the U-235 enrichment and Fe: Pu ratio be controlled to assure criticality safety in AW-105. Achieving this by addition of depleted uranium and iron was seen as straightforward. Therefore, the modified chemical and baseline chemical processes were judged to have the least complex safety-related controls and therefore received high scores.

The calcination process also uses a dissolver and as a result has the same dissolver related controls as the modified chemical and baseline chemical options. The NO_x emission controls are made more complex due to the increased variability and quantity of NO_x generated. The temperature in each zone of the calciner is controlled by a simple feedback control that adjusts the power input to each zone. The only exothermic reactions expected are from residual organic ion-exchange resin and, in the streams bypassing the dissolver, uranium <250 μm which is incompletely oxidized. It is expected that any exotherms can be controlled by reduction of the power input; in addition, the calciner will only contain small quantities (approximately 1 to 2 kg) of sludge at any one time. Control of offgas temperature is required to prevent condensation prior to exiting the blowback filter. Calciner vacuum control is needed to maintain the calciner under slight negative pressure relative to the cell to minimize spread of contamination. Administrative controls are required to prevent mixing feed that has undergone dissolution and feed that has bypassed the dissolver. Measures to control contamination spread during filling of individual cans are needed.

Vitrification was rated lower than calcination for complexity of safety related controls. As in the options discussed above, vitrification involves control of a dissolver. Vitrification requires controlled sugar addition to the feed tank to accomplish denitration. The reaction rate is controlled by the addition rate of sugar. A significant lag time between the start of the reaction and the evolution of gas complicates the control of this reaction. The NO_x emission controls are made more complex compared to options with only a dissolver emitting NO_x due to the increased variability and quantity generated. Vacuum control for the melter plenum is more complex than for the calciner which has a more steady offgas flow. Administrative controls are required to prevent mixing feed that has undergone dissolution and feed that has bypassed the dissolver. Control of melter temperature is more complex than in the calciner.

Grouting scored in the low range, primarily due to the complexity associated with operating the argon inerted cell. The grouting operation involves maintaining an argon-inerted and a nitrogen-inerted cell. The argon-inerted cell is viewed as a complex control. Argon from the cell environment is removed, filtered, and returned to the cell. A purge stream is replaced with fresh argon to offset the effect of leakage. The control scheme for operating the calcining ovens involves independently controlling the inlet oxygen and argon flowrates and the oven power input through a temperature program to fully oxidize the material. The details of the control scheme to monitor and control oxidation of the uranium have not been developed but may

introduce additional complexity. Because metallic uranium particulate could potentially be lost to the cell while filling the calciner pans, design features would be needed to assure there are not locations which could accumulate material over time. In addition, controls on the reintroduction of air to the cell may be needed.

Grinding/milling was ranked the lowest due to the uncertainties associated with maintaining a mass-based criticality control in the grinder. The hydrogen control issue is more severe in the grinder than in storage tanks due to the higher rate of emissions. In addition, there is a high level of uncertainty in the mechanisms and reaction rates that can be expected in the grinder. Although the controls are not likely to be complex (turn down, grinding intensity, add makeup water) it is difficult to assure effectiveness without previous process experience.

Upset Severity: The baseline chemical and modified chemical processes were judged to present the least consequences for off-normal events. The process step most likely to cause an upset in these processes is the dissolver. Calcination scored lower than the chemical processes because, although it operates a dissolver for fewer batches, it uses high temperature (500°C), requires a more complicated offgas system, and requires handling of a dispersible product. Vitrification scored lower than the chemical processes because, although it operates a dissolver for fewer batches, it uses high temperature (1150°C), requires a more complicated offgas system, and requires control of the sugar.denitration step. Grouting scored lower because the consequences of ignition of uranium particles in the cell were judged to be more severe than higher-ranked alternatives. In addition, the complexity associated with maintaining the argon-inerted atmosphere in the cell (allowing draining of the water from the uranium particles without ignition) is greater than control measures in higher rated alternatives. Grinding/ milling ranked the lowest due the difficulty in assuring that fissile material is quantitatively discharged from the grinder (making mass limit criticality control difficult to implement). In addition, the high level of uncertainty in the mechanisms and reaction rates in the grinder make upsets relatively more likely.

Release Potential: Grinding/milling would not create the potential for airborne releases of particulate matter during size reduction because the grinding occurs while submerged in water and significant volatilization of PCBs or radionuclides would not be anticipated. This alternative therefore received the highest score. The chemical processes received slightly lower scores because it can be expected that these processes would create the potential for some volatilization of PCBs and would generate some NO_x. Grouting scored lower than chemical processes because of the potential for airborne releases of PCBs and radionuclides (i.e., cesium) from the fraction of sludge that is batch calcined. Calcination and vitrification provide the greatest potential airborne releases. Calcination and vitrification will nearly completely volatilize PCB's, volatilize greater quantities of radionuclides and generate larger quantities of NO_x requiring treatment. Vitrification scored lowest because it provides the potential for the largest airborne releases compared to the other alternatives.

9.3.2 Risk to Worker

Dose From Transport: Vitrification and calcination received the highest score because the hours required for personnel to load and unload the waste packages are about the same and are substantially lower than hours for other alternatives. Fewer hours generally reduce the potential for worker exposure. Grouting received a midrange score because it requires approximately ten times the hours as vitrification and calcination. The chemical processes and grinding/milling all rated relatively low in this category because of the large number of shipments. The potential for exposure is also increased because of the close proximity work required for connects/disconnects at the transport cask.

Dose from Maintenance: Calcination received the highest ranking in part because of the ability to perform remote maintenance and it has a relatively small inventory to deal with if the calciner fails with a batch of sludge contained inside. Grinding/milling and vitrification had the next highest rankings because, even though they also provide remote maintenance capabilities, the potential exists for increased dose to worker due to a larger inventory in the melter or grinder compared to that in the calciner. It was also judged that the inventory would be more difficult to remove from the melter or grinder than from the calciner. Grout received the next lowest ranking because routine use of manipulators increases the need for contact maintenance on contaminated equipment. Additionally, the amount of time the operators spend in front of the processing cell increases worker dose.

The chemical processes received slightly less favorable rankings due in part to the higher reliance on hands-on maintenance as compared to the remote maintenance capabilities of vitrification, calcine, grinding/milling and grout (in-cell cranes and manipulators). Baseline chemical ranked a bit lower than alternative 2 because it has a larger number of process steps, pumps and piping (more opportunity for plugging) all potentially requiring more contact maintenance than modified chemical.

9.4 NEAR-TERM IMPLEMENTABILITY

9.4.1 Technical Maturity

Modified chemical and baseline chemical were judged to be the most mature for the intended application. The unit operation steps for the chemical process alternatives are supported by laboratory tests performed on actual sludge samples, plus similar operating processes have been used extensively to process similar materials at the Hanford site and elsewhere. Grouting for stabilization is a very well established technology and was recently used to successfully solidify N Reactor Basin sludge. Grouting was judged to be slightly less mature than the chemical processes because the procedure for calcining the fuel particles in the furnaces may require development. Calcination has been used on radioactive waste solutions at Idaho National Engineering Laboratory to stabilize reprocessing waste and in a number of other process

operations in the nuclear industry. It is also being used at PFP to stabilize plutonium-bearing materials. It was judged less mature than the chemical processes and grouting because there is no experience on this waste stream and some development testing to optimize temperature, residence time or other process parameters may be needed to assure complete oxidation, low residual moisture content and a free-flowing product.

Vitrification has been successfully demonstrated using highly radioactive waste sludge (including West Valley, Savannah River, PNNL radioactive liquid-fed ceramic melter, the PAMELA plant in Belgium, and the Tokai plant in Japan). It ranks lower than the previously discussed alternatives because it has not been demonstrated that wastes (such as the K Basin sludge) which exhibit a wide variation in waste characteristics can be successfully vitrified to meet well-defined glass compositions.

Grinding/Milling is a very mature technology that is used in to grind materials such as sand and oxides. It has not however yet been demonstrated to be capable of safely and successfully reducing irradiated uranium to meet the TWRS acceptance criteria. The lack of technical data establishing that this process would work for the K Basins sludge, resulted in a low maturity score for this alternative.

9.4.2 Technical Feasibility

Complexity: Modified chemical was judged the least complex process. Modified chemical is a simple flow through process with minimal process steps and mechanical equipment. The grouting/batch calcine process while simple in principle requires extensive use of manipulators in this application. This adds some complexity to the operations of this process and therefore grouting was judged to be slightly more complex than the modified chemical process. The baseline was judged more complex than modified chemical or grouting because of the large number of process steps. Calcination involves a minimal number of process steps however; it has the added complexity of high temperature operations and filling of a large number of small cans (1-gallon) approximately 20 per day. Grinding/milling was judged to be fairly complex due to the complexities associated with achieving a particle size separation at 10 μm. Additionally, operation of the mechanical equipment in a remote hot cell was judged to be relatively complex. Vitrification was considered the most complex. Vitrification involves a large number of process steps, high temperature (1100 to 1175 C) operation and the use of a lot of remotely operated mechanical equipment (turn table, welders, decontamination, etc.).

Maintainability: All of the alternatives are envisioned to have maintenance capabilities commensurate with a facility which handles highly radioactive material. For the two chemical processes, the approach is to seal passive equipment (tanks and piping) in the cell and place mechanical equipment (pumps, agitator motors) in a location where it may be repaired or replaced by hand after it has been flushed, therefore, these alternatives ranked the best. Grouting and calcination were scored the same because these processes do not require particularly huge or

cumbersome equipment, they due, however, still have some mechanical equipment within in the cell. This was judged a bit more difficult to fix than the chemical processes. Routine use of manipulators could increase maintenance time but the downtime would most likely be minimal due to relative ease in changing manipulators. Vitrification has several pieces of mechanical equipment (welder, decon, turntable) requiring remote maintenance. Maintenance for this option was therefore judged to be more difficult than the previously mentioned alternatives, but not as difficult as the maintenance required for the grinding/milling alternative. For the grinding/milling alternative, maintenance of a 9,000 lb. piece of mechanical equipment (filled with 7000 lbs of grinding media) in a remote cell was judged to be potentially quite difficult.

Reliability: Assessment of reliability considers the likelihood of equipment failures interrupting continuous processing in the plant. The grinding/milling operation was judged to be most reliable. The grinder is a relatively simple, off-the shelf piece of equipment routinely used in industrial applications. The option has a minimum of process steps. While it must be noted that the ability to grind the uranium is uncertain, the grinder would be expected to operate without significant mechanical reliability problems. The chemical systems (baseline and modified chemical) were also judged to be very reliable. However, they include more process steps and are expected to be slightly less reliable than the grinding option. The dissolver involves extensive instrumentation for control of the process (SpG, conductivity, ^{85}Kr, Xe, etc.) and requires operation of NO_x absorbers to control emissions. The maintenance configuration in the chemical options leads to very long shafts on tank agitators which would be a special design and be less reliable than standard agitators in the grinding option. The grout option is highly reliable in the hot water oxidation of the fines and grouting operation. However, the batch calcining furanaces placed within the argon-inerted cell is a unique process which could reduce reliability. The calcining option was expected to have similar reliability as the grout option. The rotary calciner is well established for radioactive service but involves high temperature moving parts. The dry blow-back filter has a potential to clog. The calcining system includes a dissolver and NO_x absorbing system providing some of the complexity from the chemical processes. Finally, the filling operation for the 1-gallon cans increases complexity. The vitrification process while still judged moderately reliable was expected to have the greatest potential for downtime due to equipment failure. The melter option includes a dissolver and NO_x absorber and includes sugar denitration which adds complexity. The melter uses higher temperatures and there are a variety of occurrences that could interrupt processing and require maintenance (deposits in the offgas line, feed nozzle plugging, nesting of glass in the canister, failure of heating elements, pour spout plugging, conductive sludge accumulation, etc.).

9.4.3 Flexibility/Robustness

Modified chemical and grouting were judged the most robust processes. Modified chemical uses well established operations and were viewed as having greater flexibility than the baseline chemical because secondary wastes may be sent to either ERDF or WIPP. Grout formulations can withstand relatively large variations in feed material, plus the batch furnaces increase

robustness and flexibility by providing the capability to increase calcining time if needed to fully oxidize a batch.

Calcination and baseline chemical ranked slightly lower than modified chemical and grouting. The continuous calciner has a limitation in that it has a limited residence time. This could potentially result in a failure to fully oxidize some material if the oxidation kinetics is not as rapid as expected.

Grinding of metallic uranium rated a low score because the process was judged potentially sensitive to changes in material characteristics (i.e., larger volumes of uranium fines or large particles).

Vitrification ranked lowest. In order to assure that a qualified glass product is produced, each feed batch must be analyzed and the feed composition adjusted. Because there may be significant batch-to-batch variation in oxide composition, the specified composition for each batch of glass formers must take into account not only the current feed batch but also the trend in composition in the melt over time to assure that the material can be processed (conductivity, viscosity) and meets waste form criteria. Reductant must be added to prevent release of oxygen in the melt which could cause foaming in the melter. With these controls in place, the melter is fairly robust in handling a change in feed composition. However, the fact that this degree of control is required resulted in a low score.

9.4.4 Administrative Feasibility

Programmatic Risk: The primary programmatic risks are those associated with delays in the Spent Nuclear Fuel schedule as defined in the Tri-Party Agreement. Risks that impact schedule are adequate interim storage space, availability of resources to support treatment operations (accept sludge transfers on a regular basis), and timeframe to obtain necessary agreements for waste stream acceptance.

The TWRS waste volume projections currently include volume projections for receipt of K Basin sludge. However, schedule uncertainties with TWRS activities could potentially impact the sludge treatment schedule because space availability is predicted on tank transfers and waste receipt projections. For the alternatives sending waste streams to CWC, the risk was judged to be relatively low because space is or can be made available. A new facility may need to be constructed but adequate real estate is available.

Access to the tank farms on a routine basis for transferring sludge into a DST has a relatively high degree of risk because of the constraints associated with access to the tank farms. Shut down of a tank or system in another farm has the potential to shut down operations in AW farm as well. Historically, access to the tanks on a routine basis for open-riser operation has never occurred. The alternatives sending waste products to CWC were judged more likely to support the schedule than the slurry shipments (from the chemical processes and grinding/milling) to

TWRS. Vitrification and calcination have significantly fewer shipments than the alternatives sending sludge to TWRS. Grouting requires the greatest number of shipments, but is still judged to be more supportive of the schedule than the TWRS slurry shipments because of the uncertainties associated with accessing the farm 3-4 times per week over a 13-month period to make liquid transfers.

There is also a risk in obtaining the necessary approvals for transfer of the treated sludge into a DST within the timeframe needed to support the Tri-Party Agreement schedule. It will require substantial effort and time to complete all of the necessary documents required by TWRS for sludge acceptance. For example, CWC personnel have estimated it will require 18 months to revise the Interim Storage Basis (ISB) whereas, the schedule for amending the TWRS BIO is estimated to take almost 4 years.

Hanford Waste Management personnel have indicated a preference in accepting a calcined product rather than grout for interim storage. In the near-term it is unlikely that acceptance of the grout waste by WIPP could be accomplished in the timeframe required and therefore if CWC accepted the grout waste they could potentially end up with an orphan waste (that is not easily reworked if WIPP does not accept it). Calcination provides a low risk option from the standpoint that the product would not necessarily require approval from the WIPP prior to storage in the CWC. This waste form could be qualified in the long-term for disposal at the WIPP as is or it could be treated in the future with other wastes (i.e., material in caissons) currently stored on the Hanford Site.

Regulatory Risks: Regulatory risks are associated with the ability to obtain a risk-based disposal approval under TSCA and to obtain air permits for the sludge treatment system. Baseline chemical and vitirfication pose very little risk because laboratory tests have shown PCB treatment limits can be achieved for baseline chemical. This alternative ranked highest in comparison the other alternatives. Grouting, calcination, and vitrification were judged to have the same degree of risk but higher than the baseline. No laboratory work has been done to show these alternatives would meet treatment standards for PCBs (i.e., solids < 2 ppm; liquids < 0.5 ppb); however the degree of confidence in meeting the PCB limits is higher than modified chemical or grinding/milling. The risk-based disposal approach is vital to the success of modified chemical and grinding/milling. If the risk-based disposal approval is not granted, these alternatives might not be viable and are therefore judged lower than the other alternatives (which are likely to meet TSCA treatment standards). All of the alternatives were judged the same for the attribute associated with obtaining air permits.

9.5 LONG-TERM IMPLEMENTABILITY

Estimates provided by TWRS-WDD have indicated blending treated sludge with AW-105 waste would not result in additional glass logs. Once the sludge is blended, it essentially becomes indistinguishable from other tank waste. With the remaining three alternatives, the primary waste streams form a unique waste stream. Interim storage issues (discussed in section 9.3) are

simplified but long-term programmatic risks associated with the ability to have a unique waste stream accepted at a final disposal facility and generation of orphan wastes are introduced.

Construction of a TWRS Phase II Treatment Facility has not begun. However, something will eventually need to be done with the TWRS waste. The addition of K Basin sludge is not expected to impact any future management decisions made for the TWRS tank waste. Once the sludge is blended with the tank waste it essentially loses its identity (no additional HLW glass logs). There will be an added burden for LAW glass, this is accounted for in the cost criterion, therefore the need for additional out-year management over that which is already in place for AW-105 is not expected to be impacted by addition of sludge.

The options that send the sludge to TWRS received high scores for long term implementability because they were judged to pose the least risk to the receiving facility in terms of treatability of the waste by the receiving facility and ability of the receiving facility to produce a compliant final waste form. Additionally, offsite approval was assumed to carry a higher risk than onsite approvals. The grout, calcine, and glass products also scored lower because they require approval from an outside agency for final disposal. The TWRS tank waste will also require approval from an outside agency, but because the sludge becomes indistinguishable from tank waste it should not impact acceptance of the TWRS HLW canisters by the geologic repository.

While it is expected that the glass produced would meet the waste acceptance criteria, the uranium concentration is outside the validated range of models used to predict glass properties and is outside the range of large-scale waste vitrification experience. While some crucible melt data is available, verification of the waste formulation would be needed. From a waste acceptance standpoint there may be a substantial effort involved in waste form qualification to get the glass accepted for disposal. In addition, there is a risk that the repository may determine that some or all of the glass produced is not HLW and therefore not suitable for repository disposal. This would result in an orphan waste or additional treatment.

If the grouted and calcined waste receive approval from the WIPP during the near-term implementability phase, long-term implementability should be a non-issue for these alternatives. If, however, the project decides to grout the sludge without prior approval from the WIPP, then there is a potential risk of the grout waste form becoming an orphan waste or requiring additional treatment (reworking grout would be difficult). For the calcination alternative, WIPP would need to approve the package and fissile limit. In addition, the SARP for the TRUPACT II would need to be revised to include the package. If WIPP does not allow movement on the fissile limit, it may be necessary to repackage the calcine material.

Furthermore, DOE personnel at the WIPP have expressed concerns that a waste form containing the high-activity sludge might not be acceptable for disposal at the WIPP because the sludge derives in large part from the corrosion of SNF and contains fuel pieces. This concern poses substantial uncertainty for disposal of all of the grout and calcine waste forms at the WIPP (Further discussions with Hanford TRU personnel have indicated the sludge could be designated

as a TRU waste. Fuel pieces are currently being stored at CWC that will eventually be treated then shipped to the WIPP).

Vitrification scored higher than calcination and grout because it was judged more likely to produce a compliant waste form that would not require additional treatment. Borosilicate glass is the standard HLW form for the repository and it is expected that the glass produced would meet all the waste acceptance criteria. The calcine material does not currently meet all of the WIPP criteria and the grout product is not a standard waste form for WIPP (grout falls under the category of "experimental" waste). All of these alternatives have the potential for adding orphan waste to the interim storage facilities.

9.6 COST

To allow for an evaluation of the alternatives relative to cost, comparative cost estimates were developed. For each alternative, parametric estimates developed from the process descriptions and preliminary layouts generated for each alternative. Costs were considered for the entire life cycle of the process facility, broken down into the following major categories:

- engineering and development,
- procurement and construction,
- operations,
- decontamination and decommissioning, and
- final waste disposal.

The key elements of each process through its life cycle were identified, and the major discriminating costs for these elements were estimated. The costs obtained were parametric in nature, and do not provide a basis to establish a cost baseline. It was determined that several attributes were common to all the alternatives, and would not provide discriminating cost information. Therefore, detailed costs were not generated for these attributes. These attributes include:

- contingency
- escalation
- transport costs to the treatment facility
- project management
- regulatory and environmental support

Table 9-2 summarizes the major discriminating cost elements developed in the comparative cost estimate. The detailed cost information is found in Appendix I.

The specific detailed cost information found in Appendix I does not represent a total project or life cycle cost and therefore should not be used for budgeting purposes. It does provide; however, a suitable basis for cost comparison. The uncosted elements would substantially

increase the estimates included in Table 9-2. Based on the preliminary nature of these estimates, an appropriate contingency factor is in the range of 40-50%.

Table 9-2. Summary of Discriminating Costs

Cost Element	Alternative 1 Baseline	Alternative 2 Mod. Chem.	Alternative 3 Grind/Mill	Alternative 4 Vitrification	Alternative 5 Calcination	Alternative 6 Grouting
Engineering & Development	$ 18.8 M	$ 18.3 M	$ 31.8 M	$ 38.1 M	$ 22.3 M	$ 26.0 M
Procurement & Construction	$ 37.7 M	$ 36.2 M	$ 37.8 M	$ 41.3 M	$ 37.2 M	$ 35.9 M
Operations	$ 24.9 M	$ 24.8 M	$ 23.4 M	$ 22.7 M	$ 21.5 M	$ 25.8 M
Total Near Term Costs	$ 81.4 M	$ 79.3 M	$ 93.0 M	$ 102.1 M	$ 81.0 M	$ 87.7 M
D & D	$ 14.3 M	$ 13.9 M	$ 12.6 M	$ 11.1 M	$ 11.1 M	$ 12.7 M
Final Waste Disposal	$ 44.5 M	$ 37.0 M	$ 5.4 M	$ 19.4 M	$ 0.2 M	$ 6.1 M
Total Long Term Costs	$ 58.8 M	$ 50.9 M	$ 18.0 M	$ 30.5 M	$ 11.3 M	$ 18.8 M

9.6.1 Near Term Costs

Near term costs for all alternatives, include engineering and development, procurement and construction, and operations.

Engineering and development costs identified significant differences between the various options. The major discriminators were in the areas of testing and development, waste form qualification, and safety analysis. Significantly more engineering development and laboratory testing would have to be done for the vitrification and grinding/milling options than would be needed for the chemical treatment options for reasons previously detailed. Calcining and grouting would not require as much as vitrification or grinding/milling, but would require more than the baseline chemical. In addition, the options not going to TWRS would require waste form qualification of some sort. It was estimated that vitrification would incur the most cost for this effort, with grouting next, and calcining the least expensive waste form to qualify. Estimates for safety analysis showed that vitrification and the grinding/milling option would require additional analysis to establish its safety basis, and would be the most costly alternative in this area. Safety analysis proved to be a nondiscriminatory for the other alternatives.

In the procurement and construction area, significant cost discriminators were not identified. Differences were noted in the facilities and major equipment required for each option, but total cost differences were relatively minor in comparison to other elements of the estimate. Operating costs proved non-discriminatory.

Costs portrayed for the various alternatives in Appendix I are only comparative and not representative of what the actual costs would be. Even so, the cost information strongly suggests that the existing budget baseline is not sufficient. Therefore, from this perspective, none of the alternatives is attractive. For this reason, the high end of the ranking scale was not used.

9.6.2 Long Term Costs

Long-term costs include the costs of decontamination and decommissioning the processing facility. Also included are the costs for final treatment to a disposable waste form (applies only to the alternatives sending waste slurry to TWRS for interim storage), disposal fees, and transportation to the disposal location.

Decontamination and decommissioning costs, which were based on the amount of volume of material to be handled, proved not to be a discriminator.

For final waste disposal, the baseline chemical alternative was determined to have the highest long-term costs. This is attributed to the significant volume of sodium requiring treatment and disposal. Treatment of the sodium results in a large number of LAW disposal boxes that will be disposed of on the Hanford site. Modified chemical is the next most costly, but, since it does not produce as much LAW, is not as costly as the baseline chemical alternative. Vitrification is the next most costly, due the disposal costs for the glass canisters at the geologic repository. Grinding/milling and grouting long-term costs were approximately the same. Calcination has the lowest long-term disposal costs. This cost may be understated, as there are significant uncertainties associated with viability of sending calcined particles to WIPP. The calcined waste form would be amenable to further treatment if required, but this would impact long-term costs.

The long-term costs are subject to a high degree of uncertainty, and may be unreflective of the real costs at the time of final treatment and/or disposal. Since the sludge will be treated as a CERCLA action, the final disposal path and life cycle cost to disposal were considered. The waste forms and disposal paths were developed based on current constraints and requirements, however, the criteria for acceptable waste forms can change with time. As the final disposal action for any of the alternatives will take place as a long term action (potentially between 2010 and 2040), any waste form generated in the near term to today's requirements would be subject to reexamination at the time of disposal.

9.7 SENSITIVITY ANALYSES OF THE EVALUATION PROCESS

Sensitivity analysis was used in the sludge treatment alternatives evaluation to identify the variables that most strongly influence the net scores for each of the alternatives, and the extent to which changes in these variables affect assessment decisions, i.e., relative rankings. A number of techniques were used to assess the sensitivity of various aspects of the sludge treatment alternatives evaluation process. The analysis included evaluations of the following: 1) the relative contribution of the six decision criteria to the nominal net score for each alternatives; 2)

identification of the parameters having the greatest influence on rankings; and 3) the manner and extent to which variations in the parameters influence rankings, i.e., the sensitivity of the rankings to variations in the weighting factors and attribute scores. A detailed discussion of the sensitivity analysis is provided in Appendix J.

It is indicated from the results of these sensitivity analyses, that the net score (and ranking) for each treatment alternative is most sensitive to the values of the weighting factors assigned to the decision criteria, and the scores assigned to the most heavily weighted criteria. The most sensitive parameters are the criteria with the largest weightings , i.e., near-term implementability and near-term cost, and to the scores assigned in these categories. The top four alternatives for the nominal values of weightings and scores are: 1-Modified Chemical, 2-Calcination, 3-Baseline Chemical, and 4-Grouting. The net scores for these alternatives differ by <15%. However, the net scores for Vitrification and Grinding/Milling are over 40% lower than the top-ranked score. The relative rankings are sensitive to variations in the weightings of for near-term implementabilty, long-term implementability, long-term cost and toxicity/volume/mobility reduction. One-at-a-time and paired changes in weighting criteria result in variable ranking sequences for the top four options, and involve the same four alternatives for all scenarios; Modified Chemical, Calcination, Baseline Chemical, and Grouting. The most significant consequence of weighting changes on ranking is that Calcination is the only alternative with the potential to displace Modified Chemical as the highest scored alternative. The ranking order for the top three alternatives are also sensitive to scoring variations in some categories, particularly for the scores assigned to Calcination, and Baseline Chemical treatment, and for the scores assigned in the categories of near-term cost and near-term implementability. Although the rankings are insensitive to score changes in most categories, a score increase of <1.5 points would result in Calcination replacing Modified Chemical as the highest ranked alternative. Thus, there appears to be little distinction between Modified Chemical and Calcination as the highest-ranked alternative based on the scoring process alone.

10.0 OPEN ISSUES AND ACTIONS

This section provides key information needs that were identified during the course of this study that could significantly impact technical and schedule viability of various alternatives. The open issues that have been identified by this study and proposed actions to close them are:

Memorandum of Understanding with accepting facilities: Each of the waste streams generated is required to meet the acceptance criteria for the respective receiving facility. While this study determined whether the treatment process could generate a waste stream in accordance with applicable criteria it did not submit waste data sheets for evaluation by the receiving facility for a formal determination of acceptance. The process for waste acceptance would need to be implemented for the selected alternative.

Location of treatment process: The programmatic assumption for the siting of the processing facility has been that the facility will be located within the Cold Vacuum Drying Facility (CVDF). An in-progress Siting Study for Sludge Treatment, developed information which suggests that the CVDF may not be suitable to house the Sludge Treatment processing facility. Therefore, due to the uncertainties associated with use of the CVDF, this study assumed the treatment facility would be housed in a new facility. If the siting study (currently in progress) determines that sludge processing will require a newly constructed heavily shielded facility, the budget and schedule for the K Basin sludge treatment will require revision. If a suitable existing facility is identified, the impacts to the conclusions of this study should be reviewed.

Waste designation: The sludge disposition path is dependent on waste designation of the sludge. The WIPP only accepts TRU waste and the geologic repository only accepts HLW. If a treatment and disposal path to WIPP is selected, the sludge will need to be formally designated as mixed-TRU waste. The timing of this designation is highly dependent upon the WIPP regulatory environment, which at present is in a state of flux. Formal designation, at some time in the future, when WIPP has been operational for some time and the qualification criteria for RH waste have been established may be more appropriate than obtaining a designation at this time. However, this may impact viability of the sludge disposition decision.

Interface agreement with K Basin Operations: An interface agreement will be required with K Basin Operations to incorporate sludge handling and/or separation methods (i.e., elutriation column to separate resin beads from the rest of sludge) in the basin beyond those currently planned. Schedule and budget need to be established.

Transfer method for large, dense particles: Transfer and transport of large dense particles (up to 6350 μm diameter particles with density as high as 19 g/cc) could have an impact on treatment system design including requiring sorting prior to removal from the basins or at the treatment facility. While this issue was dealt with almost uniformly by each of the alternatives, the actual means of transfer has not been demonstrated. Laboratory test data or analysis to determine a viable method for transferring sludge with large, reactive (heat and gas generation), high-density fuel pieces is required to resolve this issue.

Conservatism of TWRS Acceptance Criteria: The TWRS criticality limits represent standard criticality safety assumptions and, with the exception of particle size, do not afford much opportunity for reducing conservatism, and thereby simplifying requirements for the process.

The 10 μm particle size limit for criticality control is based on a conservative assumption of preferential plutonium separation. At that particle size, the assumption is that preferential plutonium separation can be no greater than a factor of three. Iron is added as necessary at three times the required ratio to assure that the required Pu/Fe ratio is maintained, even if preferential separation were to occur. If it could be demonstrated by laboratory experiments that there is no preferential separation up to the next most restrictive particle size of 177 μm (related to acceptance criteria for feed material to privatized vitrification contractor), the amount of iron added could be reduced. An opportunity exists for laboratory analyses to confirm the suspected behavior of plutonium preferentially associating with a particular particle size. It is

recommended that an external review of this method for criticality defense prior to initiating work be obtained (Candidate reviewers: SRS – David Hobbs, Mike Chandler or Rahn Ross, ORNL). If the 10μm particle size limit is relaxed to the next restrictive level of 177 μm, less constraining solids/liquids separation technologies could be applied and the quantity of iron can be reduced, which would decrease the volume of slurry sent to TWRS. Changes to the criteria require the coordination of DOE (TWRS, WDD, and SNFP) and the PHMC (SNFP and TWRS) to determine if process benefits to the K Basin sludge can be realized.

A second opportunity exists for relaxation of TWRS criteria as it pertains to acceptance of PCBs. RL and SNFP intend to use the risk-based approach allowed by the TPA Disposal Amendments to address the PCBs, resulting in the treated sludge to be declared a non-TSCA waste. The EPA has endorsed the use of this risk-based approach, but formal approval of this strategy has not been obtained.

11.0 CONCLUSIONS

The following presents key conclusions of the evaluation.

- Complexity of the sludge feed streams precludes a "one-step," in-basin process for treatment of the high-activity sludge (i.e., high TRU streams consisting of canister and fuel wash sludge). Key variables include; significant quantity of cesium, uranium and plutonium, and relatively large pieces (6350-micron) of metallic uranium and zircalloy cladding. The TRU content of the sludge precludes a simple, cost-effective disposition path to ERDF for the low-activity streams (i.e., low TRU streams consisting of floor and pit sludge).

- Treatment of the sludge requires processing in a heavily shielded area within a Hazard Category II nuclear facility. This requirement and the need to remove sludge from the basins by August 2005 (determines scale of facility), are key drivers in the site selection process for the sludge treatment facility and led to the assumption of a newly-constructed facility for the sludge treatment system.

- All of the alternatives, with the possible exception of the grinding/milling option, have the potential of providing an appropriate treatment and disposition pathway for the K Basins sludge. However, given the current set of regulatory and safety constraints and requirements, it was concluded that a chemical process has the greatest likelihood of success as a single treatment process for all five sludge feed streams. The other alternatives, while viable, do not provide major advantages in terms of technical viability, cost or schedule when evaluated against a modified chemical process.

- Parametric cost numbers based on the process descriptions and preliminary layouts indicate that the costs, when assuming a newly-constructed facility, exceed the baseline budget. If the

siting study (which is currently in progress) identifies an existing processing location, the results of this study would need to be reviewed. Conversely, if the siting study determines that a new facility is required, the budget and schedule for sludge treatment would need to be reexamined.

- Both the design/construct schedule (approximately five years for design and construction of the processing facility) and the assumed operating window are viewed as extremely aggressive, therefore, all of the alternatives could impact the schedule.

Based on the preceding summary, a reasonable path forward approach for consideration is to initiate a high-level review of the current set of policies, requirements, and constraints to identify disposition options unconstrained by current regulations and requirements, and/or beyond the scope of this evaluation. Additionally, review other programs to identify potential integration opportunities. The rational for this approach is all of the alternatives selected for evaluation have significant uncertainties and associated risks in completing design, construction, startup and operations of a treatment system to process the entire volume of sludge per the current Tri-Party Agreement milestones Some uncertainties are contingent on the currently imposed constraints and requirements. Additionally, near-term funding requirements would need to be increased to expedite definitive design activities for a single treatment process option. Increased funding would not support the objective of maintaining consistency with the current budget requirements.

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APPENDIX A

GROUT TO ERDF ALTERNATIVE

APPENDIX A

GROUTING OF LOW-ACTIVITY SLUDGES FOR DISPOSAL AT ERDF

This appendix examines the feasibility of directly grouting low activity sludge for disposal at ERDF as an alternative to the baseline process. The baseline process, as described in Westra et al., (1998) initially removes ion exchange resin particles by screening and elutriation. Nitric acid is then added and filtration is used to separate insoluble components. Neutron absorbers are added to the nitric acid solution and then the solution is precipitated using caustic. The slurry is adjusted to meet TWRS acceptance criteria and transferred to a double-shell tank. The insoluble material (primarily sand) and the ion exchange resin particles are leached to remove TRU radionuclides, stabilized in grout, and disposed as non-TRU LLW at ERDF.

The option for disposal of the low activity streams being evaluated in this appendix is to solidify the sludge using a cementitious grout and then dispose of the grouted waste form at ERDF. For the purposes of developing flowsheets to evaluate alternatives, compositions of feed streams were identified. The composition of these streams were specified in a letter from K. L. Pearce to G. A. Whyatt, October 28, *1998 Nominal Inventories for Low and High Activity Streams to be used in the Alternatives Study*. The low-activity feed streams for evaluation of grouting and ERDF disposal include the following:

KE1SEG - a low activity stream consisting of KE floor and pit sludge
KE1SEG+Al - Stream KE1SEG with additional canister sludge, which is assumed to fall out of aluminum canisters with screened bottoms during handling of the canister.
KW1 - Floor and pit sludge from KW basin. No data is available and KE data is used for these materials which is conservative. Actual fuel-related components of this sludge are likely lower than assumed.

Grout Waste Loading

The waste loading for the grout is a key factor influencing the feasibility of the approach. The factors influencing the selection of the grout formulation and waste loading will vary depending on the classification of the final waste form as either TRU or non-TRU. Previously, sediment from the N basin was grouted to form a non-TRU waste form (Pearce, 1998b). In this grouting operation, as-settled sludge with a TRU content of approximately 1162 nCi per gram of as-settled sludge (including water weight) was slurried with an equal volume of water to facilitate transport to a container where it was mixed with cementitious dry materials and additional water to form a non-TRU grouted waste form containing about 67 nCi/g.

However, the TRU concentrations in the low-activity as-settled K basin sludges are 5 to 15 times higher than those in the N basin sludges. Therefore, grouting of the K Basin

low-activity streams (KE1SEG, KE1SEG+Al and KW1[1]) may require excessive dilution to achieve a non-TRU final waste form. A review of other grouting applications was performed to determine a reasonable range of volume increases that are normally encountered. Table A.1 provides a sampling of grout formulations for various wastes.

Table A.1. Relative Increase in Volume and Mass for a Variety of Grout Formulations

Waste Stream Description	x Volume Increase	x Mass Increase	Reference
Hanford Tank Waste, DSSF (estimate)	1.40	1.88	Whyatt 1994
Hanford Tank Waste, 106-AN	1.44	1.87	Bagaasen 1993
Hanford Tank Waste, PSW	1.38	1.84	Fow et al. 1987
Savannah River Site, Saltstone	1.57	2.13	WSRC 1992
Army Corps of Engineers, Guidance for stabilization of LLRW/MW	1.3 to 1.5	~2	U.S.Army Corps of Engineers (1997)
Weldon Springs Rafinnate Pits 1,2,3	1.32	1.60	Gilliam and Francis 1989
Incinerator Ash (dry)	-	2.86	Yokoyama et al. 1990
12% Boric Acid "typical"	2.0	-	Iji, et al. 1985
12% Boric Acid "Advanced Process"	0.5	-	Iji, et al. 1985
Ion Exchange Resin (dry)	-	5.6	Sauda 1990
Average Solidification of Resins (wet)	1.82	-	EPRI, NP-3370[(a)]
Average Solidification of Sludges (wet)	1.89	-	EPRI, NP-3370[(a)]
Average Solidification of Concentrates	1.59	-	EPRI, NP-3370[(a)]
50 wt% Blown Dust/ 50 wt% Water	-	1.25	Whyatt 1997
N Basin Sludge (as settled)	12	17.4	Pearce 1998b

- data not reported in reference

(a) The volume increase is an overall average of operating PWR and BWR nuclear power plants. Data is taken from the period 1978 to 1981.

The most directly applicable formulation was from the Whyatt 1997 reference in which the mass increase in grouting a 50 wt% soil/50 wt% water mix was only a factor of 1.25. The soil material was obtained from a deposit of wind blown dust and was screened on a number 10 sieve

[1] The KW floor sludge inventory used in this analysis is from Pearce et al (1998). This document determines KW floor and pit sludge inventories by assuming they are represented by (or bounded by) the corresponding KE floor and pit sludges. Due to the closed canisters in KW, the actual TRU content may not result in a TRU waste form at reasonable grout waste loadings.

to remove oversize material. Approximately half the mass of the soil passed the number 200 sieve and 70% passed the 100 sieve. This may be similar to wind blown dust on the basin floor and may indicate that a relatively low volume increase formulation could be developed for stabilization of the floor sludge. Optimizing the actual formulation of a waste form would require laboratory testing with the actual sludge. However, based on the review of other grouting processes the following assumption has been made to represent a nominal grout formulation for which a formulation could almost certainly be developed:

ASSUMPTION: The nominal grout formulation will involve diluting the as-settled sludge with an equal volume of water and then grouting the slurry with cementitious solids which further increase the volume by a factor of 1.4. The added volume has a density of density of 3.0 g/cm^3 for purposes of estimating the final grouted mass and density. The formulation is assumed to not have separated water after curing.

Decanting additional water off of the slurry prior to grouting may allow some increase in waste loading. However, the assumption for waste provides a reasonably conservative starting point for the analysis.

Based on earlier discussions, it is expected that more than a factor of 10-volume increase during grouting would be considered unacceptable from a TRU dilution standpoint. Table A.2 provides the estimated TRU concentration for stabilized streams KW1, KE1SEG and KE1SEG+Al. The assumptions used to calculate the mass and volume of the stabilized streams follow the table. The table assumes that the maximum volume increase of 10X is applied **after** the waste is slurried 1:1 by volume with water to enable transfer which is the most beneficial assumption relative to resulting TRU concentrations. The table also includes cases including normal concrete aggregate and iron filing aggregate to increase the waste form density (and thus increase the dilution on a nCi/g basis). The use of these materials might be justified based on reducing the dose rate from the package relative to less dense grout material. However, even if the approaches analyzed here were to be allowed from a dilution standpoint, the concentrations of transuranic isotopes would still make the resulting waste form TRU.

Table A.2. TRU Content, Mass and Volume for Stabilized Waste Streams

Waste Stream	Stabilization Option	TRU Content (nCi/g)	Total Mass, MT (1000s of kg)	Volume (m^3)
KW1	As-Settled	6695	6.0	4.7
	Nominal Grout Formulation	1835	21.9	13.1
	N Basin Grout Formulation	407	98.7	56.0
	10X Volume Grout Formulation	244	164.4	93.4
	10X Volume Concrete	179	224.2	93.4
	10X Volume Iron Concrete	135	298.9	93.4
KE1SEG	As-Settled	12810	55.0	39.7
	Nominal Grout Formulation	3709	189.9	111
	N Basin Grout Formulation	839	839.4	476
	10X Volume Grout Formulation	504	1397.4	794
	10X Volume Concrete	370	1905.6	794
	10X Volume Iron Concrete	277	2540.8	794
KE1SEG+Al	As-Settled	17078	57.5	41.3
	Nominal Grout Formulation	4749	198.0	116
	N Basin Grout Formulation	1077	873.2	496
	10X Volume Grout Formulation	647	1453.7	826
	10X Volume Concrete	474	1982.3	826
	10X Volume Iron Concrete	356	2864.1	826

Nominal Grout: The as-settled sludge is diluted 1:1 by volume to enable transfer as a slurry and then the slurry grouted resulting in a factor 1.4 increase in slurry volume and assuming that the added volume has a density of density of 3.0 g/cm^3 for purposes of estimating the final grouted mass and density. This is believed to be a reasonable grouting process although volume and mass reduction could be obtained by decanting some of the 1:1 slurry water prior to grouting.

N Grout: The as-settled sludge is diluted 1:1 by volume to enable transfer as a slurry and then is grouted to produce a factor of 6 increase in volume matching the N basin grouting process. The mass is determined based on a grouted waste density of 1.76 g/cm^3 (matching the N basin grout density).

10X Volume Grout: The as-settled sludge is diluted 1:1 by volume to enable transfer as a slurry and then the slurry is grouted resulting in a factor 10 increase in the slurry volume (i.e. 20 times the as-settled sludge volume). The density is assumed to be 1.76 g/cm^3.

10X Volume Concrete: The as-settled sludge is diluted 1:1 by volume to enable transfer as a slurry and then is stabilized by mixing with cementitious solids and aggregate to produce a waste form with typical concrete density (2.4 g/cm^3) and a factor 10 increase relative to the slurry volume.

10X Volume Iron Concrete: The as-settled sludge is diluted 1:1 by volume to enable transfer as a slurry and then is stabilized by mixing with cementitious solids and iron filing aggregate to produce a waste form with enhanced concrete density (3.2 g/cm^3) and a factor 10 increase relative to the slurry volume.

Assuming the final grout density is 1.76 g/cm^3 (i.e. no aggregate), the waste would need to be slurried 1:1 by volume with water and then the volume increased by the following factors to reach 100 nCi/g:
KW1 = 24.5
KE1SEG = 50.4
KE1SEG+Al = 64.7

The option of grouting the low-activity streams in containers of steel scrap was also investigated. The steel scrap could come from cutting up the racks that currently hold the fuel canisters in the basin. The addition of the steel would increase the weight of containers, and reduce the nCi/g concentration. It is estimated that up to 69326 lbs of steel would be available from each basin[2].

Calculations were performed for blending of the steel with grouted K basin sludges to determine the volume fraction, mass fraction and total mass of steel needed to achieve 100 nCi/g in the final grouted package. All calculations assumed the "nominal" grout formulation (consists of 1:1 volume dilution with water followed by 40% volume increase during grouting of the slurry) and assumed carbon steel with a density of 7.86 g/cm^3. No TRU contamination was assumed on the steel.

As seen in the Table A.3, the amounts needed are unreasonable. The packing fraction for the steel would have to be unreasonably high and the total mass of steel required greatly exceeds the 6.29x10^4 kg total mass ((69326 lb. x 2 basins)/(2.2046 lb/kg)) of steel in the canister racks of the two basins.

Table A.3. Steel Required to Achieve 100 nCi/g in Grouted Waste Form - Nominal Grout

Grouted Sludge Steam Identifier	TRU Content of Grout Only (nCi/g)	Volume Fraction Steel for 100 nCi/g	Mass Fraction Steel for 100 nCi/g	Total Steel for Stream (kg)
KW1	1835	0.79	0.95	3.80x10^5
KE1SEG	3709	0.91	0.98	6.85x10^6
KE1SEG+Al	4749	0.91	0.9866	9.20x10^6

[2] Personal Communication, K.L. Pearce, 11/98

As a final effort to identify a viable option which would produce a non-TRU waste form, calculations were performed assuming that the sludge was diluted 1:1 and then underwent a factor of 10 volume increase during grouting, prior to being added to a container with steel scrap in it. In these cases, the packing fraction is more reasonable but the mass of steel required still exceeds the 6.29×10^4 kg available from the racks. Specific values are provided in Table A.4.

Table A.4. Steel Required to Achieve 100 nCi/g in Grouted Waste - x10 Volume Dilution Grout

Grouted Sludge Steam Identifier	TRU Content of Grout Only (nCi/g)	Volume Fraction Steel for 100 nCi/g	Mass Fraction Steel for 100 nCi/g	Total Steel for Stream (kg)
KW1	244	0.24	0.59	2.37×10^5
KE1SEG	504	0.48	0.80	5.65×10^6
KE1SEG+Al	647	0.55	0.85	7.95×10^6

It does not appear that these streams can reasonably be grouted to form non-TRU waste forms. The possible exception is stream KW1. The TRU content in this stream is based on data from KE basin sludge. Due to the closed canisters in KW basin, there may be substantially less TRU in this stream than assumed. However, the volume of low activity sludge from KW basin is only 4.7 m^3, which represents only about 10% of the total low-activity sludge.

Radionuclide Content

Table 3 of the ERDF waste acceptance criteria limits the concentration of radionuclides using a sum of fractions calculation. If the limit is exceeded, averaging over a package is acceptable and averaging over a waste trench or disposal site is considered on a case by case basis. Radionuclide content for the grouted low-activity streams (nominal grout formulation) is compared to the ERDF WAC Table 3 limits in the Table 5. The comparision does not include a complete list of isotopes present and as a result may not be conservative. However, even for the abbreviated list of isotopes the sum-of-fractions limit exceeds 1 by a significant margin. The majority of the problem is related to the transuranic radionuclides. However, the grouted streams KE1SEG or KE1SEG+Al exceed the limit based solely on Cs-137.

Table A.5. Comparison of Nominal Grout Concentrations to Table 3 Limit in ERDF WAC

Ratio Grout/Limit				
Nuclide	Table A.3 Limit, Ci/m^3	KW1	KE1SEG	KE1SEG+Al
Cs-137	32.00	0.41	1.58	1.75
Sr-90	7000.00	0.00	0.01	0.01
U-235	0.00	0.04	0.07	0.10
U-238	0.01	0.19	0.37	0.53
Pu-238	1.50	0.24	0.41	0.54
Pu-239	0.03	27.21	46.53	60.20
Pu-240	0.03	14.76	25.13	32.51
Pu-241	6.20	11.56	0.02	0.02
Am-241	0.05	30.00	72.69	92.85
Sum of Fractions		84.41	146.80	188.51

Dose Rates

Dose rates at contact were estimated for grouted 55-gallon drums filled with grouted sludge. The dose rate in mR/h is provided in the table below. The dose calculation calculates the self-shielding due to the grout but neglects the wall of the drum. The only radionuclide calculated was Cs-137 which in previous calculations has dominated the dose from these sludges[3]. The dose calculation used a grout density of 1.64 g/cm^3 which is slightly less than the density of 1.76 g/cm^3 which was assumed when diluting the grout to achieve the 100 nCi/g levels.

Table A.6. Estimated Contact Dose Rates for Grouted Drums

	Nominal Grout Dose Rate in mR/h	10x Dilution Grout Dose Rate in mR/h	Diluted to 100 nCi/g Dose Rate in mR/h	Dilution Factor to achieve 100 nCi/g
KW1	4966	695	284	24.5
KE1SEG	19074	2670	530	50.4
KE1SEG+Al	21108	2954	457	64.7

Clearly, the nominal grout formulation or the x10 dilution grout formulations results in a remote handled waste form that would require shielding to make it contact handled. Dilution with additional grout to achieve 100 nCi/g TRU content reduces the dose rates although they are still greater than the contact handled limit of 200 mrem/h contact.

[3] The daughter product Ba-137m is assumed to be present in secular equilibrium.

Overall Grout to ERDF Conclusion

The TRU content of the low-activity grouted sludges exceeds 100 nCi/g. Only through excessive dilution could the TRU concentration be reduced to the 100 nCi/g. As a result, this option is eliminated from further consideration.

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APPENDIX B

HOT WATER OXIDATION

APPENDIX B

HOT WATER OXIDATION

B1.0 INTRODUCTION

Hot water oxidation, considered alone, was screened from further consideration. As a result of being screened, a full appendix was not prepared for this option. The information in this appendix is presented in the same format as other appendices and where information is expected to be similar to that found in other appendices references are made and where the information simply has not been developed, that is indicated.

The concept for this option is that the sludge would be oxidized in hot water, interim stored in either a BNFL tank or Tank Waste Remediation System (TWRS) tank, and then vitrified in a privatized vitrification plant. However, due to inadequate information being available, interim storage in a BNFL tank could not be evaluated (see section 6.1.3 of main document for discussion), making TWRS the interim storage location for evaluation. In order to allow the oxidized product to meet TWRS particle size restrictions a grinder is included following the hot water oxidation process. This approach was used within the *grouting → CWC → WIPP* alternative to oxidize the metallic uranium particles in the fine solids fraction prior to grouting.

B2.0 CONSTRAINTS/REQUIREMENTS

Criticality Safety - Criticality safety must be considered both in the processing facility and in the double-shell tank (DST) used for interim storage of the sludge.

Pyrophoric Material - The pyrophoric characteristic of sludge must considered in the process design and must be removed prior to transfer to TWRS.

Flammable Gas Generation - The process must be managed to prevent deflagration of hydrogen gas generated by the oxidation of the uranium by water.

Retrieval Immobilization - A particle size of 177 μm is set to assure retrieval from the DST can be achieved. This limit is met in complying with the 10 μm criticality control limit for the DST.

Corrosion - TWRS tank corrosion specifications must be met. See baseline description for more information.

TSCA Regulated Material - The hot water oxidation process will require that a risk-based approach be used to allow placement of polychlorinated biphenyl (PCB) contaminated solids in the DST.

ERDF/WIPP Criteria - Secondary wastes must meet the acceptance criteria for ERDF or the Waste Isolation Pilot Plant (WIPP).

B3.0 PROCESS DESCRIPTION

The metallic uranium oxidation rate in water ≤100°C is slow, requiring long reaction times to fully oxidize particles up to 1/4" in dimension. The reaction time to oxidize a 1/4" uranium particle in water at 100°C is estimated to be 2557 hours (107 days). If each batch of sludge (215 total) is processed for this period, the number of oxidation tanks (96) operating in parallel to meet the 13-month processing window is excessive. In addition, this number may increase when the difficulty of rapidly delivering the sludge to the facility to initially fill the tanks is considered. However, by segregating the sludge into several size fractions the number of tanks required is greatly reduced. Segregating the sludge into size fractions <250μm, 250 to 1000μm and >1000μm results in about 14 oxidation tanks being required. This calculation assumes that the tanks operate 60% of the time during the 13-month operating window. The configuration of segregating into 3 size fractions and processing in 14 oxidation tanks is the selected configuration for examining the process.

The breakdown of the relative effects of various streams and sizes on the total number of tanks required is shown in Table B.1. Here the tanks are sized to process 160 kg of dry solids per batch.

Table B.1 Breakdown of Required Number of 100°C Hot Water Oxidation Tanks by Sludge Stream Source and by Particle Size Fraction

	Particles <250μm (Tanks)	Particles >250μm, <1000μm (Tanks)	Particles >1000μm, <6350μm (Tanks)	Total by Stream (Tanks)
KE1	2.2	1.0	3.3	6.5
KE2	0.0	1.2	3.3	4.5
KW1	0.2	0.0	0.0	0.2
KW2	0.0	0.4	2.3	2.7
KW3	0.4	0.0	0.0	0.4
Total by Size	2.8	2.6	8.9	14.3

Table B.1 indicates that a similar number of tanks are required for high activity streams (KE2, KW2 and KW3) compared to low activity streams. About 62% of the tanks are required to treat the particles >1000μm which represent only 9.2% of the solids mass. Table B.1 indicates 3.3 of the 14.3 tanks are required to treat large KE1 solids. A significant fraction of these large solids are organic ion exchange resin (OIER) so there is the potential for further reduction in the number of tanks if an elutriation step is included to remove OIER. However, the maximum reduction in tanks is only about 3 tanks. An evaluation would be needed to further refine the savings from elutriation of the OIER. It may be advantageous to perform the size segregation by elutriation rather than by screening since this may entrain fewer low density, non-metallic particles in the longest duration oxidation batches. However, for simplicity, the process is evaluated assuming a screen separation without including elutriation of the OIER.

B3.1 HIGHER TEMPERATURE WATER OXIDATION

It is possible to reduce the number of oxidation tanks by using higher temperature water under pressure or by using superheated steam. Increasing the temperature accelerates the rate of oxidation and reduces the number of oxidation tanks needed. The number of tanks and required plenum pressure is shown in Figure B.1. The curve rising to right shows the increase in pressure for a liquid water system while the dotted curve falling to the right shows the reduction in the number of vessels as the pressure is increased. The second curve falling to the right shows the slightly higher number of vessels if superheated steam at atmospheric pressure is used. The data points along the X-axis simply indicate that the steam system is not pressurized. The data in the plot is repeated in Table B.2.

Table B.2. Number of Vessels for Hot Water and Steam Oxidation Above 100°C

Temperature, °C	Water		Superheated Steam
	Number of Vessels	Pressure PSIG	Number of Vessels
101	12.5	0.6	12.7
125	3.8	19.0	5.7
150	1.3	54.4	2.8
175	0.5	114.7	1.4
200	0.2	210.8	0.8

When processing using superheated steam, the solids would not be suspended in agitated tanks. However, the number of vessels represents a generic number of batch devices required. Even with the elevated temperatures the reactions are sufficiently slow that a continuous process may not be suitable. For example, even for superheated steam at 200°C, the residence time to fully react a 1/4-inch particle is about 6 days. Operating at even higher temperatures can reduce this time but the required residence time goes through a minimum at 330°C, at which point the residence time is still in excess of 12 hours for a 1/4" particle. Thus, at least for the larger sizes a batch process is probably more suitable than a continuous process.

By operating at 125°C in a vessel with the plenum maintained at 20 psig, the number of oxidation tanks could be reduced to 4. However, this results in the production of hydrogen within a pressurized vessel. The additional complexity/safety issues associated with control of hydrogen concentration within the pressurized vessel was judged to outweigh the reduction in number of vessels. An alternative approach would be to react the uranium with superheated steam at atmospheric pressure which results in the hydrogen being produced at near atmospheric pressure, eliminating the concern over pressurized hydrogen. Operating in a batch mode[1] at 150°C about three reaction vessels would be needed. However, the use of superheated steam results in hot dry metallic

[1] The comparison is made as if the superheated steam is reacted with the uranium in a batch reactor with efficient contact between the superheated steam and uranium particles. The details of the design are unspecified.

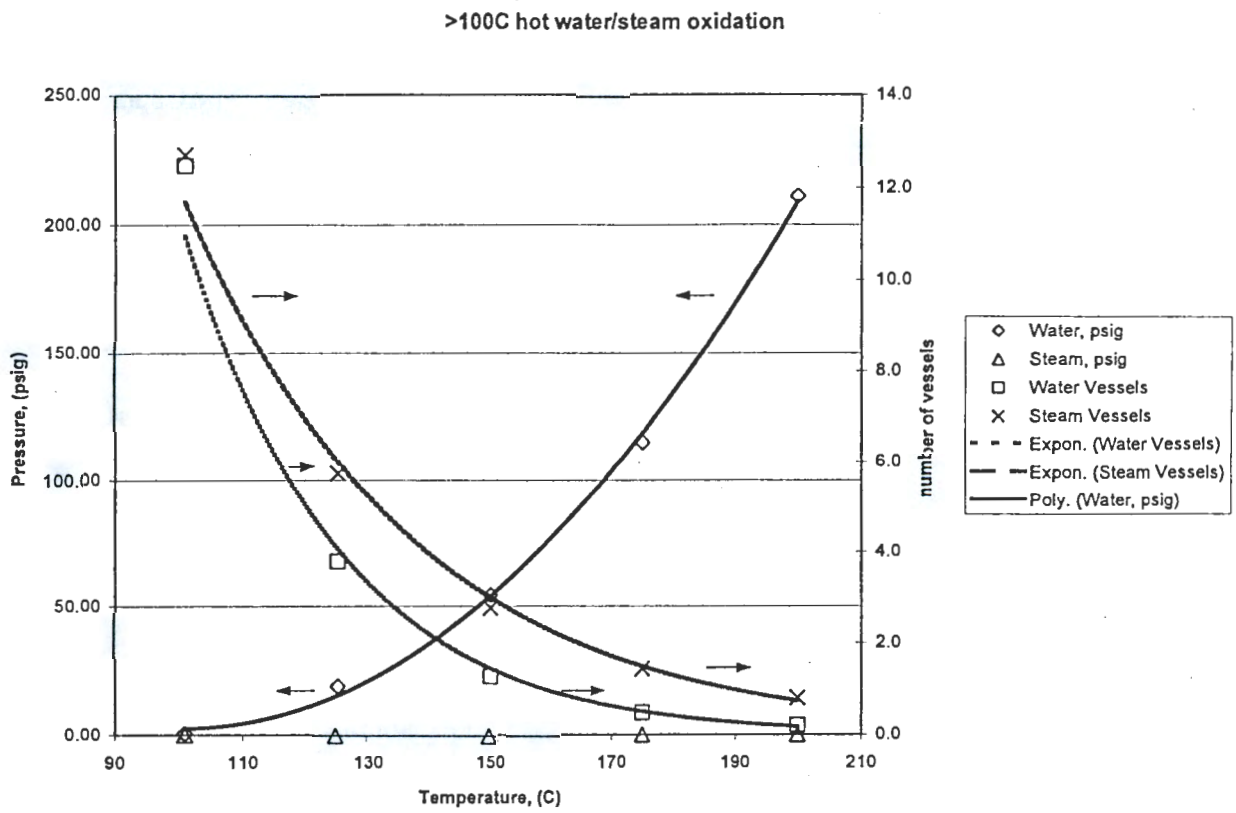

Figure B.1. Number of Vessels Required for Hot Water and Superheated Steam Options for Temperatures above 100°C. Pressure required for hot water option is shown on left axis. Superheated steam is assumed to be near atmospheric pressure.

uranium within the processing equipment. This introduces a potential uranium fire hazard if air enters the reaction vessel. As a result, the equipment would need to be operated within an inerted cell (probably argon). Thus, compared to operation in water at 100°C, the complexity/safety issues associated with atmospheric superheated steam outweigh the reduction in number of tanks.

B3.2 HYDROGEN GENERATION RATES

The primary reaction occurring in the oxidation tanks is

$$U + (2+x)\ H2O \rightarrow UO_{2+x} + (2+x)H_2$$

where x<0.25. Thus, the oxidation of the metallic uranium results in generation of hydrogen gas. The reaction proceeds linearly from the surface of the metallic particle. As a result, uranium in smaller particles will react more quickly than uranium in large particles. The hydrogen generated must be diluted and removed from the vessel plenum to prevent flammable conditions from occurring. The rate of hydrogen generated in a tank containing 160 kg of uranium of various particle sizes is shown in Table B.3 below.

Table B.3 Hydrogen Generation and Dilution Flows For Hot Water Oxidation Tanks at 100°C

	160 kg Metallic Uranium With Particle Size of:		
	250μm	1000μm	6350μm
H_2 generation, SCFM	0.62	0.16	0.025
Ventilation Flow SCFM for 2% H_2	30.5	7.68	1.21

As the particle size becomes smaller the initial hydrogen generation rate accelerates. However, this should not be a problem because the two streams expected to be high in metallic uranium (KE2, KW2) are primarily larger than 250 microns. The streams KE1, KW1 and KW3 which contain smaller particle sizes, contain small amounts of metallic uranium (0.2 wt%, 0.05 wt%, 1.9 wt% respectively). Thus, the rates of hydrogen production would be expected to be low for these streams despite the smaller particle size.

B4.0 PROCESS FLOWSHEET DESCRIPTION

B4.1 SIZE SEGREGATION

The sludge is screened using 2 screens to segregate into 3 size fractions consisting of particles <250μm, between 250μm and 1000μm, and >1000μm. Each batch of size-segregate sludge delivered to the processing facility contains a single size fraction.

B4.2 TRANSFER FROM TRANSPORT CONTAINER

Sludge is slurry transferred directly from the transport container to an oxidation tank that is sized to accept one transport batch of sludge.

B4.3 HOT WATER OXIDATION

A total of 14 hot water oxidation tanks are anticipated. After receiving sludge, the oxidation tank is agitated and heated to just below its boiling point (~100°C). The tank is then held at temperature and agitated for a time period sufficient to oxidize the largest uranium particles in the batch. This time period ranges from about 100 hours for the fine solids fraction to 2557 hours for the large particle batches. Hydrogen is generated into the tank plenum space and removed by a ventilation sweep to prevent flammable mixtures of hydrogen from accumulating. The rate of reaction and completion of the process is determined by monitoring the hydrogen evolution from each tank.

B4.4 GRINDING

After oxidation is complete and hydrogen generation has subsided, the batch is transferred to a grinder to reduce particle size to less than 10 μm. A grinder of similar type to that described in Appendix E would be used. However, the operation would be greatly simplified due to the fact that there would be no heat producing reactions occurring, no hydrogen generation, and the uranium as an oxide is not expected to be

difficult to grind. A single grinder is expected to be sufficient to process all of the sludge.

B4.5 HYDROCYCLONE

After grinding, any particles not meeting the 10 μm size criteria are removed by a hydrocyclone similar to the process described in Appendix E with the exception that there is no recycle of oversize material. The oversize material is expected to consist primarily of zircaloy-2 cladding pieces.

B4.6 GROUTING OVERSIZE FRACTION

The zircaloy-2 cladding pieces and any other oversize material would be grouted and disposed as secondary waste. The waste stream is expected to be very similar to that described for the grinding option.

B4.7 ADDITION OF NEUTRON ABSORBERS/CORROSION SPECIFICATION ADJUSTMENTS

The slurry would be sampled and analyzed and depleted uranium would be added to reduce the ^{235}U enrichment to 0.84%, iron would be added to assure a Fe:Pu mass ratio of 353:1[2], and NaOH and $NaNO_2$ would be added to meet TWRS corrosion specification. The process is essentially identical to the grinding/milling process. See Appendix E for more information.

B4.8 TRANSFER TO TWRS

If required, the slurry would be diluted to 40 g solids/liter prior to transport to TWRS.

B5.0 DOE/FOREIGN/COMMERCIAL/PREVIOUS EXPERIENCE

The reaction of metallic uranium with water has been studied and there is substantial data on the reaction rates etc. Previous experience with a similar process was not investigated.

B6.0 SAMPLING REQUIREMENTS

Samples and analyses are needed to accomplish final slurry adjustment and to demonstrate compliance with TWRS acceptance criteria. In addition, analyses of the oversize fraction to be grouted are needed to properly classify and or formulate the secondary waste grout produced for disposal at WIPP or ERDF.

B6.1 PROCESS CONTROL CRITERIA

The oxidation of the uranium in water generates hydrogen. The hydrogen concentration in the plenum of each tank will be monitored and used to adjust the dilution gas flow that

[2] The value of 353 is used in the baseline process. A slightly lower value is currently used in the CSER.

sweeps the hydrogen out of the plenum. The rate of hydrogen generation will be used to assess the rate of reaction occurring. The cessation of hydrogen generation is taken as an indicator that the oxidation is complete. The vessel temperature is controlled by supplying sufficient heat to maintain temperature. Any excess heat is removed as steam along with the generated hydrogen. No decision on whether to provide individual condensers on each tank or a single offgas system condenser has been made. If a single condenser is used for all tanks, water makeup would be added to the oxidation tank to maintain the weight of the vessel and prevent evaporating a tank to dryness.

B6.2 PRODUCT VERIFICATION CRITERIA

B6.2.1 TWRS

Waste destined for disposal in TWRS tank farms must have data to show compliance with analytes identified in the double-shell tank waste acceptance criteria (Mulkey 1998). In addition, a waste fact sheet must be developed prior to shipment that includes other specific requirements to be considered. Process knowledge may provide information that can reduce direct analytical measurements but these changes require negotiation prior to material shipments. The details of the acceptance measurements required are included in the baseline process alternative and therefore are not repeated. The difference in this product is inclusion of solids in the sample intended for analyses. This additional sample preparation will increase the analytical cost, however this cost is small compared to the reduced sodium impact in terms of LAW eventually produced.

A TWRS drafted policy sets forth additional interim criteria for the acceptance of PCBs to tank farms that ensure TSCA regulated PCBs are not received by the DST system (Interim Acceptance Criteria). Because this option would send high concentrations of PCBs to the DST than the baseline process a risk-based approach to the PCBs may be needed.

The slurry product of the hot water oxidation operation will be adjusted to comply with criticality prevention requirements (iron and depleted uranium addition) and for TWRS acceptance criteria based on corrosion specifications for hydroxide, nitrate, and nitrite concentrations. The hydroxide measurement will be performed, after adjustment, on the slurry sample; nitrate and nitrite will be performed on filtrate. Metals and radionuclide analyses will be performed on the slurry sample received after fusion of the aliquot to dissolve all constituents.

Timeframe

Approximately 1 batch of slurry will be transferred per day on line for the plant. Individual batches can be sampled and analyzed for major constituents prior to completion of the oxidation process allowing additional time for analysis. However, the final slurry adjustment (addition of iron, depleted uranium, sodium hydroxide and sodium nitrite) to meet criticality and tank corrosion specifications must be verified after adjustment which requires analytical within a 24 hour period of sample receipt to

minimize process perturbations. Some radionuclide analyses, which require sample preparation steps, require approximately 24 hours to complete. As a result, it is expected that the hot water oxidation process alternative will require a dedicated analytical staff to prevent process delays.

Analyses of the oversize solids destined for grouting should not require a rapid turnaround since the accumulation rate of this material is low.

B7.0 APPLICATION TO K BASIN SLUDGE

This section evaluates the treated sludge against the TWRS waste acceptance criteria. Evaluation against the ERDF and/or WIPP waste acceptance criteria for the grouted product was not conducted.

The organic resin beads in the K East sludges (KE1 and KE2 streams) are to be ground with the sludges for interim storage at TWRS. TWRS operations has indicated their acceptance of these organics (since they are ground to <10 um diameter and constitute less than 10 wt % of the solids in streams KE1 and KE2) without a requirement for additional monitoring of waste at TWRS (Erlandson, 1999).

The hot water oxidation treatment process would treat the sludge to meet the TWRS waste acceptance criteria for criticality control, elimination of pyrophoric materials, corrosion control, prevention of flammable gas retention, particle size and exclusion of TSCA-regulated materials. The hot water-oxidation step insures that essentially all of the uranium is converted to solid oxide. Meeting the size criteria would require adding a grinder to the process to grind the oxide particles along with sand, zeolite, OIER etc. after oxidation[3]. There is reasonable confidence that after oxidation, the uranium will be easily ground. Sufficient depleted uranium (as required) and iron nitrate are added to the slurry prior to pH adjustment to meet the criticality specifications. A total of 379 m^3 (100,000 gallons) solids can be added to AW-105 before exceeding the flammable gas retention requirement. The baseline process is estimated to produce between 115 and 435 m^3 of settled solids. The hot water oxidation process is estimated to produce a *mass* of solids to TWRS that is at most about 35% greater. However, since the sludge is not precipitated from an acid solution, the solids may settle into a more compact layer in the tank. As a result, it is uncertain whether the hot water oxidation process solids would fit within the desired maximum of 379 m^3 sludge. The requirements for corrosion control are met by adding NaOH and $NaNO_2$ prior to transfer. This process eliminates pyrophoric materials by oxidizing the metallic and hydride uranium material in the hot-water oxidation step. The zircaloy will be separated out in the knockout pot and stabilized in a grout matrix.

[3] The alternative of making a particle segregation at 10 μm would generate a large volume of highly TRU contaminated solids for stabilization/WIPP disposal. In this case the most practical option would be to abandon TWRS as a destination and simply grout all solids to WIPP which would make it a variation on the grout alternative.

The concentration of PCBs in the sludge is likely to be reduced in the hot-water oxidation process via the grinding step. The Sweco grinding mill considered for the grinding application comes standard with a ~1-in. thick abrasion-resistant polyurethane liner. [Other linings, such as stainless steel, are available.] PCBs are known to sorb onto polyurethane, and polyurethane foam is used in a number of analytical PCB extraction techniques (Erickson 1991). In a previous evaluation to determine the fate of PCBs during K Basin sludge processing, several tests were conducted with PCB-spiked K Basin sludge simulant (spiked to nominally 1000 ppm PCB) using heated water (60°C/1 hr and boiling temperatures/6 hr) (Mong et al. 1998). About 20 to 70% (depending upon the PCB congener) of the recovered PCBs from this testing were found to be associated with the glass test equipment (i.e., recovered after completion of the tests via solvent washing of the test equipment). Nearly all of the remaining recovered PCB was associated with the solids from the K basin sludge simulant. These results indicate that PCBs can migrate from the sludge to a processing vessel. Given that the PCBs have a higher affinity for polyurethane than glass, it is possible that significant quantities of PCBs will collect on the liner in the vibratory grinder. However, at some point, the surface of the liner will likely become saturated, and further PCB adsorption may cease. It should also be noted that at temperatures up to 52°C, the polyurethane liner is expected to last about 13,000 hours of grinding [Personal communication, Tom Dunkar, Sweco (2/12/99)]. Thus, if the grinding temperature is maintained at this level, the liner should last the life of the plant. At higher temperatures, the life of the liner would be expected to decrease.

In addition to adsorption onto the liner, and to a lesser extent, on the other surfaces of the processing equipment, a small fraction of the PCBs may also be carried into the offgas stream in mist and vapors.

Without performing experiments, it is difficult to quantitatively estimate the extent of PCB removal from the sludge during hot-water oxidation. The granulated activated carbon bed installed in the offgas system will ensure the PCB concentration in the offgas will be less than the $10\mu g/m^3$ limit.

Oversize material that is not ground (primarily zircaloy-2 cladding pieces) could be separated as in the grinding alternative and grouted for disposal as a secondary waste.

B8.0 SAFETY CONSIDERATIONS

B8.1 CRITICALITY SAFETY

Mass control will be utilized similar to baseline chemical, plus rinsing of vessels and supplementary monitoring, as required. Additional analysis may be needed to determine if interaction between the 14 oxidation tanks may require additional controls. Criticality safety within the grinder needs to be addressed so that an inventory does not buildup in the grinder over time.

B8.2 HYDROGEN GENERATION

Hydrogen generation must be managed to prevent flammable mixtures of hydrogen in the oxidation tank plenums. The hydrogen is produced in the uranium-water oxidation reaction. Due to the elevated temperature in the oxidation tanks, the rate of hydrogen generation is greater than the lag storage or dissolver feed tanks in the nitric acid options. The hydrogen would be swept from the plenum of each reaction tank and diluted to below flammable concentrations. Requirements for nitrogen versus air purge and/or a nitrogen inerted cell have not been evaluated.

B8.3 PYROPHORIC PARTICLES

The pyrophoric nature of the metallic uranium particles is managed by maintaining the particles within a water slurry throughout the process.

B8.4 ORGANIC ION EXCHANGE RESIN

Because nitric acid is not used the hazard associated with energetic reactions between OIER and nitrates are eliminated.

B8.5 CONTROL OF PCB OFFGAS EMISSIONS

Some fraction of PCBs may be volatilized during the extended heating of the slurry. An activated carbon filter would be used to control PCB emissions.

B9.0 MAINTENANCE REQUIREMENTS

A maintenance concept has not been specified for this option. However, the hot water oxidation tanks are relatively simple such that the process could be adapted to either the baseline approach where agitators, pumps etc are placed in pits for hands-on maintenance or adapted for a remote maintenance environment.

B10.0 FACILITY LAYOUT

No facility layout for this option was prepared.

B11.0 TRANSPORT AND INTERIM STORAGE

See Appendix E, section E.4.

B12.0 FINAL DISPOSAL

See Appendix E, section E.5.

B13.0 OTHER ISSUES

This section was not prepared.

B14.0 ADVANTAGES/DISADVANTAGES

B14.1 SCREENING COMPARISON TO NITRIC ACID DISSOLUTION

Compared to the nitric acid flowsheet the hot water oxidation with grinding option would replace screening/elutriation, two dissolvers, a centrifuge and polishing filter with screening, 14 hot water oxidation tanks, a grinder and hydrocyclone separator. The hot water oxidation process results in a 7-fold increase in the number of hot water oxidation tanks compared to dissolvers although the complexity of the oxidation tanks are less than the dissolvers. The hot water approach does increase the complexity associated with managing hydrogen generation[4] but this is partially offset by the elimination of the need for nitric acid and NO_x absorber columns. The greater number of oxidation tanks relative to dissolvers would be expected to require additional hot cell space and increase the initial facility cost. It is expected that the hot water oxidation process would involve additional complexity in demonstrating compliance with TWRS size specifications. The pH and nitrite adjustment processes would be essentially the same between the two processes. The hot water oxidation would reduce the amount of sodium sent to TWRS (no need to neutralize nitric acid with NaOH) resulting in a long-term savings in LAW glass volume. In addition, the hot water oxidation process would have a lower volume of secondary sludge waste to dispose[5]. These savings would be partially offset by the additional sodium introduced during caustic sludge washing in the DST due to the additional solids sent to TWRS (ground sand, zeolite, OIER). Unlike the nitric acid flowsheet, a large fraction of PCBs would go with the ground solids to TWRS, requiring a risk-based PCB approach be used for the hot water oxidation..

The hot water oxidation option was discounted for further evaluation because it was judged that the 7-fold increase in oxidation tanks compared to dissolvers would increase the hot cell size and increase the initial facility cost. There does not appear to be any significant benefit to offset the higher initial cost. In the evaluation, near term costs are weighted 4 times higher than long term costs so that if the alternative were evaluated, it is unlikely that the savings would be sufficient to offset the higher initial cost.

B15.0 REFERENCES

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[4] Each of 14 hot water oxidation tanks would require hydrogen monitoring and purging to control concentration in the vessel plenum. The rate of evolution would be much greater than in the lag storage and dissolver feed tanks in the nitric acid flowsheet due to the elevated temperature. Oxidation during nitric acid dissolution does not generate hydrogen.

[5] Consisting primarily of unground zircaloy-2 cladding pieces compared to undissolved solids (zircaloy-2 cladding, zeolite, SiO_2) plus elutriated OIER stream.

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APPENDIX C

BASELINE CHEMICAL ALTERNATIVE

APPENDIX C

BASELINE CHEMICAL DISSOLUTION ALTERNATIVE

C1.0 INTRODUCTION

The baseline chemical dissolution alternative treats the sludge by dissolving the fuel constituents in nitric acid, separating the insoluble material, adding neutron absorbers for criticality safety, and reacting the solution with caustic to co-precipitate the uranium and plutonium. This process produces a slurry which meets the waste acceptance criteria established by the Tank Waste Remediation System (TWRS). The resulting slurry will be transferred to an underground storage tank (currently identified as 241-AW-105) for interim storage. Final treatment will be via the Phase II high-level melter with subsequent transport to the national geologic repository for final disposal.

The undissolved solids and ion exchange media (separated before the dissolution step) will be treated to reduce the transuranic (TRU) and ^{137}Cs content, stabilized in a grout matrix, and transferred to the Environmental Restoration Disposal Facility (ERDF) for disposal.

C2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Analysis of safety, waste compatibility, retrievability, regulatory, and immobilization aspects identified a number of issues that required adjustment of the K Basin sludge characteristics prior to acceptance of the sludge into the double-shell tank (DST) system. In general, the most unique safety issues with the K Basin sludge materials and safety issues relative to commingling the sludges with AW-105 wastes are associated with criticality safety (including chemical reactions that could increase reactivity and preferential settling of like-size particles), potential exothermic chemical reactions (pyrophoric reactions), and flammable gas generation and retention. This section provides a discussion of the key TWRS waste acceptance criteria that must be met and the unit operations which were selected to meet the criteria. Additionally, the key criteria which resulted in selection of unit operations for treating insoluble sludge solids for acceptance by the ERDF are also discussed. Waste acceptance criteria for TWRS and the ERDF are also provided in Section 4.0 of this report.

C2.1 CRITICALITY SAFETY

Sludge currently in the K Basins contains a quantity and particle size of fissile materials (^{235}U and ^{239}Pu) that poses a criticality concern for retrieval and storage in a DST. Sludge is defined as all material in the basin which is less than or equal to 6350 μm. Characterization samples indicate that flocculation and agglomeration of small particles exists, however, the data does not exclude the presence of large primary particles. Therefore, the discharge of the K Basin sludge

into AW-105 must be preceded with treatment that reduces the primary particle size to less than 10 microns (to facilitate agglomeration and prevent particle segregation) and adds a quantity of absorbers that assures the ^{235}U content is less than 0.84 wt% and the Fe/Pu ratio is greater than 353 (Carothers, et. al. 1997). The unit operations which have been selected to satisfy the criticality requirements are acidic dissolution and added ferric nitrate followed by precipitation. A similar acid dissolution and precipitation process formed the sludges currently stored in the double shell tanks. Depleted uranium in the form of uranyl nitrate will be added on an as needed basis to assure the ^{235}U content is below 0.84 wt%. Additionally a solids/liquid separation step partitions insoluble solids from the acid solution.

C2.2 PYROPHORIC MATERIALS

Uranium and zirconium metal and uranium hydride are expected to be in the sludge from canisters and fuel washing processes. It is also estimated that a small percent (1 wt%) of the uranium in the floor and pit sludges will be metallic uranium (Pearce et. al. 1998). Uranium and zirconium metals and uranium hydride are known pyrophoric materials because under specific physical states and environmental conditions they undergo spontaneous combustion (DOE, 1994). Pyrophoricity is much less of a problem with zircalloy than with uranium. Pyrophoric materials will not be accepted into the TWRS waste tanks. The unit operation (i.e., oxidation with concentrated acid) which resolves the criticality issue will also eliminate the pyrophoric properties associated with uranium metal and uranium hydride. A centrifuge and filter will remove the pyrophoric zircaloy cladding pieces from the stream sent the waste tank.

C2.3 FLAMMABLE GAS GENERATION/RETENTION

Due to the presence of uranium metal and uranium hydride in the sludge, the potential exists for non-radiolytic hydrogen gas generation from metal-water reactions. Generation of gases (Xe, Kr, and H_2) has been observed in canister sludge samples. It has been suggested that the formation of these gases is the result of metallic fuel corrosion or the result of hydride reactions (Omberg 1996). Wastes that exhibit flammable gas generation rates above those from radiolysis are not acceptable for storage in a DST. Acidic dissolution of the sludge will eliminate non-radiolytic sources of flammable gas.

Calculations have indicated that up to 379 m^3 (100,000 gal) of solids can be added to tank AW-105 before reaching the flammable gas retention limit (Carothers et. al. 1997). It has been estimated that the total volume of precipitated solids produced by chemical treatment of the sludge will range from 115m^3 to 435 m^3 solids (Westra 1999). If the solids exceed the TWRS criteria, a portion of the sludge could be transferred to another DST.

C2.4 RETRIEVAL/IMMOBILIZATION

As was mentioned previously, the sludge contains particles with diameters as large as 6350 μm. TWRS has established a secondary particle size limit of <177μm to preclude adverse impacts to retrieval operations and glass melter performance. The unit operations selected to meet the criticality and pyrophoric criteria will satisfy this requirement.

C2.5 CORROSION

The acidic dissolver product solution will require neutralization to meet the TWRS corrosion limits. The parameters for controlling corrosion in DSTs are hydroxide, nitrate, and nitrite ion concentrations in the tank wastes. Sodium nitrite will be added along with NaOH to meet the ion concentration requirements.

C2.6 TSCA REGULATED MATERIAL

Lab testing has indicated that reduced levels of polychlorinated biphenyls (PCBs) can be achieved by normal partitioning as they go through the process, with nearly all of the PCBs adsorbing to the undissolved solids (which will be removed from the sludge stream by the centrifuge), plating out on the process equipment, or volatilizing into the off gas. Additionally, a polishing filter will be located downstream from the centrifuge to remove the 0.1 to 5 μm solids that pass through the centrifuge. The filter media will be polyethylene which is known to have an affinity for PCBs.

C2.7 ERDF CRITERIA

The organic ion exchange resin, zeolite and undissolved solids will be grouted for disposal at ERDF so they must meet the ERDF acceptance criteria. The most restrictive requirements for sludge solids disposal are the limits for TRU (< 100 nCi/g) and ^{137}Cs (<32 Ci/m^3). Ion exchange resin beads, known to be in some of the sludges will be separated from the sludge upstream from the dissolver by an elutriation column. This is done to prevent loading Pu and Am onto the resin which would occur in the acidic conditions in the dissolver. These beads are then treated by acid leaching and washing to reduce the TRU and ^{137}Cs concentration. The undissolved solids from the dissolver also will be treated by acid leaching and washing to reduce the TRU and ^{137}Cs concentration. The leached ion exchange resin and undissolved solids will be transferred to a common holding tank and grouted at the end of the campaign. The results of laboratory leaching tests and flowsheet calculations indicate that the grouted solids will meet ERDF acceptance criteria for TRU and ^{137}Cs (Westra et. al. 1998). Grouting satisfies ERDF disposal requirements for immobilization of pyrophoric material and ion exchange resin.

C3.0 PROCESS DESCRIPTION

In the chemical dissolution option, the sludge is transported from the K East and K West Basins to a newly constructed treatment facility located on the Hanford site. The sludge will be transferred to the treatment facility in batches and will also be processed in batches. The batch size is 160 kg of solids (dry basis) suspended in water at a concentration of 12 wt% solids. The 160-kg of dry sludge allows mass limits to be used for criticality control. The total number of

batches to be processed is 214. Assuming a one batch/day processing rate and 60% operating efficiency, all of the sludge can be processed in a 13-month period.

The baseline chemical dissolution process includes the following process steps, transfer to lag storage, resin separation, acid dissolution, solids/liquid separation, neutron absorber additions, neutralization/precipitation, solids/resin leaching, grouting, offgas treatment. A block flow diagram is shown in Figure C-1. A description of the baseline chemical dissolution process steps, as excerpted from Westra et. al. (1998) follows.

C3.1 SLUDGE TRANSFER TO LAG STORAGE VESSEL

The sludge is transferred from the transport container to a lag storage vessel where it will be agitated to suspend the solids. An air in-bleed to the feed tank is used to dilute and sweep hydrogen gas away as it is produced by the uranium metal- and uranium hydride-water reactions and by radiolysis. Hydrogen generation has been observed during sludge movement. This is presumably from water reactions with freshly exposed uranium metal and uranium hydride.

Transferring sludge containing 6.35-mm diameter pieces of U metal between vessels in the sludge treatment facility is recognized as a difficult problem that has not yet been solved. An engineering study on sludge transfer methods recommended several pumps that should be tested for sludge transfer. Laboratory tests are in progress using simulated sludge to test these pumps and determine if they can transfer the sludge. This problem will be one of the main focuses of development work.

C3.2 RESIN SEPARATION

The sludge will be transferred from lag storage through a screen to the sludge buffer tank. The screen will separate most particles larger than 300 μm from the rest of the sludge and will direct the larger particles, including the resin beads, to an elutriation column. The screen upstream will be flushed with water periodically to prevent plugging. The resin beads and other large particles will enter the elutriation column around the midpoint. The resin beads will be elutriated from the other large particles by pumping water upward through the column at a velocity of about 4 cm/s. The water and elutriated resin will exit the top of the column and drain to the resin buffer tank.

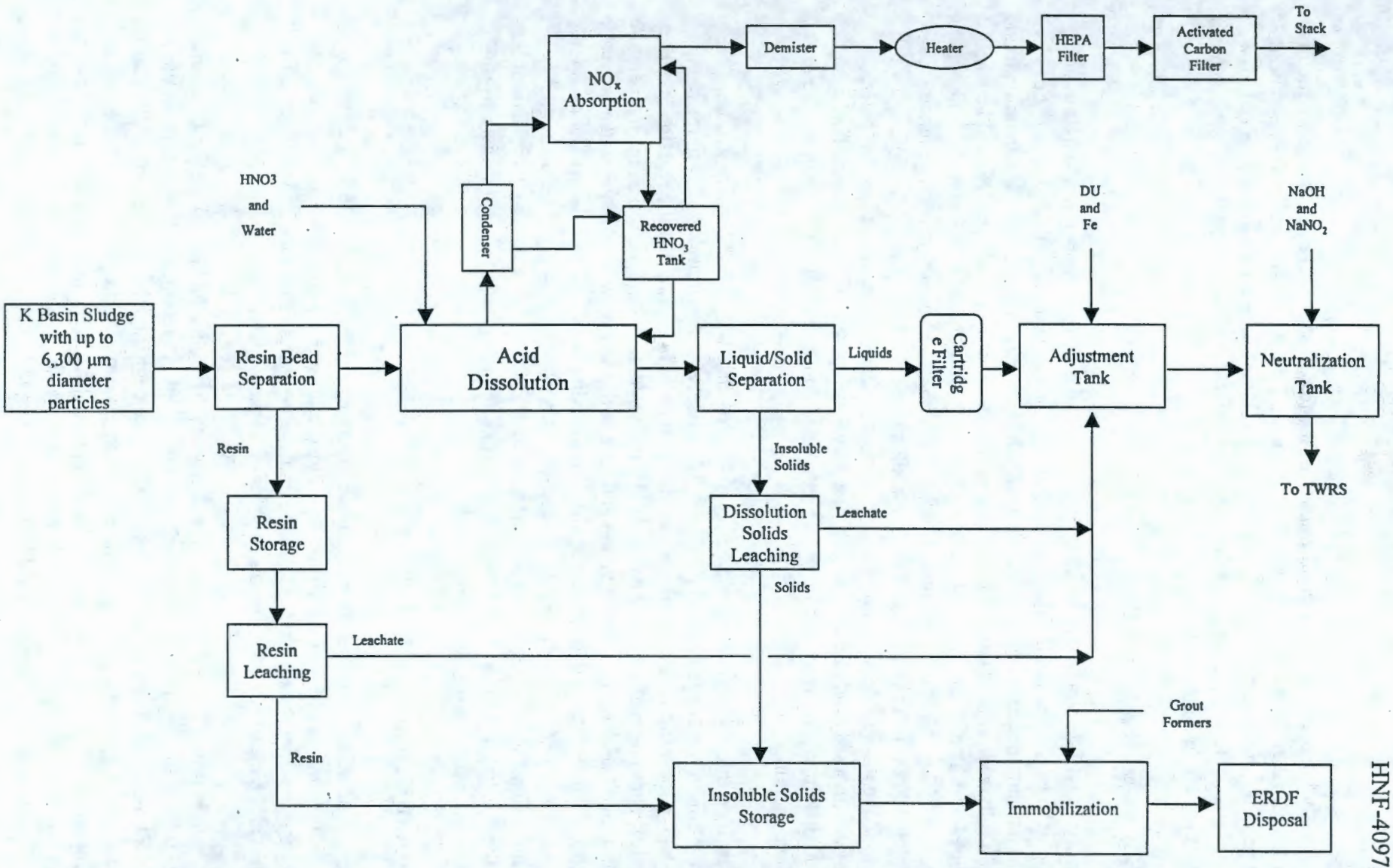


Figure C-1. Conceptual Flowchart for Baseline Chemical Dissolution Option

The heavier sludge particles and a small amount of the resin beads will settle to the bottom of the elutriation column and drain from there to the sludge buffer tank. Periodically, the resin beads will be transferred from the resin buffer tank to the leach tank where they will be treated to remove ^{137}Cs and TRU. A resin separation efficiency of 95% was achieved during demonstration of the technique in laboratory testing.

C3.3 SLUDGE DISSOLUTION

Two dissolvers will be required to process the sludge in the 13-month operating window. Operation of the dissolvers will require making up 6M HNO_3 in the dissolver, heating it to 95 C, and then metering in sludge slurry and additional HNO_3 over an 8-hr period. The uranium oxide and uranium hydride constituents in the sludge will dissolve very rapidly in HNO_3. The reaction rate will be controlled by continuously feeding the sludge into the dissolver at a slow enough rate (2.5 L/min or 20 kg solids/h) to maintain a stable reaction. Continuously feeding sludge containing 6.35-mm pieces of U metal at such a slow rate will be difficult. Development work is planned to solve this problem. Feeding the sludge to the dissolver in multiple small batches instead of continuously may need to be considered if development of a continuous feed system proves too difficult. This may require reducing the acid concentration and/or temperature to control the reaction.

Air will be bled into the dissolver vapor space to help oxidize NO to NO_2, which will improve NO_2 absorption in the condenser and absorber. The dissolver temperature and vacuum, along with the NO_x concentration in the off gas, will be monitored to ensure that the reaction is under control. Temperature instrumentation also can be used to detect foam as well as the temperature of the solution. The concentration of xenon and ^{85}Kr in the off gas will be monitored along with the solution conductivity to determine the dissolution endpoint. Cooling coils will be used to remove the heat generated by the exothermic reactions. A drown tank provides additional cooling capability for off-normal events. The total time for dissolving the floor, pit, and settler tank sludge is estimated to be 10 hours/batch; whereas the dissolution time for canister/wash sludge is estimated to take 22 hours/batch.

C3.4 SOLIDS/LIQUID SEPARATION

Following completion of sludge dissolution, the dissolver will be cooled to 45 °C and the solution will be transferred to a centrifuge for solids/liquid separation. The dissolver solution will be agitated during the transfer to keep the undissolved solids suspended. The dissolver will be rinsed with 380 L of water following completion of the transfer.

As the dissolver product is fed into the centrifuge bowl, the solids and liquid are forced against the inside wall of the bowl by centrifugal force. The solids are retained below baffles on the sides of the bowl. The clarified liquid will overflow the centrifuge bowl and drain to the clarified liquid tank. The liquid will then be transferred through a cartridge filter to one of three adjustment tanks. The filter elements will be changed out when the pressure drop across the filter approaches the design limit. The filter cartridges will be placed in 0.208 m^3 waste drums and stabilized with grout. The grouted filters will be sent to ERDF for disposal or Central Waste

Complex (CWC) for storage based on TRU content. Approximately 49 filters will be used to process all of the sludge. There is a risk that the filters will plug with lower solids loading than expected. This will result in more frequent filter change outs and more filters for disposal.

C3.5 ADDITION OF NEUTRON ABSORBERS

Depleted uranium (as required) and iron will be added to the liquid in the adjustment tank to meet TWRS criticality specifications. Before addition of the absorbers, the solution in the tank will be agitated for at least 0.5 hours and then sampled. The samples will be analyzed to determine the required amount of iron and depleted uranium to be added. Depleted uranium will be added as a concentrated uranyl nitrate solution and the iron as a ferric nitrate solution. The solution in the adjustment tank will be agitated during absorber addition and held at approximately 40 °C. After addition, the solution will be agitated for at least 0.5 hours before transferring the solution to the neutralization tank.

C3.6 NEUTRALIZATION/PRECIPITATION

The acidic solution will be reacted with 19 M sodium hydroxide at 40 °C to neutralize the solution and co-precipitate the uranium, plutonium, and iron. The NaOH will be added to the neutralization tank first, and then the acidic sludge stream will be pumped in from the adjustment tank (reverse strike neutralization). Following neutralization, $NaNO_2$ will be added. Cooling coils will be used to remove the heat generated by the neutralization reactions. Dilution water will be added as needed to reduce the total solids concentration to less than 40 g/L to ensure that the slurry is dilute enough to be transferred without plugging lines.

C3.7 LEACHING OF DISSOLVER RESIDUE AND RESIN BEADS

The solids that are removed in the centrifuge will be washed once with dilute nitric acid or water before being transferred from the centrifuge to the leaching tank where additional TRU and fission products will be leached from the solids. The leach solution will be made up of 4.8 M nitric acid and 0.24 M hydrofluoric (HF) acid held at 90 °C for 4 hours. The HF will react with zircaloy pieces in the solids. This may decrease the leaching efficiency. Following leaching, the leach solution and suspended solids will be transferred back to the centrifuge for solids/liquid separation and solids washing. The solids will be washed three times with water to reduce the radioactivity in the interstitial liquid. The washed solids will be transferred from the centrifuge (as a slurry) to a solids reception tank for eventual grouting along with the leached resin beads.

The resin beads that are separated from the sludge in the elutriation column will be transferred to the leaching tank to remove TRU and cesium from the beads. The leach solution will be made up of 0.1 M oxalic acid and 2 M nitric acid held at 40 °C for 4 hours. Following the leaching, the leach solution and suspended resin beads will be sent to the centrifuge for solids/liquid separation and resin washing. The resin will be washed twice with water before being removed from the centrifuge. The washed resin beads will be transferred from the centrifuge to the solids reception tank to be grouted with the undissolved solids.

The leachate from the resin beads and solids washing processes will drain from the centrifuge to the clarified liquid tank and then be transferred through the cartridge filter to the adjustment tank.

The total volume of resin beads and undissolved solids (including slurry) will be about 51 m^3. It will contain approximately 9800 kg of solids/resin on a dry basis. Grouting will be done at the end of the sludge processing campaign. The solids/resin mixture will be thoroughly agitated to homogenize the solids so representative samples can be obtained. Analyses of the waste will be done to ensure the grouted waste will meet the ERDF waste acceptance criteria.

C3.8 GROUTING OF UNDISSOLVED SOLIDS AND RESIN BEADS

Excess liquid will be decanted to obtain the appropriate solids/liquid ratio for grouting. A total of 33 m^3 of liquid will be decanted during the grout process. This liquid will be routed through the filter for solids removal and then to the neutralization tank for transfer to the DST.

Following solids characterization, the solids will be transferred from the solids storage tank to a Chem Nuclear L14-170 cask liner for immobilization. The slurry will be transferred through sleeved and shielded hoses that connect to a fill head unit installed on the top of the cask. The fill head unit is connected to a high-efficiency particulate air (HEPA) filtered exhaust system to contain contamination inside the liner. A flag marker will be pre-installed inside each disposal liner to mark the level to which the sediment will be filled. A video camera will be used to verify this sediment level and the operator will stop the filling operation. A dewatering line in each disposal liner will be available if the sediment level should exceed this desired level.

A screw conveyor will be used to carry the cement mixture to the fill head and into the disposal liner. A motor located on the fill head unit turns mixing blades to stir the sediment, water and cement material into a homogenous mixture. A steel lid similar to a barrel lid is then put in place and the liner will be ready to be lifted with a crane onto the transport trailer for curing and subsequent transport to the ERDF for disposal.

The sediment removal process will be conducted in a batch operation filling two to three liners then solidifying two to three liners at a time. The final grout matrix will contain about 15wt% dry sludge solids. Seven liners (4.8 m^3 each) will be required to grout the solids/resin mixture resulting in a total grout volume of about 34 m^3.

C3.9 OFFGAS TREATMENT

The dissolver off gas will be routed through a condenser before it is combined with the off gas from the other vessels. The combined off gas will be routed through the NO_x absorption system and high-efficiency mist eliminator, heated above its dew point, and then routed through HEPA filters before it is exhausted to the stack. The off gas will be sampled and monitored to verify that it complies with regulatory criteria. Additionally, a granulated activated carbon bed will be installed in the off gas system to ensure PCB concentration limits are met.

C4.0 DOE/FOREIGN/COMMERCIAL/PREVIOUS EXPERIENCE

The chemical technologies proposed are expected to be technically feasible based on the fact that acid dissolution and precipitation of uranium-bearing material has been used extensively in the fuel manufacturing and reprocessing industries and at Hanford. The specific unit operations proposed for the K Basins sludge have been developed and tested in the laboratory using actual or simulated sludge (Logan 1998). The off-gas emission controls identified are based on standard technologies used in the nuclear industry.

Hundreds of thousands of MTUs of uranium reactor fuel elements have been dissolved in nitric acid in Hanford reprocessing plants. Uranium oxide fuel and metallic fuel elements have been dissolved in nitric acid in commercial reprocessing plants in France and Japan. The Robatel centrifuge has been designed specifically for nuclear reprocessing plants.

Grouting low level nuclear waste is commonly done at nuclear facilities in the USA and abroad. Sludge from the N Reactor basin was recently grouted at Hanford.

C5.0 SAMPLE REQUIREMENTS

This section describes the analytical work required to satisfy process control and product verification criteria.

C5.1 PROCESS CONTROL CRITERIA

Each batch of sludge will be sampled at the basin for accountability and process control prior to transfer to the sludge treatment facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations.

Periodic samples will be taken of process tanks in the hot cell for process control. All of these samples will be pulled from the sample cave and will need to be shielded for transfer to the 222 S laboratory. Only laboratory analyses to determine caustic, nitrite and nitrate additions necessary to meet TWRS product criteria need to be made for process control. In-line measurements will be used to provide reaction rates and progress of the dissolution process.

Weekly process control samples will be taken from the solids tank to track the TRU content of the solids undissolved by the acid treatment. These will be dip samples that can be contact handled.

Timeframe

Since the acid dissolution process is expected to maintain a processing schedule of nearly one batch each 24-hour day, analytical data will be needed within that time. An estimate has been made of the time required to perform each process control analysis. These process control

analyses can be completed within 4 hours from the time samples are received at the laboratory if a dedicated staff is available on each shift to complete the work.

C5.2 PRODUCT VERIFICATION CRITERIA

C5.2.1 TWRS

Liquid waste destined for disposal in TWRS tank farms must have data to show compliance with analytes identified in the DST waste acceptance plan (Mulkey 1998). In addition, a waste fact sheet must be developed prior to shipment that includes other specific requirements to be considered. Process knowledge may provide information that can reduce direct analytical measurements but these changes require negotiation prior to material shipments. Table C-1 lists the analytes and drivers that are required currently for storage in double shell waste tanks. Those measurements that are reasonably negotiable are noted in the table.

There are several analytes that are required to complete waste stream profile sheets in addition to criteria established by the waste acceptance criteria. These analytes can be expected to be absent based on process knowledge. Before they can be eliminated, the requirement must be negotiated with TWRS and waived. These analytes include:

1) Carbonate
2) Cyanide
3) Phosphate
4) Dissolved Solids
5) Sulfate

Prior to initiating processing K Basin Sludges, a compatibility study will likely be necessary. This process test is commonly performed by mixing wastes from the TWRS receiver tank with processed sludge and observe incompatible reactions such as gas generation, solids dissolution or formation, final concentration of analytes specified in Table C-1 with the identified driver being compatibility data quality objectives (DQO).

Table C-1. TWRS Product Verification Criteria

Parameter	Requirement	Analytical Method	Driver
Strontium-90	Every shipment	Not specified	BIO
Yitrium-90	Analysis not needed if Yttrium assumed to be equal to strontium level	Not specified	BIO
Cesium-137	Every shipment	Not specified	BIO
Plutonium-239	Every shipment (8)	Solvent extraction/AEA	BIO, Compatibility DQO, WAP
Americium-241	Every shipment	Not specified	BIO
Total Uranium or Uranium 233/235	Every shipment	Laser induced kinetic phosphorescence	BIO, Compatibility DQO, WAP
Neutron absorbers	If Pu equivalent ≤ 0.001 g/L	Chromium, Iron, Manganese, nickel, aluminum, and zirconium by ICP/AES	BIO, Compatibility DQO
Ammonia (1)	Every shipment	Not specified	BIO
Sodium Hydroxide (2, 3) (caustic demand)	Every shipment	Not specified	BIO
Sodium	Every shipment	Not specified	BIO
Total organic carbon (oxalate may also be required if TOC exceeds a screening level	Every shipment	TOC – Silver catalyzed persulfate oxidation*. Oxalate – IC *Method will not detect IX resin – need furnace method	BIO, Compatibility DQO, (if water < 20%)
Percent Water (4)	Every shipment (8)	TGA	Compatibility DQO, WAP
Specific Gravity	Every shipment	Not specified	Compatibility DQO, WAP
Percent Solids	Every shipment (8)	Not specified	Compatibility DQO, WAP
Nitrate/Nitrite	Every shipment (8)	IC	Compatibility DQO, WAP
PH (5)	Every shipment (8)	pH direct	BIO, Compatibility DQO, WAP
Hydroxide (6)	Every shipment (8)	Titration	Compatibility DQO, WAP
Energetics (7)	Every shipment (8)	DSC/TGA	Compatibility DQO, WAP
Separable Organics	Every shipment	Visual	Compatibility DQO, WAP
PCB (9)	Special Instructions (10)	Separation + GC/MS	

NOTES:

AEA = alpha energy analysis

BIO = Basis for Interim Operation (HNF)

Compatibility DQO = Compatibility Data Quality Objectives (Mulkey and Miller 1997)

DSC = differential scanning calorimetry
GC = gas chromatograph
IC = ion chromatography
ICP = inductively coupled plasma
IX = ion exchange
MS = mass spectroscopy
N/A = Not Applicable
N/R = Not Required
TGA = thermal gravimetric analysis
TOC = total organic carbon
WAP = Waste Analysis Plan (Mulkey 1998)

1. Ammonia will not be present in acid system and no source in sludge fraction
2. Caustic Demand should be substituted for sodium hydroxide in the acid sample
3. Sodium hydroxide is meaningless on sludge solids
4. Percent Water in a liquid sample is meaningless; may be required on settled solids fraction one-time.
5. pH required on neutralized sample for tank farm disposal.
6. Hydroxide must be performed on final slurry.
7. The definition of energetics will need clarification; organic fuel not an issue in K Basin, but will provide an indication of reactive metal species.
8. Analyte required on final adjusted waste form before transport to TWRS. Alpha total for transuranics. Percent water in settled solids one time estimate.
9. Verification would not be required for a waste stream that has been declared, in writing by EPA, to be not TSCA regulated. The requirements listed under Sampling and Analytical methods must be met if EPA has not declared "in writing" that the waste is non-TSCA material
10. Sampling and Analytical Methods for TSCA Material
    - A sample and PCB analysis will be required whenever the Waste Stream Profile Sheet (WSPS) indicates that solids may be over 5%. The analysis must either be conducted on the dried material or adjusted via calculation to a dry weight basis. If the dry weight is calculated the result must be accompanied by 1) the measured moisture composition, 2) actual measured PCB concentration, 3) the calculated dry weight PCB concentration, and 4) the calculation used for correcting the measured concentration to dry weight basis.
    - The analytical method must be either Method 3500B/3540C or Method 3500B/3550B from EPA's SW-846.
    - If the sample contains over 0.5% solids, then the solid and liquid phases must be separated and analyzed independently.
    - A minimum of two samples must be obtained from each phase.
    - The sampling and analysis must be conducted per a written sampling and analysis plan (or equivalent). This plan must address QA/QC, rationale for determining number of samples, test method, detection limit, and chain of custody requirements. Note: It is recommended that sampling and analysis plans be reviewed by TWRS Environmental Permits and Policy to ensure that they will satisfy DST Waste Acceptance Policy.

Timeframe

It is estimates that the analyses specified in Table C-1 can be performed and data transmitted within 24 hours if conditions below are followed. In developing this turnaround time, analyses are assumed to be performed on the acid fraction except those required on the neutralized product.

- A dedicated work force is available to perform the analysis with no interruptions
- Minimum quality control (QC) is performed with each measurement
- Analytical results only are provided as a spreadsheet
- No data package with additional information, raw analytical data, and QC results are included
- Analytical instrumentation is not down for repair
- Preplanning for radiation screening, waste handling, prioritization of work has preceded the receipt of samples.
- Presumptive and indicative methods are not substituted for the analyte specified
- Time estimated for analysis is initiated at time the sample is received at the laboratory

C5.2.2 ERDF

Solids generated as a result of processing and remaining after acid dissolution will be sampled separate from the liquid stream according to criteria established for acceptance of waste by the ERDF. Acceptance criteria for radionuclide content are based on Class C limits, ERDF performance assessment, ERDF Remedial Investigation and Feasibility Study Report, and groundwater exposure scenarios. Specific concentration limits are established for many radionuclides although most nuclides can be assumed absent. A distribution of nuclides consistent with the irradiation history of the fuel and decay products from those parents is of concern. Only those nuclides are of concern that are insoluble in the acid digestion or sufficiently abundant that decontamination does not reduce the concentration. Most metals and organic compounds can be eliminated from concern. Other than the potential for PCB compounds, organic compounds are not present in the initial sludge and therefore can be eliminated from consideration. Zircaloy and some iron compounds are expected to be the only metals present that may not completely dissolve during the acid digestion. Grouting the solids fraction prior to transport to ERDF will immobilize and render these metals innocuous. Weekly grab samples of the separated solids fraction will be analyzed.

Each filter cartridge used for final solids/liquid separation will be sampled before it is grouted to determine if the grouted matrix will be within the TRU limits. The filter samples will be taken from the sample cave. The solids samples and filter samples will be transferred to the 222 S laboratory for analysis.

Timeframe

Because the samples received at the laboratory are solid, significant additional preparation is required prior to analyte quantitation. Several analyses will require 24 hours to complete even with a staff dedicated to support of this program. This additional time should not inhibit the process operations.

C6.0 APPLICATION TO K BASIN SLUDGE

The baseline chemical treatment process would treat the sludge to meet the TWRS waste acceptance criteria for criticality control, elimination of pyrophoric materials, corrosion control, prevention of flammable gas retention/generation, particle size and exclusion of TSCA-regulated materials. The added NaOH, depleted uranium (as required) and iron meet the criticality specifications. Caustic precipitation will form crystals which are less than 10 μm and the filter upstream from the neutralization tank will prevent particles greater than 177 μm from being added to the neutralized solution.

This process is expected to produce between 115 m^3 and 435 m^3 solids in the waste sent to TWRS. The solids limit specified for tank AW-105 before exceeding the flammable gas retention requirement is (379 m^3). If the solids volume exceeds 379 m^3, some of the sludge waste will need to be transferred to another DST. The requirements for corrosion control are met by adding NaOH and $NaNO_2$ in the neutralization step. This process eliminates pyrophoric materials by oxidizing the metallic and hydride uranium material in the dissolution step. The zirconium will be separated out in the centrifuge and stabilized in a grout matrix.

Material balance calculations indicate that the maximum PCB concentration in the neutralized waste will be 0.01 ppb in the liquid and 0.66 ppm in the precipitated solids (Westra et. al. 1998). The granulated activated carbon bed installed in the off gas system will ensure the PCB concentration in the off gas will be less than the 10 $\mu g/m^3$ limit.

C7.0 SAFETY CONSIDERATIONS

The baseline approach has a number of safety considerations that influenced the description of the option and which would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed need a significant amount of shielding (up to 75 cm of concrete for the main process vessels); hence much of the process operations would need to be performed remotely. Contact maintenance will be required on a significant number of pumps and valves; thus, there is a potential for exposure to the worker. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain as low as reasonably achievable (ALARA). The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

Although the baseline process is relatively complex (and hence presents more opportunities for uncontrolled releases of radionuclides and hazardous chemicals) it has the advantage of utilizing unit operations which have been successfully used in fuel reprocessing facilities for forty years. Thus, the process control and safety control technology is mature and well established.

C7.1 HANDLING OF PYROPHORIC PARTICLES

The feed that contains metallic uranium particles is maintained under water. The pyrophoric nature of the metallic uranium is eliminated when the sludge is oxidized in the dissolver. Zircaloy pieces are potentially pyrophoric although not as reactive as the metallic uranium pieces. The zircaloy pieces will be separated as undissolved solids from the dissolver and immobilized in grout.

C7.2 DISSOLVER CONTROL

Control of the reaction rate in the dissolver is achieved by controlling the feed rate of solids to the dissolver. The controlled feeding of up to 1/4-inch uranium particles to the dissolver is an issue that is common to all options which include the dissolver. Cooling is provided via cooling coils to control temperature. If needed, a drown tank is available to quickly add cold water to drop the temperature and reduce the acid concentration to bring a reaction under control.

C7.3 ORGANIC ION EXCHANGE RESINS

Organic Ion Exchange Resins (OIER) are separated by screening and elutriation prior to feeding the dissolver, leached in 2M nitric and 0.1 M oxalic acid, water rinsed, and then accumulated for grouting. By separating the OIER prior to feeding the dissolver, Pu concentration on the resin beads is prevented. In addition, the potential for nitration of the resin bead structure is greatly reduced. Relative to the potential for nitration of the OIER structure, the leaching conditions are less severe than in the dissolver. There is a potential for energetic reaction between OIER and the nitric acid it is physically mixed with during the leach step if it is allowed to dry. However, two rinses with water are expected to sufficiently reduce the nitrate content to minimize this hazard.

C7.4 CRITICALITY MASS LIMITS

The criticality control on the feed to the facility is a mass based limit on a batch such that no vessel will contain greater than 1/3 of a critical mass of fissile material. Vessels will be designed to be rinsed to prevent the accumulation of fissile material. Supplementary monitoring may be included.

C7.5 HYDROGEN GENERATION

Hydrogen would be generated in the lag storage tank due to the reaction of water with metallic uranium. This rate is much higher than the radiolytic source. The tanks preceding the dissolver would be vented and/or diluted with air to keep concentrations low. Downstream from the

dissolver, only radiolytic hydrogen would be expected.

C7.6 DOSE RATES DURING MAINTENANCE

The baseline and modified baseline processes are performed within a shielded hot cell which has no manipulators, in-cell crane or windows. Pumps, valves, and agitator motors which may require maintenance are placed in pits which are shielded from the cell. The equipment is flushed prior to maintenance to reduce the dose. However, the dose rates to workers performing maintenance activities in these pits needs to be evaluated. No maintenance of equipment placed within the cell is possible. If maintenance were required, major pieces of equipment would be removed from the cell through cover blocks in the ceiling of the hot cell and replaced.

C7.8 CONTROL OF RADIONUCLIDE OFFGAS EMISSIONS

Fission product gases (^{129}I and ^{85}Kr) will be generated in the dissolver. The offgas from the dissolver will be routed to a HEPA filter to reduce emissions. These releases are not expected to exceed EPA or Washington State standards.

C7.9 CONTROL OF NO_X OFFGAS EMISSIONS

NO_x will be generated in the dissolver. The offgas from the dissolver will be routed to NO_x absorber columns to reduce emissions.

C7.10 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. However, only a small fraction of the PCBs would be volatilized from the dissolver. Most of the PCBs would be associated with the smaller particles in stream KE1. The majority of the PCBs would be associated with insoluble solids from the dissolver for this stream and would be disposed of at ERDF with the grouted solids.

C7.11 RISK TO WORKER

Chemical hazards which could affect workers include acids (nitric acid, oxalic acid, and hydrofluoric acid), caustics (sodium hydroxide), hazardous dusts from grout formers, and depleted uranium. Physical hazards include pressurized vessels and piping, rotating equipment (pumps, centrifuge, and fans), vehicular traffic, and electrical hazards associated with equipment.

These hazards will be addressed by an appropriately administered health and safety plan.

C8.0 MAINTENANCE REQUIREMENTS

Due to the radiation dose rate from the K Basin sludge, the main processing equipment will be located inside a hot cell. The hot cell will be designed with minimal remote maintenance

capability to minimize costs. Only equipment that will not require maintenance will be located inside the hot cell. All pumps, valves, and flow meters handling sludge streams will be located in small shielded cubicles above the hot cell so that contact maintenance can be used to repair or replace failed items. The agitator and centrifuge motors will also be located on top of the cell with shafts extending down through the shielding to the equipment inside the cell. Flushing of the failed equipment to lower the dose rate will be required prior to contact maintenance. The centrifuge motor and other heavy items can be lifted if required for maintenance using a bridge crane located above the cell.

The radiation dose from the solids tank and the grouting equipment is expected to be low enough that contact maintenance can be used to make repairs.

C9.0 FACILITY LAYOUT

A shielded hot cell with inside dimensions of 12.2 m x 5.5 m x 4.5 m high will be required to house the main processing equipment. A preconceptual layout of equipment in the processing cell is shown in Figures C-2 through C-6. The equipment that will be located in the hot cell includes three 1920-liter tanks (lag storage, sludge buffer, and leach tanks), two 3200-liter dissolvers, four 7280-liter tanks (clarified liquid and three adjustment tanks), a 960-liter resin tank, and a 14,850-liter neutralization tank. In addition to the tanks, there will be two screens, an elutriation column, a centrifuge, a cartridge filter, and two condensers. Vessel monitoring in a remote cell needs to be investigated.

On one side of the cell there will be an extension that goes up to a height of 5.9 m to provide the addition elevation required by some of the equipment (condensers, screen, centrifuge). There will be no windows, manipulators, or cranes in the hot cell. There will be an airlock on top of the cell for changing out the filter cartridges. A sample cave will also be located in this area.

The insoluble solids tank will be located in a shielded area beside the hot cell. Adjacent to the solids tank and the corner of the hot cell will be the loadin/loadout area and grouting area. A bridge crane above the loadin/loadout area will be used to move the sludge transport container from the transport vehicle to the area next to the hot cell and back to the transport vehicle after it is unloaded. The grouting area will be located next to the sludge loadin area so that the grout containers can be loaded on the transport vehicle using the same overhead crane. Making connections to the grout containers and filter drums will be a hands-on operation.

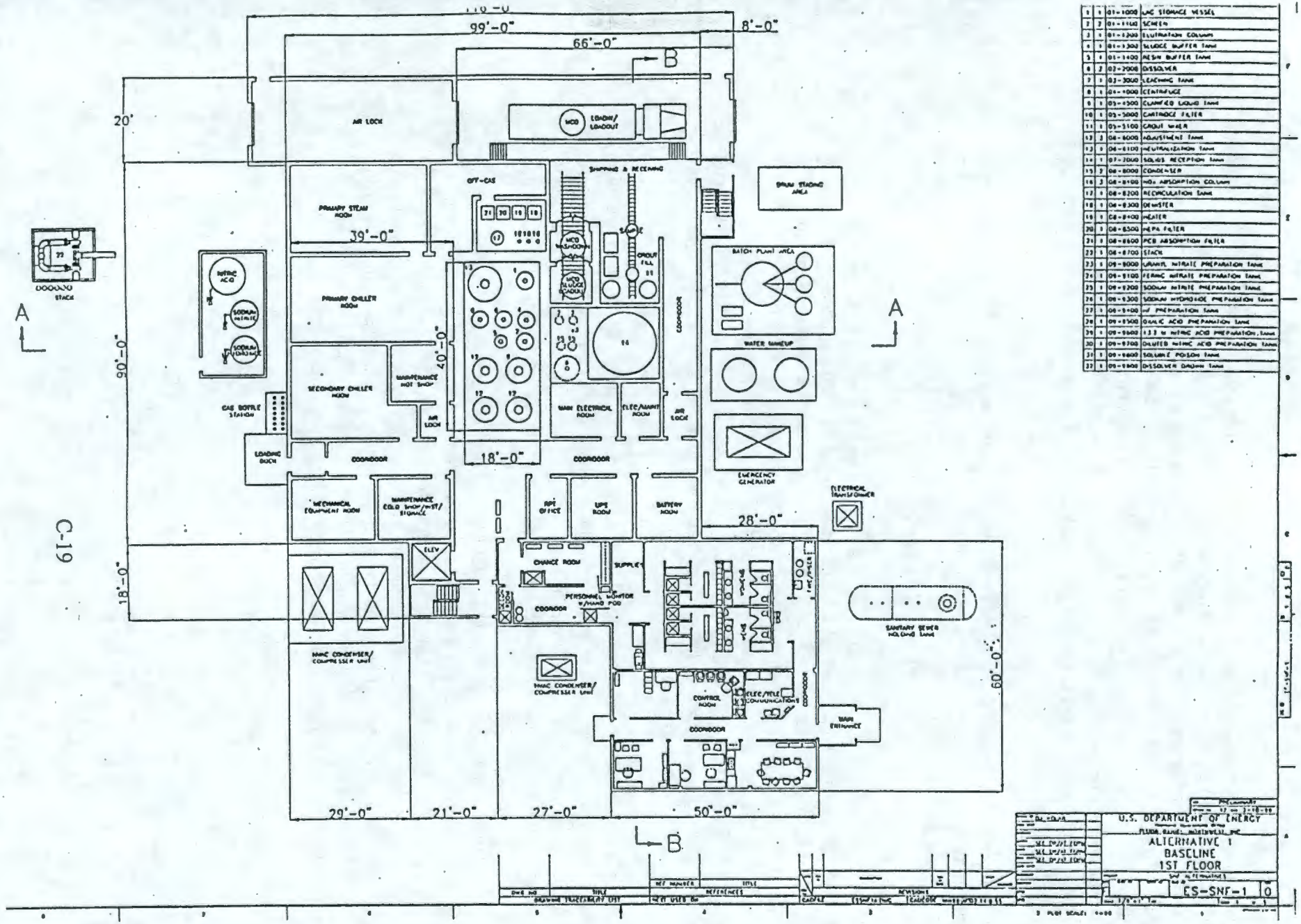


Figure C-2. 1st Floor Plan View for Baseline Chemical Process Facility

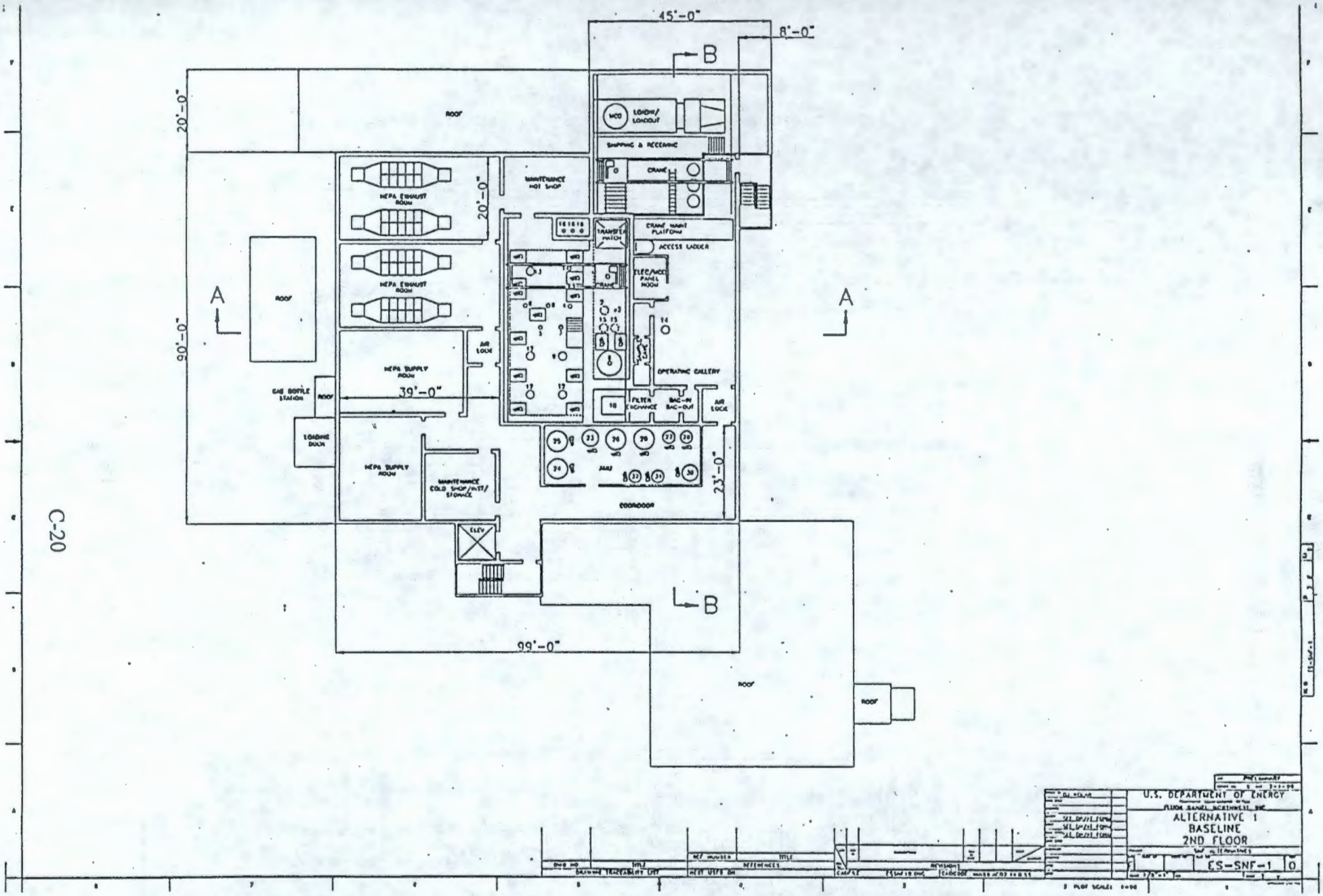
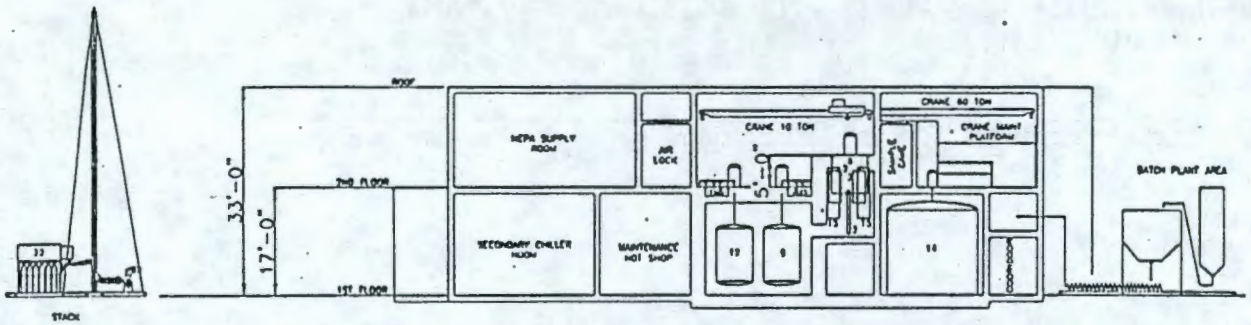
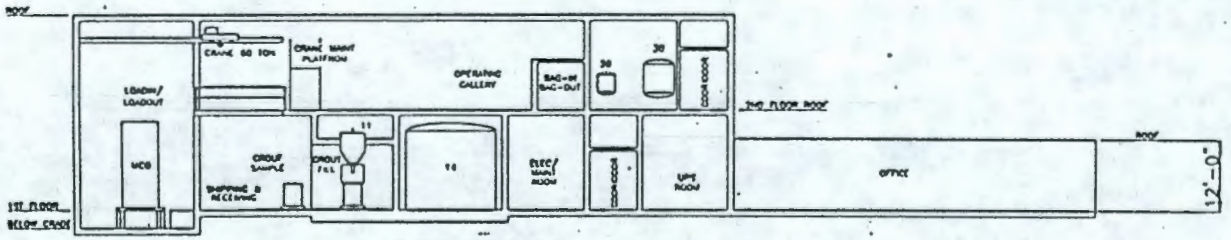


Figure C-3. 2nd Floor Plan View for Baseline Chemical Process Facility



SECTION A



SECTION B

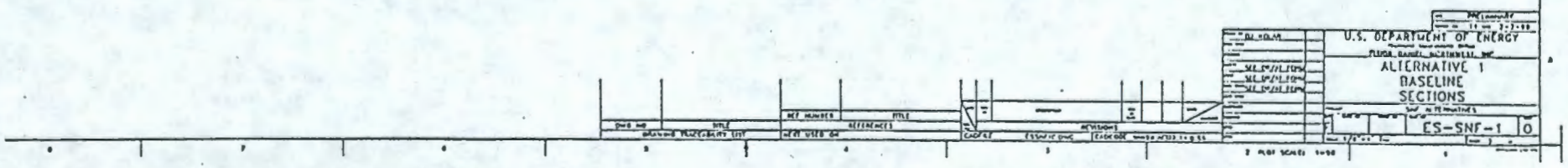


Figure C-4. Sections of Baseline Chemical Process Facility

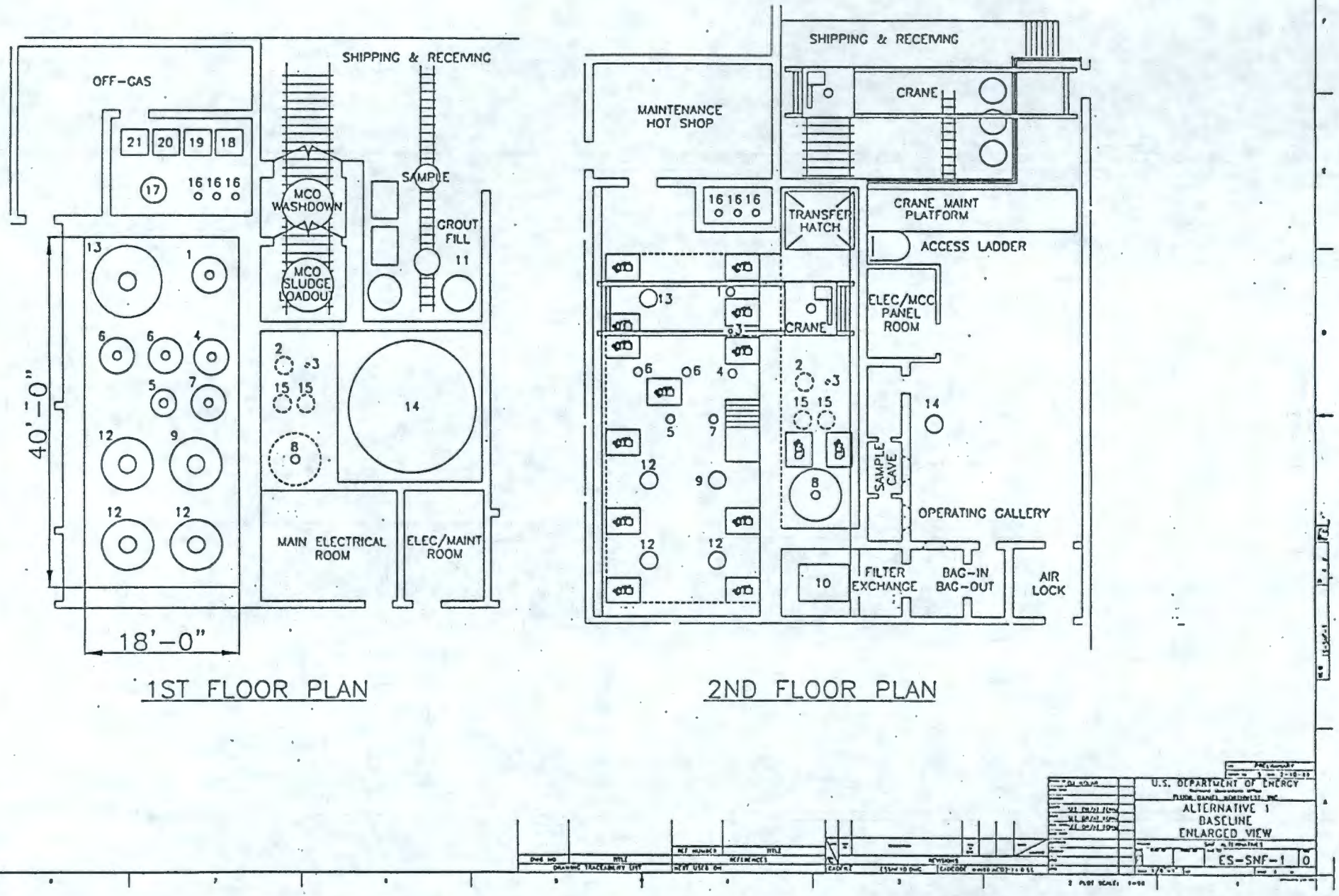
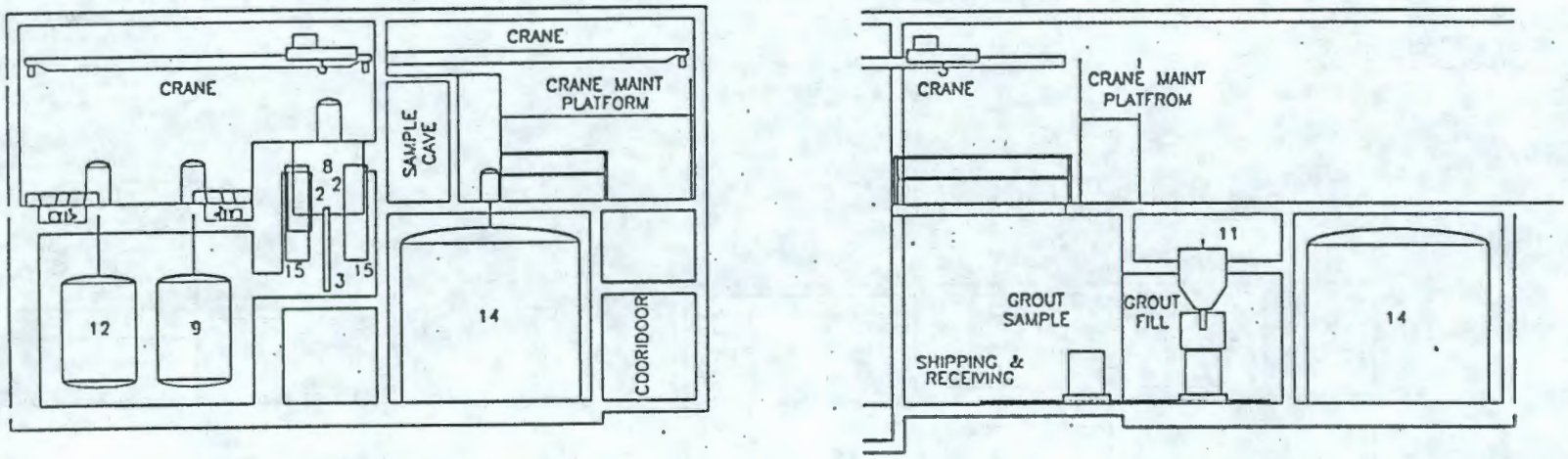


Figure C-5. Enlarged 1st and 2nd Floor Plan View of Baseline Chemical Process Area



U.S. DEPARTMENT OF ENERGY
ALTERNATIVE 1
BASELINE
ENLARGED VIEW
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Figure C-6. Enlarged Sections of Baseline Chemical Process Area

C10.0 TRANSPORT AND INTERIM STORAGE

The neutralized slurry will be shipped to the AW tank farm using a specially designed Sludge Transportation System. Modifications will be made at tank farms to enable direct transfer of the neutralized slurry from the transportation system into tank 241-AW-105 located in the 200 East Area. The offload system at tank farms is referred to as the Sludge Receiving Station.

The Sludge Transportation System consists of a trailer ASME pressure vessel, designed to meet onsite shipping criteria for a Type B transportation system for highway-route controlled quantities of radioactive materials. The container is estimated to have a capacity of 8 m^3 and fit on a single-drop, flatbed trailer. The transportation system will include a pumping system capable of transferring the neutralized solution from the transport package through a transfer line into AW-105, a flexible hose for connecting the pumping system to the transfer line, and equipment for monitoring and controlling the offload process. Controls for the pumping system will be interlocked with the tank farms Sludge Receiving Station leak detection sensors. Connections and equipment will also be provided for the TWRS supplied utilities (i.e., electrical, flush water). Container ports and closures will be sealed from the atmosphere during transport with positive closure devices that are designed to prevent unintentional opening.

The Sludge Receiving Station consists of three main elements; 1) spill retention basin, 2) male coupler for connecting to the sludge transportation system, and 3) transfer line from valve station to sludge distribution system connection. The spill retention basin is located adjacent to AW-105 and functions primarily as a leak collection system in the event that a transfer connection or line ruptures or otherwise leaks. It is assumed that any leakage will be collected in a sump and pumped back into the DST.

The male coupler contains the necessary connections to mate to the sludge transportation system and provides a terminus for the nonpermanent 1.5-inch transfer line from the tank. The transfer line provides the flowpath for the neutralized slurry to be placed in the tank. The transfer line will be above ground and is double contained (hose-in-pipe or pipe-in-pipe) with leak detection capabilities between the inner and outer line. The leak detectors are interlocked to the pump on the shipping container to automatically stop the pump upon detection of leakage. The transfer line will have sufficient slope to prevent pooling of liquid during normal operation and concrete half-shells over the aboveground portion for shielding. Process water will be provided to flush the transport package and the receiving station pipeline after each sludge transfer. Freeze protection may also be required for winter operations.

The truck will drive onto the spill retention basin, the trailer wheels will be chocked, and the tractor will be uncoupled and moved away. Operations are envisioned to include a period of time to allow the slurry to be mixed after the trailer has been positioned on the spill retention basin. The mixer pump will be started first. While the slurry is mixing the operators will perform the connection activities. A quick-connect system is planned to minimize the time operators spend near the transportation system. The design of the connectors will accommodate the use of glovebags during the offload process. There is always a risk of contamination when

breaking connections on lines used for transfer of radioactive solutions, the use of "dry" quick-connects and glovebags will reduce the risk.

Precautions will be taken to minimize radiation exposure to the operators. Portable shielding, such as leaded blankets or lead bricks, will be provided for the flexible transfer hose to reduce dose rates. These shields will be placed over the flexible line before the transfer occurs. Operator stay time will be limited in this area. The transfers will be performed from a control panel on the trailer, therefore, there will be no need for the operators to remain near the flexible line for any length of time, except during the connection process.

The total volume of neutralized waste to be transferred to tank 241-AW-105 is approximately 1620 m^3. This will require 203 shipments from the treatment facility to the DST.

The L14-170 liners will be loaded onto a flatbed trailer using a crane then shipped to the ERDF for disposal. Each shipment will contain two or three liners per trailer bed. For this analysis it is assumed that 3 drums can be placed onto each truck shipment. It will require approximately 19 shipments to transfer the 7 liners and 46 drums to the ERDF for disposal and one shipment to transfer the remaining three drums to CWC for storage.

C11.0 FINAL DISPOSAL

The treated sludge will be processed with TWRS waste in a high-level vitrification plant and eventually disposed of at the geologic repository. Vitrification services are currently planned to be secured from a private contractor (TWRS-P). The treated K Basin sludge will be transferred to at least two other double shell tanks prior to vitrification. One will be the TWRS feed staging tank and the other will be the vendor's staging or lag storage tank. These transfers will intimately mix the K Basin sludge with the existing tank sludge, thus masking any unique identity the treated sludge may have had. The volume of waste from the K Basin sludge is negligible compared to the existing tank waste volume.

No additional glass logs from the high activity waste will be produced as a result of blending the treated K Basin sludge with AW-105. There will however, be an increase in the amount of glass produced from the low activity waste due to the additional volume of sodium (resulting from the K Basin sludge treatment process) added to AW-105. The sodium in K Basin sludge results in approximately 571 m^3 of additional glass, which will increase long-term cost for this alternative.

At the present time, the TWRS-P contract to provide those services is not in place. The current contract with the vendor is to produce certain technical, regulatory and business deliverables over a two year period which will demonstrate the technical viability and economics of the privatization approach. At the end of the two-year period, the U.S. Department of Energy (DOE) will review the deliverables and a path forward decision will be made either to proceed with privatization or to adopt an alternate coarse of action. No alternate strategy for treatment of tank wastes has been proposed at this time as a fall back to failure of privatization. If the decision is made, for

whatever reason, not to proceed with the TWRS-P contract for tank waste vitrification services, there is no clear end point for the basin sludge. It will remain in storage until a decision is promulgated regarding the ultimate disposition of the tank wastes.

C12.0 OPEN ISSUES

Key information needs that were identified during the course of the evaluation that could significantly impact technical and schedule viability of this alternative include the following:

- Amendment to the TWRS Authorization Basis is required prior to TWRS providing definitive acceptance of the sludge.
- Two of the cartridge filters are currently projected to exceed PCB concentrations acceptable at the Waste Isolation Pilot Plant (WIPP); and therefore will be stored with other Hanford TSCA/TRU waste until a definitive disposal path is identified.
- Potentially use backflushable type filter (for example, hydropulse) instead of cartridge filters due to using risk based approach for resolving PCB issue.

- The total volume of solids in the sludge waste stream sent to Tank Farms after chemical treatment may exceed 100,000 gallons. Some of the waste may need to be sent to another DST.
- A siting study is being conducted to determine the location of the sludge treatment facility. One of the locations being considered in near the AW tank farms.
- A transport study is being conducted to determine the method for transferring the sludge to the treatment facility and to the DST. Another option being considered besides a transport package is transfer via pipeline.

C13.0 ADVANTAGES/DISADVANTAGES

The advantages of the baseline chemical dissolution process include:

- This process utilizes mature technology and processes. All the major components of the process have been demonstrated on a bench-scale with actual K Basin sludge.
- Process control and safety control technology is mature and well established.
- Engineering studies and laboratory testing of the baseline treatment process indicate it would be sufficient to meet TWRS safety and operational criteria for AW-105.
- Engineering studies and laboratory testing indicated the baseline treatment process would be sufficient to meet the ERDF waste acceptance criteria for disposal.
- Acceptance of primary waste streams is within control of PHMC and Hanford site. Does not require involvement from other DOE Sites (i.e., Nevada, New Mexico).
- Negligible TWRS HLW processing cost impact by blending K Basin sludge solids with AW-105 tank waste solids.

The disadvantages of the baseline chemical dissolution process include:

- Numerous process steps are needed.
- Generates a large volume of waste (616 m^3) that will end up in land-fill disposal
- Product verification requires sample and analysis of every batch
- Large number of transfers (203) from treatment facility to TWRS. Introduces schedule risk that this many transfers can be accomplished within 13-months.

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APPENDIX D

MODIFIED CHEMICAL ALTERNATIVE

APPENDIX D

MODIFIED CHEMICAL DISSOLUTION

D1.0 INTRODUCTION

The modified chemical dissolution alternative treats the sludge by dissolving the fuel constituents in nitric acid, separating the insoluble material, adding neutron absorbers for criticality safety, and reacting the solution with caustic to co-precipitate the uranium and plutonium. The modified chemical dissolution alternative is a modification of the baseline chemical process and is predicated on the assumptions that enhancements to the baseline process could be realized by use of the polychlorinated biphenyl (PCB) mega rule and use of maximum permissible grout volume increases. These assumptions resulted in the following changes to the baseline process; 1) eliminate polishing filters, 2) replace centrifuge with less expensive solid/liquid separation method, 3) eliminate buffer tank and 4) eliminate use of resin bead and insoluble solids leaching steps and associated chemicals.

Additionally, this option considered locating the organic ion exchange resin (OIER) bead separation step in the Basins. The OIER beads are separated to avoid contacting them with nitric acid in the dissolver. Nitrated resin if allowed to dry out could undergo an energetic reaction that could pose a safety issue. The elutriation and screening steps are moved to the basin to eliminate equipment which otherwise would need to be placed in a hot cell. This provides the opportunity to minimize expensive hot cell space.

The modified chemical process produces a slurry which meets the waste acceptance criteria established by the Tank Waste Remediation System (TWRS). The resulting slurry will be transferred to an underground storage tank (currently identified as 241-AW-105) for interim storage. Final treatment will be via the Phase II high-level melter with subsequent transport to the national geologic repository for final disposal.

The undissolved solids will be grouted to meet the Environmental Remediation Disposal Facility (ERDF) waste acceptance criteria.

D2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Analysis of safety, waste compatibility, retrievability, immobilization and regulatory aspects identified a number of issues that required adjustment of the K Basin sludge characteristics prior to acceptance of the sludge into the double-shell tank (DST) system. In general, the most unique safety issues with the K Basin sludge materials and safety issues relative to commingling the sludges with AW-105 wastes are associated with criticality safety (including chemical reactions that could increase reactivity and preferential settling of like-size particles), potential exothermic

chemical reactions (pyrophoric reactions), and flammable gas generation and retention. This section provides a discussion of the key TWRS waste acceptance criteria that must be met and the unit operations which were selected to meet the criteria. Additionally, the key criteria, which resulted in selection of unit operations for treating insoluble sludge solids for acceptance by the ERDF, are also discussed. Waste acceptance criteria for TWRS and the ERDF are also provided in Section 5.0 of this report.

D2.1 CRITICALITY SAFETY

Sludge currently in the K Basins contains a quantity and particle size of fissile materials (^{235}U and ^{239}Pu) that poses a criticality concern for retrieval and storage in a DST. Sludge is defined as all material in the basin that is less than or equal to 6350 μm. Characterization samples indicate that flocculation and agglomeration of small particles exists, however, the data does not exclude the presence of large primary particles. Therefore, the discharge of the K Basin sludge into AW-105 must be preceded with treatment that reduces the primary particle size to less than 10 microns (to facilitate agglomeration and prevent particle segregation) and adds a quantity of absorbers that assures the ^{235}U content is less than 0.84 wt% and the Fe/Pu ratio is greater than 353 (Carothers, et. al. 1997). The unit operations which have been selected to satisfy the criticality requirements are acidic dissolution and added ferric nitrate followed by precipitation. The sludges currently stored in the double shell tanks were formed by a similar acid dissolution and precipitation process. Depleted uranium in the form of uranyl nitrate will be added on an as-needed basis to assure the ^{235}U content is below 0.84 wt%. Additionally a solids/liquid separation step partitions insoluble solids from the acid solution.

D2.2 PYROPHORIC MATERIAL

Uranium, zirconium metal, and uranium hydride are expected to be in the sludge from canisters and fuel washing processes. It is estimated that a small percent (1wt%) of the uranium in the floor and pit sludges will be metallic uranium (Pearce et. al. 1998). Uranium and zirconium metals and uranium hydride are known pyrophoric materials because under specific physical states and environmental conditions they undergo spontaneous combustion (DOE, 1994). Pyrophoricity is much less of a problem with zircaloy than with uranium. Pyrophoric materials will not be accepted into the TWRS waste tanks. The unit operation (i.e., oxidation with concentrated acid) which resolves the criticality issue will also eliminate the pyrophoric properties associated with uranium metal and uranium hydride. The liquid/solids separation step will remove the zircaloy cladding pieces from the stream sent to the waste tank.

D2.3 FLAMMABLE GAS GENERATION/RETENTION

Due to the presence of uranium metal and uranium hydride in the sludge, the potential exists for non-radiolytic hydrogen gas generation from metal-water reactions. Generation of gases (Xe, Kr, and H_2) has been observed in canister sludge samples. It has been suggested that the formation

of these gases is the result of metallic fuel corrosion or the result of hydride reactions (Omberg 1996). Wastes that exhibit flammable gas generation rates above those from radiolysis are not acceptable for storage in a DST. Acidic dissolution of the sludge will eliminate non-radiolytic sources of flammable gas.

Calculations have indicated that up to 379 m^3 (100,000 gal) of solids can be added to tank AW-105 before reaching the flammable gas retention limit (Carothers et. al. 1997). It has been estimated that the total volume of precipitated solids produced by chemical treatment of the sludge will range between 115 m^3 and 435 m^3 of solids (same as baseline chemical). Portions of the sludge could be transferred to another DST if the solids criteria are exceeded.

D2.4 RETRIEVAL/IMMOBILIZATION

As was mentioned previously, the sludge contains particles with diameters as large as 6350 µm. TWRS has established a secondary particle size limit of <177 µm to preclude adverse impacts to retrieval operations and glass melter performance. The unit operations selected to meet the criticality and pyrophoric criteria will satisfy this requirement.

D2.5 CORROSION

The acidic dissolver product solution will require neutralization to meet the TWRS corrosion limits. The parameters for controlling corrosion in DSTs are hydroxide, nitrate, and nitrite ion concentrations in the tank wastes. Sodium nitrite will be added along with NaOH to meet the ion concentration requirements.

D2.6 TSCA REGULATED MATERIAL

The administrative/regulatory solution currently being developed by the U.S. Environmental Protection Agency (EPA) is based on the 40 CFR 761.61 (Mega Rule) provision for a risk-based management approach for PCBs. This will require EPA to interpret the mega rule such that if risk-based equivalency is demonstrated, the sludge becomes "non-regulated" under the *Toxic Substances Control Act* (TSCA). In this case, the downstream waste management facility does not have to be concerned about receiving PCBs with the sludge. The risk-based approach requires that the treatment process "reduce the PCB concentration," it does not, however, stipulate treatment limits (i.e., solids < 2ppm and liquids < 0.5 ppb). Lab testing has indicated that reduced levels of PCBs can be achieved by normal partitioning as they go through the process, with nearly all of the PCBs adsorbing to the undissolved solids (which will be removed from the sludge stream by the hydropulse filter), plating out on the process equipment, or volatilizing into the off gas. Therefore, the modified chemical alternative eliminated the polishing filter.

D2.7 ERDF CRITERIA

The organic ion exchange resin, zeolite and undissolved solids will be grouted for disposal at ERDF so they must meet the ERDF acceptance criteria. The most restrictive requirements for sludge solids disposal are the limits for TRU (< 100 nCi/g) and ^{137}Cs (<32 Ci/m^3). Ion exchange resin beads, known to be in some of the sludges will be separated from the sludge upstream from the dissolver by an elutriation column. This is done to prevent loading Pu and Am onto the resin which would occur in the acidic conditions in the dissolver. The results of flowsheet calculations indicate that the grouted solids will meet ERDF acceptance criteria for TRU, ^{137}Cs and immobilization of pyrophoric material and ion exchange resin. Eliminating the unit operation steps for resin leaching and solids leaching requires a larger volume increase in grout (1:6) but decreases the quantity of sodium added (sodium is a limiting factor for the LAW glass).

D3.0 PROCESS DESCRIPTION

In the modified chemical dissolution option, the sludge is transported from the K East and K West Basins to a newly constructed treatment facility located on the Hanford site. Segregation of the sludge is first performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250 μm followed by an elutriation of the oversize particles to separate the organic ion exchange resin beads. The organic ion exchange resin beads are delivered as a segregated batch for grouting in the facility. The remaining sludge streams will be transferred to the treatment facility in batches and will be processed in batches. The batch size is 160 kg of solids (dry basis) suspended in water at a concentration of 12 to 15 wt% solids. The 160 kg of dry sludge allows mass limits to be used for criticality control. The total number of batches to be processed is 214. Assuming a one batch/day processing rate and 60% operating efficiency, all of the sludge can be processed in a 13-month period.

The process steps for the modified chemical process include transfer to lag storage, acid dissolution, solid/liquid separation, neutron absorber additions, adjustment and neutralization, grouting, offgas treatment. A block flow diagram is shown in Figure D-1. A description of the modified chemical dissolution process steps follows.

D3.1 SLUDGE TRANSFER TO LAG STORAGE

The sludge is transferred from the transport container to a lag storage vessel where it is agitated to suspend the solids. This lag storage feed tank is used to allow flexibility of receiving sludge hydrogen gas away as it is produced by the uranium metal- and uranium hydride-water reactions and by radiolysis. Hydrogen generation has been observed during sludge movement of sludge. This generation is presumably from water reactions with freshly exposed uranium metal and uranium hydride.

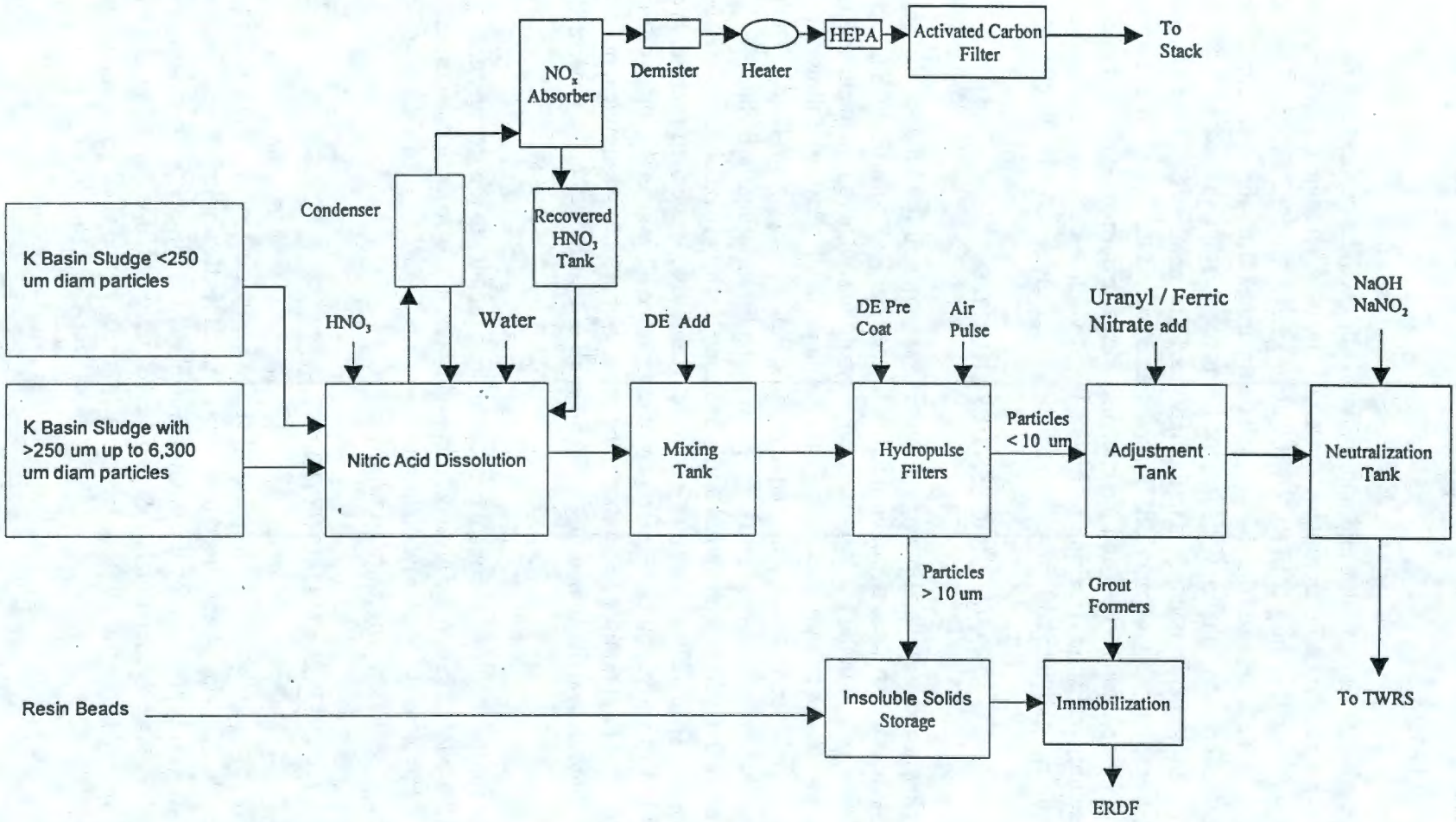


Figure D-1. Conceptual Flowchart for Modified Chemical Dissolution Option

Transferring sludge containing 6.35 mm diameter pieces of U metal between vessels in the sludge treatment facility is recognized as a difficult problem that has not yet been solved. An engineering study on sludge transfer methods recommended several pumps that should be tested for sludge transfer. Laboratory tests are in progress using simulated sludge to test these pumps and determine if they can transfer the sludge. This problem will be one of the main focuses of development work.

D3.2 SLUDGE DISSOLUTION

The sludge is pumped at a controlled rate over an eight-hour period to a dissolver that has a 6 M HNO_3 solution heated to 95 °C. Additional HNO_3 at 13.2 M is added during the slurry delivery and dissolution periods to maintain the nitric acid concentration at 6 M. The uranium oxide and uranium hydride constituents in the sludge dissolve very rapidly in 6 M HNO_3. The reaction rate is controlled by continuously feeding the sludge into the dissolver at a slow enough rate (2.5 L/min or 20 kg solids/h) to maintain a stable reaction. Continuously feeding sludge containing 6.35 mm pieces of U metal at such a slow rate will be difficult. Development work is planned to solve this problem. Feeding the sludge to the dissolver in multiple small batches instead of continuously may need to be considered if development of a continuous feed system proves too difficult. This may require reducing the acid concentration and/or temperature to control the reaction.

Air is bled into the dissolver vapor space to help oxidize NO to NO_2, which improves NO_2 absorption in the condenser and absorber. The dissolver temperature and vacuum, along with the NO_x concentration in the offgas, will be monitored to ensure that the reaction is under control. Temperature instrumentation also can be used to detect foam as well as the temperature of the solution. The concentration of xenon and ^{85}Kr in the offgas will be monitored along with the solution conductivity to determine the dissolution endpoint. Cooling coils will be used to remove the heat generated by the exothermic reactions. A drown tank provides additional cooling capability for off-normal events. The total time for dissolving the floor, pit, and settler tank sludge is estimated to be 10 hours/batch whereas the dissolution time for canister/wash sludge is estimated to take 22 hours/batch (Westra et al. 1998).

Following completion of sludge dissolution, the dissolver is cooled to 45°C and the resulting solution/slurry transferred to the filter-staging tank. A water rinse of the dissolver is performed to remove residuals from the dissolver after the slurry has been moved to the filter-staging tank and processed through the filter.

D3.3 SOLIDS/LIQUID SEPARATION

An inverted pneumatic hydropulse filter is precoated with diatomaceous earth filter aid to an amount of 0.452 kg/m^2 filter surface area from a precoat tank. Diatomaceous earth (DE) filter aid is added to the filter-staging tank (dissolver acid slurry) at a ratio of 1 weight part DE to 1 weight part of solids slurry. This mixture is agitated and pumped at 0.489 $m^3/h/m^2$ filter surface area to a hydropulse filter for solids/liquid separation. The staging tank solution/slurry is agitated during the transfer to keep the undissolved solids suspended. After pumping the solution/slurry to the filter, the dissolver filter staging tank rinse (agitated to carry residual solids to the filter) is pumped through the filter to wash the solids and filter aid material. The dissolver, filter-staging tank, and loaded media on the filter are rinsed with 760 L of water following completion of the initial slurry transfer. The filter performance is measured by the pressure drop across the filter during solution/slurry transfer and water rinse. Commercial units automatically inject a back pressure pulse of air to reduce the caking at specified differential pressures while operating.

The washed solids are removed from the inverted hydropulse filter by applying pneumatic pressure to the inside of the filter. Pulse pressure up to 90 psig is applied with the last of the rinse water in the filter to remove the process solids along with the filter aid off the filter where it drains to a back flush tank. The filter aid is used to prevent blinding of the sintered metal filter and allow reuse of the same filter. The solids are mixed, sampled, adjusted for water content, and prepared for grouting.

D3.4 ADDITION OF NEUTRON ABSORBERS

The filtrate and following rinse water are collected in an adjustment tank. Depleted uranium (as required) and iron are added to the liquid in the adjustment tank to meet TWRS criticality specifications. Before addition of the absorbers, the solution in the tank is agitated for at least 0.5 hours and then sampled. The samples are analyzed to determine the required amount of iron and depleted uranium to be added. Depleted uranium is added as a concentrated uranyl nitrate solution and the iron as a ferric nitrate solution. The solution in the adjustment tank is agitated during absorber addition and held at approximately 40°C. After addition, the solution is agitated for at least 0.5 hours before transferring the solution to the neutralization tank.

D3.5 ADJUSTMENT AND NEUTRALIZATION

The acidic solution is reacted with 19 M sodium hydroxide at 40°C to neutralize the solution and co-precipitate the uranium, plutonium, and iron. The NaOH will be added to the neutralization tank first, and then the acidic sludge stream will be pumped in from the adjustment tank (reverse strike neutralization). Following neutralization, $NaNO_2$ will be added. Cooling coils will be used

to remove the heat generated by the neutralization reactions. Dilution water will be added as needed (KE2, KW2, KW3) to reduce the total solids concentration to less than 40 g/L to ensure that the slurry is dilute enough to be transferred without plugging lines.

D3.6 RECEIPT OF ORGANIC ION EXCHANGE RESIN

Organic ion exchange resin (OIER) which is separated from the sludge in the basin is delivered directly to the grout-mixing tank. The resin is grouted as a separate batch of material without mixing with oversize material from the dissolver. The reason for not routing the OIER through the dissolver is to avoid contacting the resin with nitric acid which would result in nitrating of the resin. Nitrated resin, which is allowed to dry out, could undergo an energetic reaction which could pose a safety issue. In addition, not feeding the OIER to the dissolver prevents the resin from becoming loaded with Pu and Am allowing a non-TRU waste form to be produced without requiring extraordinary volume increase on grouting.

D3.7 GROUTING OF ORGANIC ION EXCHANGE RESIN

If the process stream containing the elutriated resin is directly grouted, the waste form is expected to have a TRU content of about 300 nCi/g, an organic resin content of 111 g/l and a dose rate on a 55 gallon drum of 6.9 R/hr. A nitric acid rinse prior to grouting would reduce the Cs and TRU levels although this step is not included in the current process. Providing some dilution of the grout to reduce the concentration of organic ion exchange resin would improve the quality of the grout waste form, reduce the dose rate and potentially make the resulting package non-TRU. Assuming a volume expansion factor of 3 beyond the nominal grout formulation results in a waste form with a resin content of 37 g/l, a TRU content just under 100 nCi/g, and a surface dose of about 2.3 R/hr. It is assumed that this material is placed in drums with shielding sufficient to drop the dose to <200 mR/h and disposed at ERDF. It is estimated 154 contact handled, shielded drums would be generated for ERDF disposal.

D3.8 GROUTING OF UNDISSOLVED SOLIDS

Following solids characterization, the solids are transferred to 55-gallon drums for grouting and subsequent shipping to ERDF. Sufficient grout formers are added to the slurry in drums. Grout formers are added to obtain a 1.4 increase in volume to fill the drums. Weigh cells will be used to transfer the appropriate amount of slurry and grout formers for the proper mixture. An agitator is used while adding the grout formers to thoroughly mix the grouting formers and slurry in the drums. The mass control and mixing are important parameters to control for compliance with ERDF requirements. The grout formers added might include portland cement, fly ash, blast furnace slag, clays, or other additives that may be specified during formulation development.

After the grout mix has been added and the mixture allowed to cure, the waste will be ready for transport to ERDF. The total grout volume is approximately 371 m^3 (for CH-nonTRU drums).

D3.9 OFFGAS TREATMENT

The dissolver offgas will be routed through a condenser before it is combined with the offgas from the other vessels. The acid condensate is returned to the dissolver. The combined offgas will be routed through the NO_x absorption system and high-efficiency mist eliminator, heated above its dew point, and then routed through a HEPA filter before it is exhausted to the stack. The offgas will be sampled and monitored to verify that it complies with regulatory criteria. Additionally, a granulated activated carbon bed will be installed in the offgas system to ensure PCB concentration limits are met.

D4.0 DOE/FOREIGN/COMMERCIAL EXPERIENCE

The chemical technologies proposed are expected to be technically feasible based on the fact that acid dissolution and precipitation of uranium-bearing material has been used extensively in the fuel manufacturing and reprocessing industries and at Hanford. The specific unit operations proposed for the K Basins sludge have been developed and tested in the laboratory using actual or simulated sludge (Logan 1998). The off-gas emission controls identified are based on standard technologies used in the nuclear industry.

Hundreds of thousands of MTUs of uranium reactor fuel elements have been dissolved in nitric acid in Hanford reprocessing plants. Uranium oxide fuel has been dissolved in nitric acid in commercial reprocessing plants in France and Japan. The hydropulse filters have been used at nuclear processing plants.

Grouting for waste stabilization is a very well established technology. Within the DOE complex, grout (Saltstone) is used at SRL to immobilize LLW into large concrete vaults. Floor sludges from a fuel storage basin at Hanford (N Basin) were previously stabilized and disposed in a grout matrix (reference). Numerous other DOE applications exist and many grouting formulations were prepared for the Hanford Grout Disposal Program.

Within the commercial power industry, grout has been used extensively to stabilize LLW. A number of commercially available vendors are identified in DOE/LLW-240 Commercially Available Low-Level and Mixed Waste Treatment Technologies.

D5.0 SAMPLING REQUIREMENTS

This section describes the analytical work required to satisfy process control and product verification criteria for the chemical treatment of K Basin sludge.

D5.1 PROCESS CONTROL CRITERIA

Analytical support for process control of the liquid fraction will be identical to the baseline process since the liquid will be transferred to tank farms. Each batch of sludge will be sampled at the basin for accountability and process control prior to transfer to the sludge treatment facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations.

Periodic samples will be taken of process tanks in the hot cell for process control. All of these samples will be pulled from the sample cave and will need to be shielded for transfer to the 222 S laboratory. Only laboratory analyses to determine caustic, nitrite and nitrate additions necessary to meet TWRS product criteria need to be made for process control. In-line measurements will be used to provide reaction rates and progress of the dissolution process.

Process control samples will be taken from the solids tank to track the TRU content of the solids undissolved by the acid treatment. These dip samples can be contact handled although light shielding will be required for shipment.

Timeframe

Since the acid dissolution process is expected to maintain a processing schedule of one batch each 24-hour day, analytical data will be needed within that time. An estimate has been made of the time required to perform each process control analysis. These process control analyses can be completed within 4 hours from the time samples are received at the laboratory if a dedicated staff is available on each shift to complete the work.

D5.2 PRODUCT VERIFICATION CRITERIA

D5.2.1 TWRS

Liquid product from the simplified acid digestion process will be transported to TWRS and must meet the same criteria as the baseline process. Analyses and analytical turnaround time will be identical with the baseline operation.

Timeframe

The analyses required for TWRS (see Table C-2 in Appendix C) can be performed and data transmitted within 24 hours if conditions below are followed. In developing this turnaround time, analyses are assumed to be performed on the acid fraction except those required on the neutralized product.

- A dedicated work force is available to perform the analysis with no interruptions
- Minimum QC is performed with each measurement
- Analytical results only are provided as a spreadsheet
- No data package with additional information, raw analytical data, and QC results are included
- Analytical instrumentation is not down for repair
- Preplanning for radiation screening, waste handling, prioritization of work has preceded the receipt of samples.
- Presumptive and indicative methods are not substituted for the analyte specified
- Time estimated for analysis is initiated at time the sample is received at the laboratory

D5.2.2 ERDF

Solids generated as a result of processing and remaining after acid dissolution will be sampled separate from the liquid stream according to criteria established for acceptance of waste by the ERDF. Acceptance criteria for radionuclide content are based on Class C limits, ERDF performance assessment, ERDF Remedial Investigation and Feasibility Study Report, and groundwater exposure scenarios. Specific concentration limits are established for many radionuclides although most nuclides can be assumed absent. A distribution of nuclides consistent with the irradiation history of the fuel and decay products from those parents is of concern. Only those nuclides are of concern that are insoluble in the acid digestion or sufficiently abundant that decontamination does not reduce the concentration. Most metals and organic compounds can be eliminated from concern. Other than the potential for PCB compounds, organic compounds are not present in the initial sludge and therefore can be eliminated from consideration. Zircaloy and some iron compounds are expected to be the only metals present that may not completely dissolve during the acid digestion. Grouting the solids fraction prior to transport to ERDF will immobilize and render these metals innocuous. Weekly grab samples of the separated solids fraction will be analyzed.

Timeframe

Because the samples received at the laboratory are solid, significant additional preparation is required prior to analyte quantitation. Several analyses will require 24 hours to complete even with a staff dedicated to support of this program. This additional time should not inhibit the process operations.

D6.0 APPLICATION TO K BASIN SLUDGE

This section evaluates the treated sludge against the TWRS waste acceptance criteria and against the ERDF waste acceptance criteria for the grouted product. The modified chemical treatment

process would treat the sludge to meet the TWRS waste acceptance criteria for criticality control, elimination of pyrophoric materials, corrosion control, prevention of flammable gas retention, particle size and exclusion of TSCA-regulated materials. The acid dissolution step insures that essentially all of the uranium is converted to a soluble nitrate solution such that when mixed with NaOH primary particles precipitated are less than 10 μm diameter. Sufficient depleted uranium (as required) and iron nitrates are added to the nitrate solution prior to neutralization to meet the criticality specifications. The filter upstream from the neutralization tank will prevent particles greater than 177 μm from being added to the neutralized solution.

This process is expected to produce between 115 m^3 and 435 m^3 of solids in the waste sent to TWRS. The solids limit specified for tank AW-105 before exceeding the flammable gas retention requirement is (379 m^3). If the solids volume exceeds 379 m^3, some of the sludge waste will need to be transferred to another DST. The requirements for corrosion control are met by adding NaOH and $NaNO_2$ in the neutralization step. This process eliminates pyrophoric materials by oxidizing the metallic and hydride uranium material in the dissolution step. The zircaloy will be separated out in the hydropulse filter and stabilized in a grout matrix.

Material balance calculations indicate that the PCB concentrations in the neutralized waste will be reduced. The granulated activated carbon bed installed in the offgas system will ensure the PCB concentration in the offgas will be less than the 10 $\mu g/m^3$ limit.

The insoluble solids including the diatomaceous earth removed from the hydropulse filters would be mixed, grouted, and dispositioned to ERDF. Streams KE1, KW1, and KW3 would be grouted to nominal grouting. Streams KW2 and KE2 would be diluted to approximately six times initial volume to allow contact handling for disposition to ERDF. These dilutions would allow the 55-gallon drums to be <200 mR/hr such they would all be contact handled. The wastes from these streams would be grouted as they are produced to not require a large holding tank. Sampling of each batch would be necessary to assure compliance.

D7.0 SAFETY CONSIDERATIONS

The modified baseline approach has a number of safety considerations that influenced the description of the option and would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed in this facility need a significant amount of shielding (up to 75 cm of concrete for the main process vessels), hence much of the process operations would need to be performed remotely. Contact maintenance will be required on a significant number of pumps and valves; thus, there is a potential for exposure to the worker. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain ALARA. The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

The modified chemical process is less complex than the baseline process, and hence presents fewer opportunities for uncontrolled releases of radionuclides and hazardous materials. In common with the baseline process, it utilizes unit operations that have been utilized in fuel reprocessing plants for many years. Therefore, the safety and control technology is considered mature and well established.

D7.1 HANDLING OF PYROPHORIC PARTICLES

As in the baseline, the feed, which contains metallic uranium particles, is maintained under water. The pyrophoric nature of the metallic uranium is eliminated when the sludge is oxidized in the dissolver. Zircaloy pieces are potentially pyrophoric although not as reactive as the metallic uranium pieces. The zircaloy pieces will be separated as large (>10 μm) undissolved solids from the dissolver and immobilized in grout.

D7.2 DISSOLVER CONTROL

Control of the reaction rate in the dissolver is achieved by controlling the feed rate of solids to the dissolver. The controlled feeding of up to 1/4-inch uranium particles to the dissolver is an issue that is common to all options which include the dissolver. Cooling is provided via cooling coils to control temperature. If needed, a drown tank is available to quickly add cold water to drop the temperature and reduce the acid concentration to bring a reaction under control.

D7.3 ORGANIC ION EXCHANGE RESINS

Organic Ion Exchange Resins (OIER) are separated by screening and elutriation prior to shipment to the facility. These materials do not go to the dissolver and instead are sent directly to the grouting process without a leaching step. Avoiding the dissolver and eliminating the leaching step eliminates any hazard associated with reactivity between the OIER and nitrates.

D7.4 CRITICALITY MASS LIMITS

Mass will be controlled such that no vessel will contain greater than 1/3 of a critical mass of fissile material. Vessels will be designed to be rinsed to prevent the accumulation of material. Supplementary monitoring may be included.

D7.5 HYDROGEN GENERATION

Hydrogen would be generated in the lag storage tank due to the reaction of water with metallic uranium. This rate is much higher than the radiolytic source. The tanks preceding the dissolver would be vented and/or diluted with air to keep concentrations low. Downstream from the dissolver, only radiolytic hydrogen would be expected.

D7.6 DOSE RATES DURING MAINTENANCE

The baseline and modified baseline processes are performed within a shielded hot cell that has no manipulators, in-cell crane or windows. Pumps, valves, and agitator motors that may require

maintenance are placed in pits which are shielded from the cell. The equipment is flushed prior to maintenance to reduce the dose. However, the dose rates to workers performing maintenance activities needs to be evaluated. No maintenance of equipment placed within the cell is possible. If maintenance is required, major pieces of equipment

D7.7 CONTROL OF RADIONUCLIDE OFFGAS EMISSIONS

Fission product gases (^{129}I and ^{85}Kr) will be generated in the dissolver. The offgas from the dissolver will be routed to a HEPA filter to reduce emissions. These releases are not expected to exceed EPA or Washington State standards.

D7.8 CONTROL OF NO_X OFFGAS EMISSIONS

NO_x will be generated in the dissolver. The offgas from the dissolver will be routed to NO_x absorber columns to reduce emissions.

D7.9 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. However, only a small fraction of the PCBs would be volatilized from the dissolver. Most of the PCBs would be associated with the smaller particles in stream KE1. The majority of the PCBs would be associated with insoluble solids from the dissolver for this stream and would be disposed of at ERDF with the grouted solids. Due to the elimination of the cartridge filter, some quantity of fine solids contaminated with PCBs may end up in TWRS.

D7.10 RISK TO WORKERS

Chemical hazards that could affect workers include nitric acid, caustic (sodium hydroxide), hazardous dusts from grout formers and diatomaceous earth, and depleted uranium. Physical hazards include pressurized vessels and piping, rotating equipment (pumps, and fans), vehicular traffic, and electrical hazards associated with equipment. These hazards will be addressed by an appropriately administered health and safety plan.

D8.0 MAINTENANCE REQUIREMENTS

Due to the radiation dose rate from the K Basin sludge, the main processing equipment will be located inside a hot cell. The hot cell will be designed without any remote maintenance capability to minimize costs. Only equipment that will not require maintenance will be located inside the hot cell. All pumps, valves, and flow meters handling sludge streams will be located in small shielded cubicles above the hot cell so that contact maintenance can be used to repair or replace failed items. The agitator motors will also be located on top of the cell with shafts extending down through the shielding to the equipment inside the cell. Flushing of the failed equipment to lower the dose rate will be required prior to contact maintenance. Heavy items can be lifted, if required for maintenance, using a bridge crane located above the cell.

The radiation dose from the solids tank and the grouting equipment is expected to be low enough that contact maintenance can be used to make repairs.

D9.0 FACILITY LAYOUT

A shielded hot cell with inside dimensions of 10.5 m x 5.5 m x 4.5 m high will be required to house the main processing equipment. A conceptual layout of equipment for this process is shown in Figures D-2 through D-6. The layout of the modified chemical dissolution process includes a shipping and receiving station for bringing the untreated sludge in and for shipping the treated sludge to TWRS. The layout includes hot cell areas to enclose a lag 1920-liter lag storage tank, two 3200-liter dissolvers, a 3200-liter filter staging tank, two inverted pneumatic hydropulse sintered metal filters, adjustment tank, neutralization tank, solids staging tank for grouting, and grouting area. The layout includes an aqueous makeup area, offgas treatment, stack, control room, offices, change rooms, and other supporting areas. There will be no windows, manipulators, or cranes in the hot cell. There will be an airlock on top of the cell for changing out the filter cartridges. A sample cave will also be located in this area.

The solids collection tank for grouting will be located in a shielded area beside the hot cell. Adjacent to the solids tank and the corner of the hot cell will be the loadin/loadout area and grouting area. A bridge crane above the loadin/loadout area will be used to move the sludge transport container from the transport vehicle to the area next to the hot cell and back to the transport vehicle after it is unloaded. The grouting area will be located next to the sludge loadin area so that the grout containers can be loaded on the transport vehicle using the same overhead crane. Making connections to the grout containers and filter drums will be a hands-on operation.

D10.0 TRANSPORT AND INTERIM STORAGE

The neutralized slurry will be shipped to the AW tank farm using a specially designed Sludge Transportation System. Modifications will be made at tank farms to enable direct transfer of the

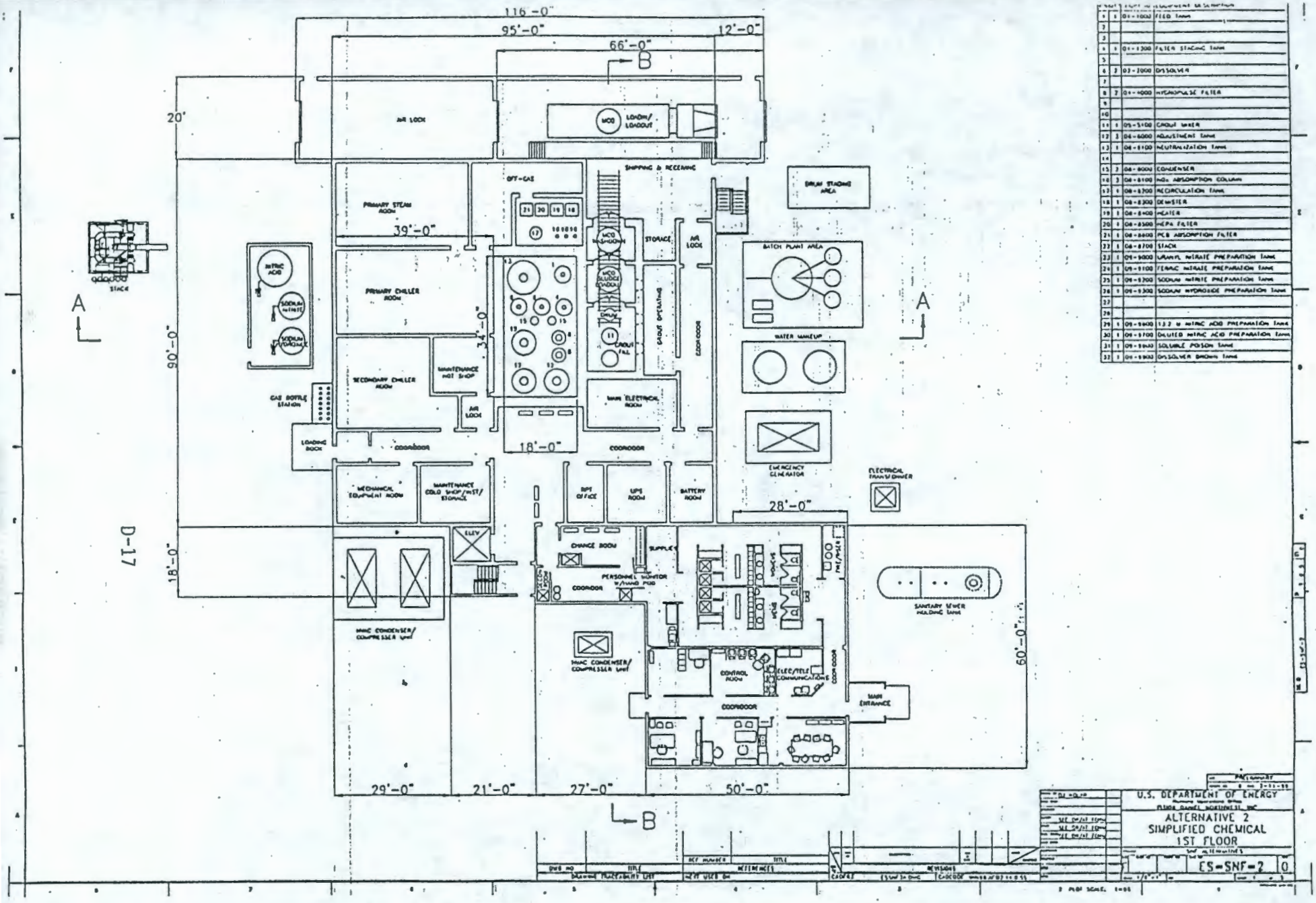


Figure D-2. 1st Floor Plan View for Modified Chemical Process Facility

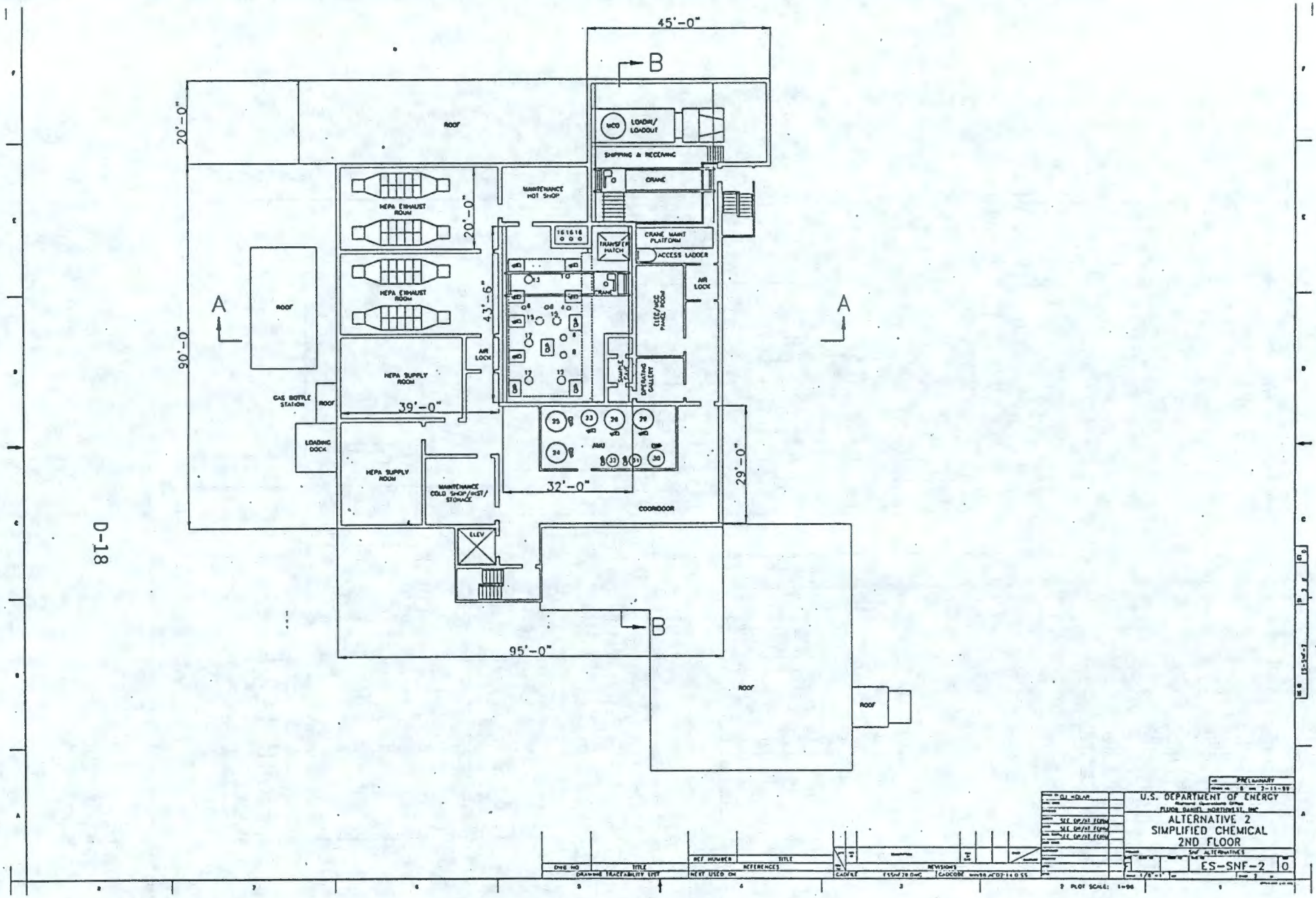


Figure D-3. 2nd Floor Plan View for Modified Chemical Process Facility

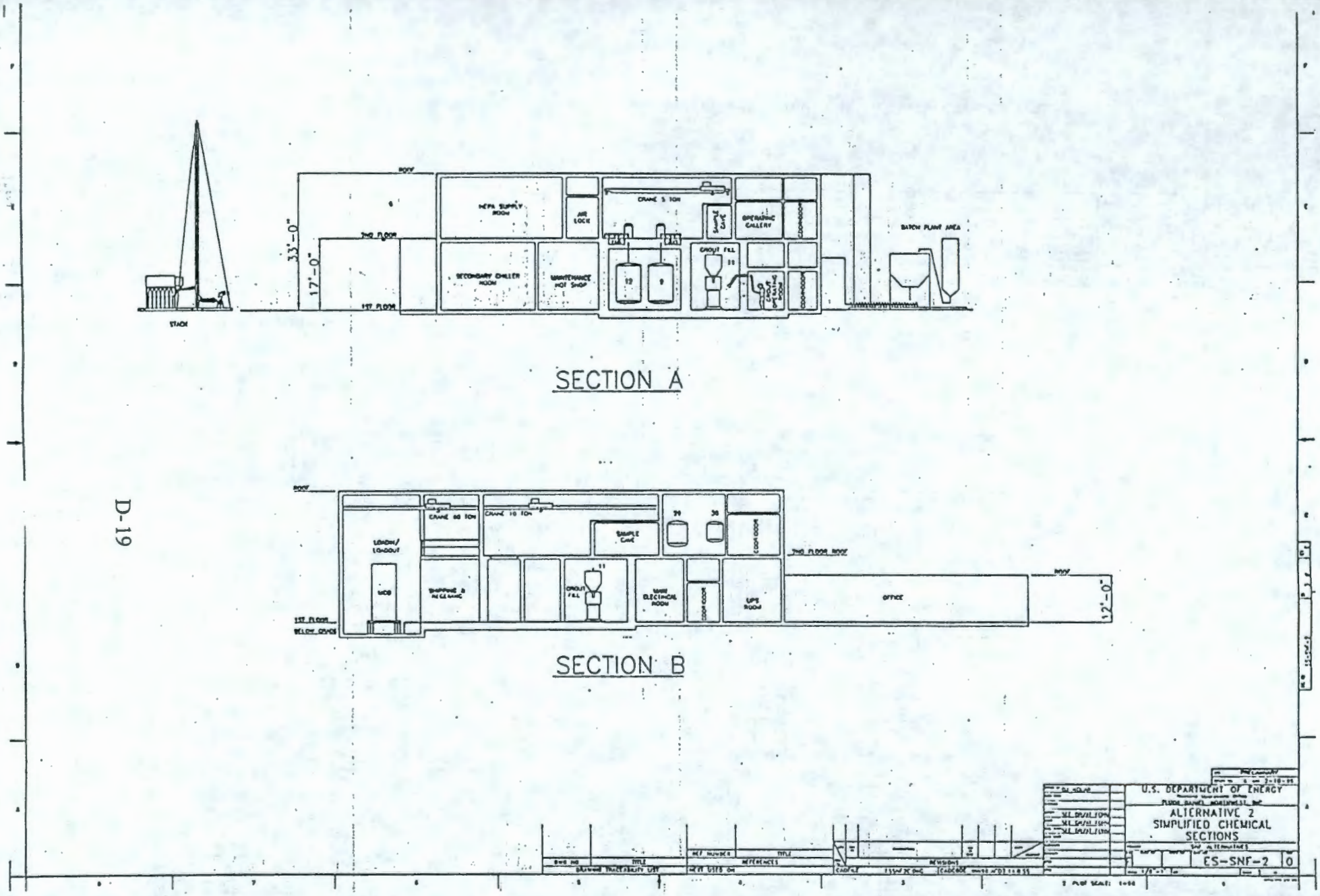


Figure D-4. Sections of Modified Chemical Process Facility

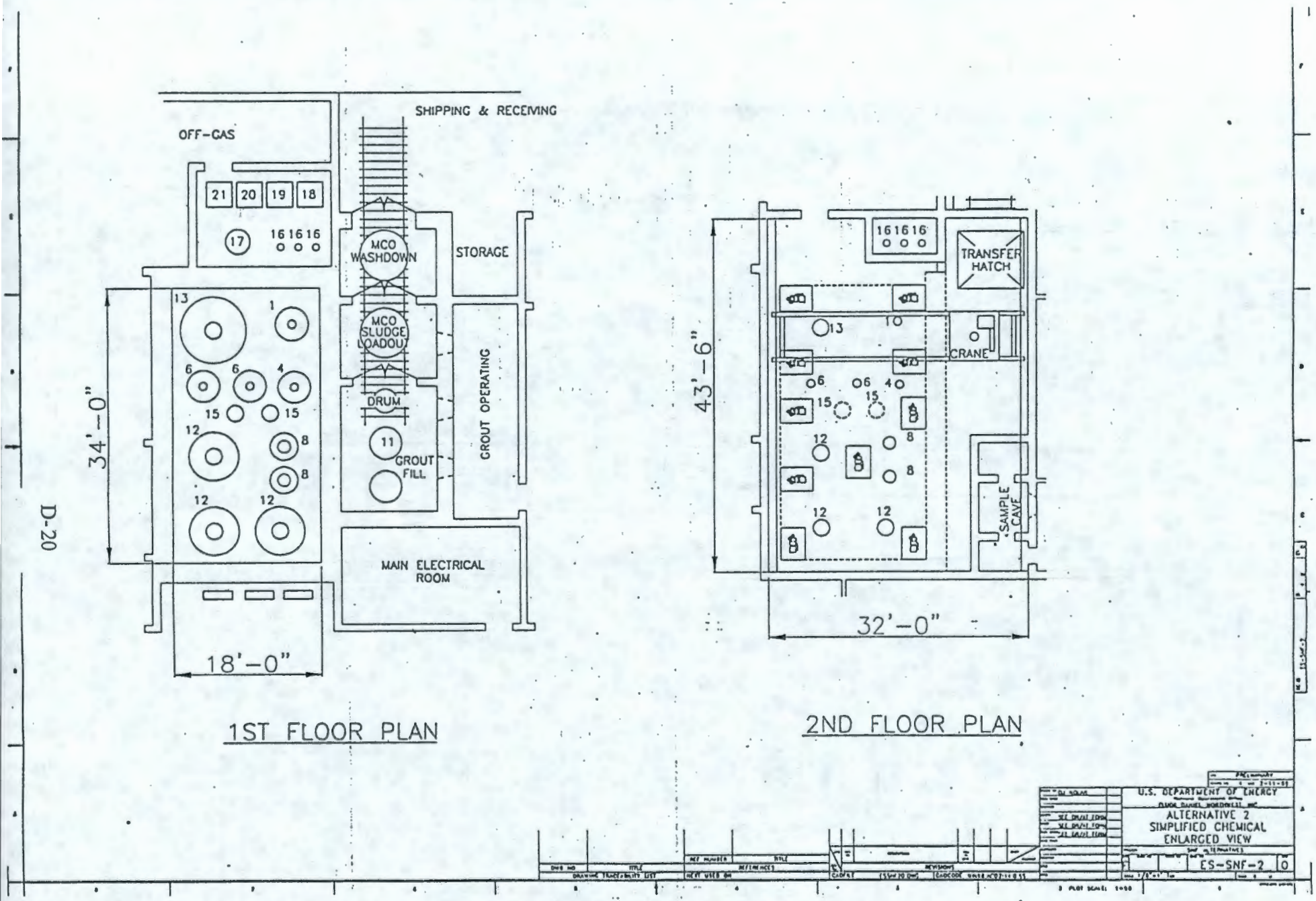
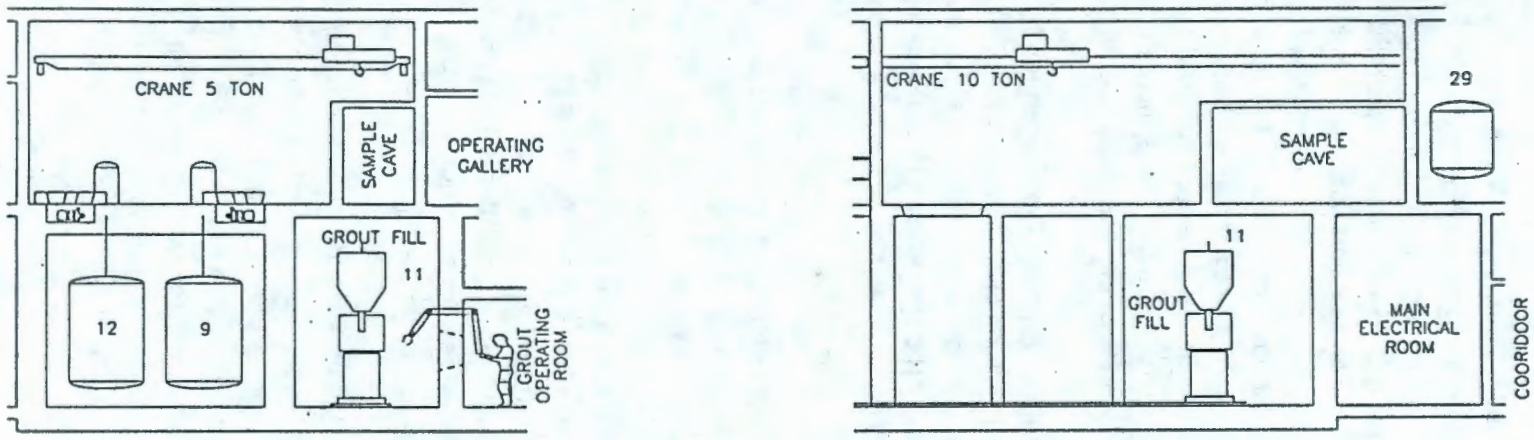


Figure D-5. Enlarged 1st and 2nd Floor Plan View of Modified Chemical Process Area



SECTION A

SECTION B

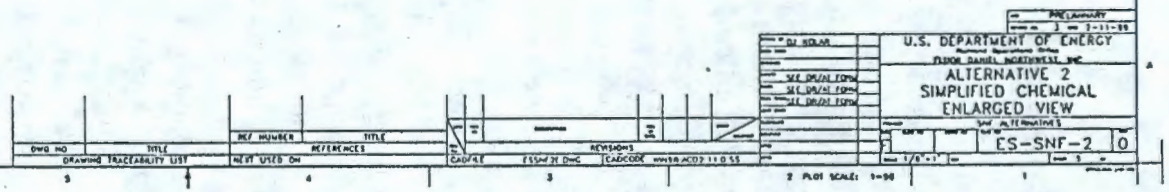


Figure D-6. Enlarged Sections of Modified Chemical Process Area

neutralized slurry from the transportation system into tank 241-AW-105 located in the 200 East Area. The offload system at tank farms is referred to as the Sludge Receiving Station.

The Sludge Transportation System consists of a trailer mounted ASME pressure vessel, designed to meet onsite shipping criteria for a Type B transportation system for highway-route controlled quantities of radioactive materials. The container is estimated to have a capacity of 8 m^3 and fit on a single-drop, flatbed trailer. The transportation system will include a pumping system capable of transferring the neutralized solution from the transport package through a transfer line into AW-105, a flexible hose for connecting the pumping system to the transfer line, and equipment for monitoring and controlling the offload process. Controls for the pumping system will be interlocked with the tank farm's Sludge Receiving Station leak detection sensors. Connections and equipment will also be provided for the TWRS supplied utilities (i.e., electrical, flush water). Container ports and closures will be sealed from the atmosphere during transport with positive closure devices which are designed to prevent unintentional opening.

The Sludge Receiving Station consists of three main elements; 1) spill retention basin, 2) male coupler for connecting to the sludge transportation system, and 3) transfer line from valve station to sludge distribution system connection. The spill retention basin is located adjacent to AW-105 and functions primarily as a leak collection system in the event that a transfer connection or line ruptures or otherwise leaks. It is assumed that any leakage will be collected in a sump and pumped back into the DST.

The male coupler contains the necessary connections to mate to the sludge transportation system and provides a terminus for the nonpermanent 1.5-inch transfer line from the tank. The transfer line provides the flow path for the neutralized slurry to be placed in the tank. The transfer line will be above ground and is double contained (hose-in-pipe or pipe-in-pipe) with leak detection capabilities between the inner and outer line. The leak detectors are interlocked to the pump on the shipping container to automatically stop the pump upon detection of leakage. The transfer line will have sufficient slope to prevent pooling of liquid during normal operation and concrete half-shells over the aboveground portion for shielding. Process water will be provided to flush the transport package and the receiving station pipeline after each sludge transfer. Freeze protection may also be required for winter operations.

The truck will drive onto the spill retention basin, the tractor will be uncoupled and moved away, and the trailer chocked. Operations are envisioned to include a period of time to allow the slurry to be mixed after the trailer has been positioned on the spill retention basin. The mixer pump will be started first. While the slurry is mixing the operators will perform the connection activities. A quick-connect system is planned to minimize the time operators spend near the transportation system. The design of the connectors will accommodate the use of glovebags during the offload process. There is always a risk of contamination when breaking connections onlines used for transfer of radioactive solutions, the use of "dry" quick-connects and glovebags

will reduce the risk.

Precautions will be taken to minimize radiation exposure to the operators. Portable shielding, such as leaded blankets or lead bricks, will be provided for the flexible transfer hose to reduce dose rates. These shields will be placed over the flexible line before the transfer occurs. Operator stay time will be limited in this area. The transfers will be performed from a control panel on the trailer, therefore, there will be no need for the operators to remain near the flexible line for any length of time, except during the connection process.

The total volume of neutralized waste to be transferred to tank 241-AW-105 is approximately 1525 m^3. This will require about 191 shipments from the treatment facility to the DST.

For the transport of the secondary waste, it is assumed that 3 drums can be placed onto each truck shipment. It will require approximately 595 shipments to transfer the 1784 drums of grouted CH-nonTRU wastes to the ERDF for disposal.

D11.0 FINAL DISPOSAL

The treated sludge will be processed with TWRS waste in a high-level vitrification plant and eventually disposed at the geologic repository. Vitrification services are currently planned to be secured from a private contractor (TWRS-P). The treated K Basin sludge will be transferred to at least two other double shell tanks prior to vitrification. One will be the TWRS feed staging tank and the other will be the vendor's staging or lag storage tank. These transfers will intimately mix the K Basin sludge with the existing tank sludge, thus masking any unique identity the treated sludge may have had.

No additional high level waste (HLW) glass canisters from the high activity waste will be produced as a result of blending the treated K Basin sludge with AW-105. There will, however, be an increase in the amount of glass produced from the low activity waste due to the dissolved sodium (123,000 kg) in the treated sludge sent to AW-105 plus the sodium (7863 kg) used to caustic leach the sludge by TWRS prior to delivery to the vitrification vendor. This quantity of sodium results in approximately 468 m^3 of low activity waste (LAW) (see Appendix J).

The TWRS-EIS (DOE 1987) and Record of Decision delineate the selection of vitrification of high-level waste and low activity waste. Current TWRS privatization approaches produce certain technical, regulatory, and business deliverables over a two-year period which will demonstrate the technical viability and economics of the privatization approach. At the end of the two-year period, the Department of Energy will review the deliverables and a path forward decision will be made either to proceed with privatization or to adopt an alternate coarse of action. No alternate strategy for treatment of tank wastes has been proposed at this time as a fall back to failure of privatization. If the decision is made, for whatever reason, not to proceed with the TWRS-P contract for tank waste vitrification services, there is no clear end for the basin

sludge. It will remain in storage until a decision is promulgated regarding the ultimate disposition of the tank wastes. The TWRS baseline will treat sludge to HLW glass.

D12.0 OPEN ISSUES

Key information needs that were identified during the course of the evaluation that could significantly impact technical and schedule viability of this alternative include the following:

- Amendment to the TWRS Authorization Basis is required prior to TWRS providing
- definitive acceptance of the sludge.
- The total volume of solids in the sludge waste stream sent to Tank Farms after chemical treatment may exceed 100,000 gallons. Some of the waste may need to be sent to another DST.
- Additional data is required before final selection of the solids/liquid separation step.
- A siting study is being conducted to determine the location of the sludge treatment facilty. One of the locations being considered is near the AW tank farms.
- A transport study is being conducted to determine the method for transferring the sludge to the treatment facility and to the DST. Another option being considered besides a transport package is transfer via pipeline.

D13.0 ADVANTAGES/DISADVANTAGES

The advantages of the modified chemical dissolution process include:

- This modified chemical alternative option uses mature technology and processes. The dissolution step of this process has been demonstrated on a bench-scale with actual K Basin sludge.
- Engineering studies and laboratory testing of the treatment process steps indicate it would be sufficient to meet TWRS safety and operational criteria for AW-105.
- Calculations indicate the insoluble solids stream can be grouted to meet the ERDF waste acceptance criteria for disposal.
- Acceptance of primary waste stream is within control of PHMC and Hanford site. Does not require involvement from other DOE Sites (i.e., Nevada, New Mexico).
- Negligible TWRS HLW processing cost impact by blending K Basin sludge solids with AW-105 tank waste solids.

The disadvantages of the modified chemical dissolution process include:

- Generates a large volume of waste (839 m^3) requiring landfill disposal.
- Product verification for TWRS waste streams requires sample and analysis of every batch.

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APPENDIX E

GRINDING/MILLING ALTERNATIVE

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GRINDING/MILLING ALTERNATIVE

E1.0 INTRODUCTION

The grinding/milling alternative for sludge treatment involves grinding and oxidizing particulate sludge materials to produce a slurry that meets the Tank Waste Remediation System (TWRS) waste acceptance criteria for interim storage in an underground tank (currently identified as 241-AW-105). Subsequent treatment would be via the Phase II high-level melter for final disposal to the national geologic repository. Oversized solids (e.g., zircalloy-2 cladding) surviving the grinding process would be accumulated over the processing period and then stabilized in a grout matrix along with the grinding media and transferred to the Environmental Remediation Disposal Facility (ERDF) for disposal.

E2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Analysis of safety, waste compatibility, retrievability, and immobilization aspects identified a number of issues that require adjustment of the K Basin sludge characteristics prior to acceptance of the sludge into the double-shell tank (DST) system. In general, the most unique safety issues with the K Basin sludge materials and safety issues relative to commingling the sludges with AW-105 wastes are associated with criticality safety (including chemical reactions that could increase reactivity and preferential settling of like-size particles), potential exothermic chemical reactions (pyrophoric reactions), and flammable gas generation and retention. This section provides a discussion of the key TWRS waste acceptance criteria that must be met and the unit operations, which were selected to meet the criteria. Additionally, the key criteria, which resulted in selection of unit operations for solidifying the insoluble sludge solids for acceptance by the ERDF, are also discussed. Waste acceptance criteria for TWRS and the ERDF are also provided in Section 5.0 of this report.

E2.1 CRITICALITY SAFETY

Sludge currently in the K Basins contains a quantity and particle size of fissile materials (^{235}U and ^{239}Pu) that poses a criticality concern for retrieval and storage in a DST. Sludge is defined as all material in the basin, which is less than or equal to 6350 μm. Characterization samples indicate that flocculation and agglomeration of small particles exists, however, the data does not exclude the presence of large primary particles. A detailed analysis of the particle size distribution of the different sludge streams is provided in Pearce et. al. (1998). The main conclusions which can be derived from the data (particle size distribution after sonication of the sludge) are:

- about 50 vol % of the particles included in the KE1, KW1 and KW3 streams

correspond to particles larger than 10 μm
- by definition all the particles of the KE2 and KW2 are larger than 10 μm (these streams correspond to particles larger than 250 μm or 500 μm)

Therefore, the discharge of the K Basin sludge into AW-105 must be preceded with treatment that reduces the primary particle size to less than 10 μm (to facilitate agglomeration and prevent particle segregation) and adds a quantity of absorbers that assures the ^{235}U content is less than 0.84 wt% and the Fe/Pu ratio is greater than 353 (Carothers et. al. 1997). The unit operations, which have been selected to satisfy the criticality requirements, are grinding/milling and added ferric nitrate followed by pH adjustment and sodium nitrite addition. Depleted uranium (uranyl nitrate) will be added on an as-needed basis to assure the ^{235}U content is below 0.84 wt%.

E2.2 PYROPHORIC MATERIAL

Uranium and zirconium metal and their hydrides are expected to be in the sludge from canisters and fuel washing processes. It is also estimated that a small percent (1 wt%) of the uranium in the floor and pit sludges will be metallic uranium (Pearce et. al. 1998). Uranium and zirconium metals and uranium hydride are known pyrophoric materials because under specific physical states and environmental conditions they undergo spontaneous combustion (DOE 1994). Pyrophoric materials will not be accepted into the TWRS waste tanks. The unit operation (i.e., uranium-oxidation with water while grinding and milling) which resolves the criticality issue will also eliminate the pyrophoric properties associated with uranium metal and uranium hydride. The coarse separation step will remove the zircaloy cladding pieces from the stream sent to the waste tank.

E2.3 FLAMMABLE GAS GENERATION/RETENTION

Due to the presence of uranium metal and uranium hydride in the sludge, the potential exists for non-radiolytic hydrogen gas generation from metal-water reactions. Generation of gases (Xe, Kr, and H_2) has been observed in canister sludge samples. It has been suggested that the formation of these gases is the result of metallic fuel corrosion and the result of hydride reactions (Omberg 1996). Wastes that exhibit flammable gas generation rates above those from radiolysis are not acceptable for storage in a DST. Oxidation of the uranium and uranium hydride via grinding process will eliminate non-radiolytic sources of flammable gas. The grinding process oxidizes the uranium in water, generating hydrogen in the process.

Calculations have indicated that up to 379 m^3 (100,000 gal) of solids can be added to tank AW-105 before reaching the flammable gas retention limit (Carothers et. al. 1997). It has been estimated that the total volume of solids produced by grinding/milling of the sludge will be approximately 62 m^3 of solids (this is an estimate, laboratory testing is required to verify this value).

E2.4 RETRIEVAL/IMMOBILIZATION

As was mentioned previously, the sludge contains particles with diameters as large as 6350 μm. TWRS has established a secondary particle size limit of <177 μm to preclude adverse impacts to retrieval operations and glass melter performance. The unit operations selected to meet the criticality and pyrophoric criteria will satisfy this requirement.

E2.5 CORROSION

The grinding/milling slurry will require pH adjustment and nitrite addition to meet the TWRS corrosion limits. The parameters for controlling corrosion in DSTs are hydroxide and nitrite ion concentrations in the tank wastes. Sodium nitrite will be added along with NaOH to meet the ion concentration requirements.

E2.6 TSCA REGULATED MATERIAL

The administrative/regulatory solution currently being developed by the U.S. Environmental Protection Agency (EPA) is based on the 40 CFR 761.61 (Mega Rule) provision for a risk-based management approach for PCBs. This will require EPA to interpret the mega rule such that if risk-based equivalency is demonstrated, the sludge becomes "non-regulated" under the *Toxic Substances Control Act* (TSCA). In this case, the downstream waste management facility does not have to be concerned about receiving PCBs with the sludge. The risk-based approach requires that the treatment process "reduce the PCB concentration," it does not, however, stipulate treatment limits (i.e., solids < 2 ppm and liquids < 0.5 ppb). Some reduction in PCB concentrations in the sludge is expected in the heated (80 °C) grinding/milling process during the grinding operation. A fraction of the PCBs are expected to be sorbed onto the polyurethane liner (coating on inside of the vibratory grinding mill) and, to a lesser extent, on the other surfaces of the processing equipment. A small fraction of the PCBs may also be carried into the offgas stream in mist and vapors. The PCBs associated with the processing equipment and grinding media will be appropriately dispositioned during decontamination and decommissioning activities.

E2.7 ERDF CRITERIA

After processing is complete, the grinding media, zircalloy-2 pieces and any other unground material are grouted for disposal at ERDF. The most restrictive requirements for disposal of the grout in the ERDF waste acceptance criteria are the limits for TRU (< 100 nCi/g), $^{239/240}Pu$ (<0.029Ci/m^3), ^{241}Pu (<0.052 Ci/m^3), ^{241}Am (<0.05Ci/m^3) and ^{137}Cs (<32 Ci/m^3). The acceptance criteria describe a sum-of-fractions calculation on limits for individual radionuclides. However, the acceptance criteria also note that where the sum-of-fractions limit is exceeded "These waste sources shall be evaluated on a case-by-case basis using the ERDF radiological Inventory Assessment Data Sheet (BHI-FS-133) to determine an integrated inventory concentration consistent with DOE policy as described in the *Performance Assessment Task Team Progress*

Report (DOE 1994). If the integrated inventory concentration of the waste source is below the Class C limits, the waste is then acceptable for transportation and disposal at ERDF. Such integration of radionulcide inventory can be applied to the contents of a waste package. Application of the inventory integration over an entire waste site or disposal trench may be considered on a case by case basis. " As a result, the grout was required to meet the 100 nCi/g limit to remain within Class C limits and then compared to selected individual radionuclide limits. In the particular case of the grouted zircaloy/grinding media, the sum of fractions criteria is met, primarily due to the large volume of grinding media which is assumed to be lightly contaminated compared to the zircaloy-2 cladding pieces. A small volume increase is still required to allow the grout to be contact-handled without addition of shielding.

E3.0 PROCESS DESCRIPTION

The grinding/milling alternative being discussed here reduces sludge particle size through fracturing/mechanical abrasion and accompanying oxidation reactions of the metallic uranium in water. The process steps include sludge grinding, offgas treatment, solids separation, oversized particle recycling, neutron absorber use for criticality safety, and chemical adjustment of slurry. For this process, the sludge will be transported in batches from the K Basins to a newly constructed treatment facility, located on the Hanford Site. The process chemistry and flowsheet are described below, along with some challenges and uncertainties associated with adequately grinding irradiated uranium fuel particles and the impact of the oxidation reactions.

Particle size reduction by milling was originally examined to determine if commercially available technologies could be used for processing K Basin sludge to meet the TWRS waste acceptance criteria (Precechtel and Packer 1997). Technologies considered included hammer mills, an impact type shredder, a grinding/dispersing system, and a tooth mill grinder. That evaluation concluded there was insufficient experience and confidence in existing size reduction processes to reduce the particle size of the K Basin sludge to less than 177 μm. In particular, there was no relevant experience involving the processing of uranium metal. A subsequent study evaluated the use of high-energy vibratory milling for processing K Basin sludge (Precechtel and Turnbaugh 1998). This technology had not been considered in the previous particle size reduction study. Precechtel and Turnbaugh (1998) concluded that high-energy milling could potentially offer cost, schedule, safety, and feasibility advantages over the baseline nitric acid dissolution process. However, they also concluded that further evaluation, as provided in the following text, was necessary to address assumptions and uncertainties associated with the process.

Milling of solids to 10 μm diameter is done in the commercial industry for friable materials such as sand, sodium azide, silicon carbide, zirconium silicate, etc. Vibratory grinding mills, which have been selected for evaluation in this study, typically are used to reduce particle sizes from about 1000 μm to less than 10 μm (Lowrison 1974). Vibratory grinding mills, however, cannot grind tough/ductile materials and cannot efficiently reduce particles larger than a certain critical

diameter determined by the grinding media size and amplitude of the vibration (Lowrison 1974, Weiss 1985). For appropriate materials, such as silica and silicon carbide, a vibration mill can reduce the particle size from 250 μm to 10 μm in about 2 hours (Sweco Product Brochure, "Vibro-Energy Grinding Mills," 1990). Zirconium silicate sand particles have been reduced from a mean particle size of 260 μm (with particles as large as 700 μm) to 10 μm (90% less than 10 μm) in about 6 hours. Larger particles can be processed, although additional grinding time will be required [Personal communication, Tom Dunkar, Sweco, 2/19/99). Particles of aluminum silicates with 10% silica have been reduced from ~12,500 μm (0.49 in.) to 44 μm (i.e., 90% less than 44 μm) in a Humboldt Pallu 50 U vibratory grinding mill at a rate of 3000 kg/hr (residence time in mill was not specified) (Weiss 1985). Other typical applications for vibratory mills include the production of organic and inorganic pigments (e.g., titanium dioxide, zirconium silicate, calcium carbonate, kaolin); ceramic glazes, polishing abrasives, iron oxide for magnetic tape production, and tungsten carbides.

A typical industrial approach for the production of small particle metals is to convert the metals to the hydride form, grind, and then dehydride the ground material back to metal. Metals for which this process is utilized routinely include zirconium, hafnium, nickel, titanium, vanadium, and tantalum [Personnel communications Tim McQueary, Oremet- Wah Chang (12/8/98) and Craig Voichet, Oremet- Wah Chang (2/11/99)].

E3.1 MECHANICAL FRACTURING OF IRRADIATED URANIUM FUEL PARTICLES

This section summarizes related testing and anecdotal information collected to assist in determining if irradiated fuel particles are likely to fracture in a grinding mill. The rates at which K Basin sludge can be processed in a grinding/milling operation will be much higher than those calculated from the oxidation reactions alone, if the irradiated uranium fuel fragments are mechanically fractured within the grinder. However, as shown below, there is insufficient information to conclusively determine whether significant fracturing of irradiated uranium metal will occur.

This assessment included contacting vendors of particle size reduction equipment, who recommended conducting tests with a nonradioactive surrogate for irradiated uranium fuel. A brief review of the literature was performed (Danielson 1999), and a zirconium alloy (Zircaloy-2) was identified as a reasonable surrogate on the basis of its hardness and pyrophoric nature. Furthermore, Zircaloy-2 particles are included within the K Basin sludge inventory. However, Zircaloy-2 [diamond pyramid hardness (DPH) = 184] cannot be considered a perfect match with irradiated uranium fuel (DPH = 440). After performing some screening tests and consulting with other technical experts, the vendors concluded that off-the-shelf size reduction equipment would not be effective for reducing the size of Zircaloy-2 particles. Because of differences between Zircaloy-2 and irradiated uranium, testing with irradiated uranium would be required to conclusively determine if available size reduction technology will be effective on K Basin sludge (Schmidt 1999).

Recent size reduction testing was performed at Argonne National Laboratory in which particles of unirradiated metallic uranium/10% molybdenum fuel (greater than 425 μm) were subjected to high-energy ball milling under cryogenic conditions (Clark and Meyer 1998). The cryogenic conditions were used as an attempt to embrittle the fuel particles. The objective of this testing was to produce a powder size of 45 to 150 μm. Results from this testing showed that the initial particles were reduced slightly in size, but only after several milling runs. The particles were flattened into flakes. The uranium/10% molybdenum fuel particles were almost certainly more ductile than the irradiated fuel particles in the K Basin sludge; however, these results demonstrate the potential challenge associated with fragmenting uranium metal.

Particle size reduction of unirradiated metallic uranium has been attempted in France by Compagnie d'Etude et de Realisation de Combustibles Atomiques (CERCA) using shock, shearing, and milling. CERCA (a subsidiary of Framatome and Cogema) specializes in the design and manufacturing of nuclear fuel for research reactors and is the world's largest producer of "exotic" fuels. Based on their testing and experience, they do not believe it is possible to grind metallic uranium (even containing low concentrations of iron and aluminum), although they have been able to grind a metallic uranium-molybdenum alloy. While CERCA has no direct experience with grinding irradiated metallic uranium, they are not optimistic that it can be done successfully (Personal communication, Jean-Pierre Duran, CERCA, 2/17/99).

Irradiated uranium metal is expected to be friable compared to unirradiated uranium or zirconium metal. A report by Swanson et al. (1985) provides a qualitative comparison of the fracturability of irradiated fuel compared to unirradiated fuel. Experience from the West Valley Demonstration Project with the chop, leach, and crushing operations of irradiated Hanford N Reactor fuel indicates that the irradiated fuel breaks up more cleanly and does not smear on cutter blade surfaces like unirradiated fuel. In N Reactor fuel element crushing tests, a greater degree of uranium crumbling and cracking, and a more extensive separation of the cladding was observed with irradiated fuel (Swanson et al. 1985). The Reactor Handbook (Tipton 1960) reports a 20 to 50% reduction in malleability of irradiated uranium compared to unirradiated uranium. A 4X decrease in impact strength was reported for hot rolled uranium after an exposure of 10^{20} nvt (Tipton 1960).

Nitric acid dissolution testing using K Basin sludge and K Basin irradiated uranium fuel fragments was recently performed (Schmidt et al. 1999). For this testing, several larger pieces of irradiated fuel were cut under an argon atmosphere using a pair of bolt cutters (to provide fuel fragments for dissolution testing less than 6350 μm in size). During the cutting, several fragments were fractured into a large number of smaller particles (See Figure E-1). Based on discussions with vendors with significant grinding experience, if a material can be fractured by hitting it with a hammer, it will most likely be fractured in a grinding mill (Schmidt 1999). The fracturing that occurred while cutting fragments with the bolt cutters (very high forces in a small area) does not provide definitive proof that similar fracturing will occur in a grinding mill. However, it does show the potential exists to achieve a faster particle size reduction rate than can be provided by oxidation reactions alone. Actual grinding testing with irradiated uranium fuel

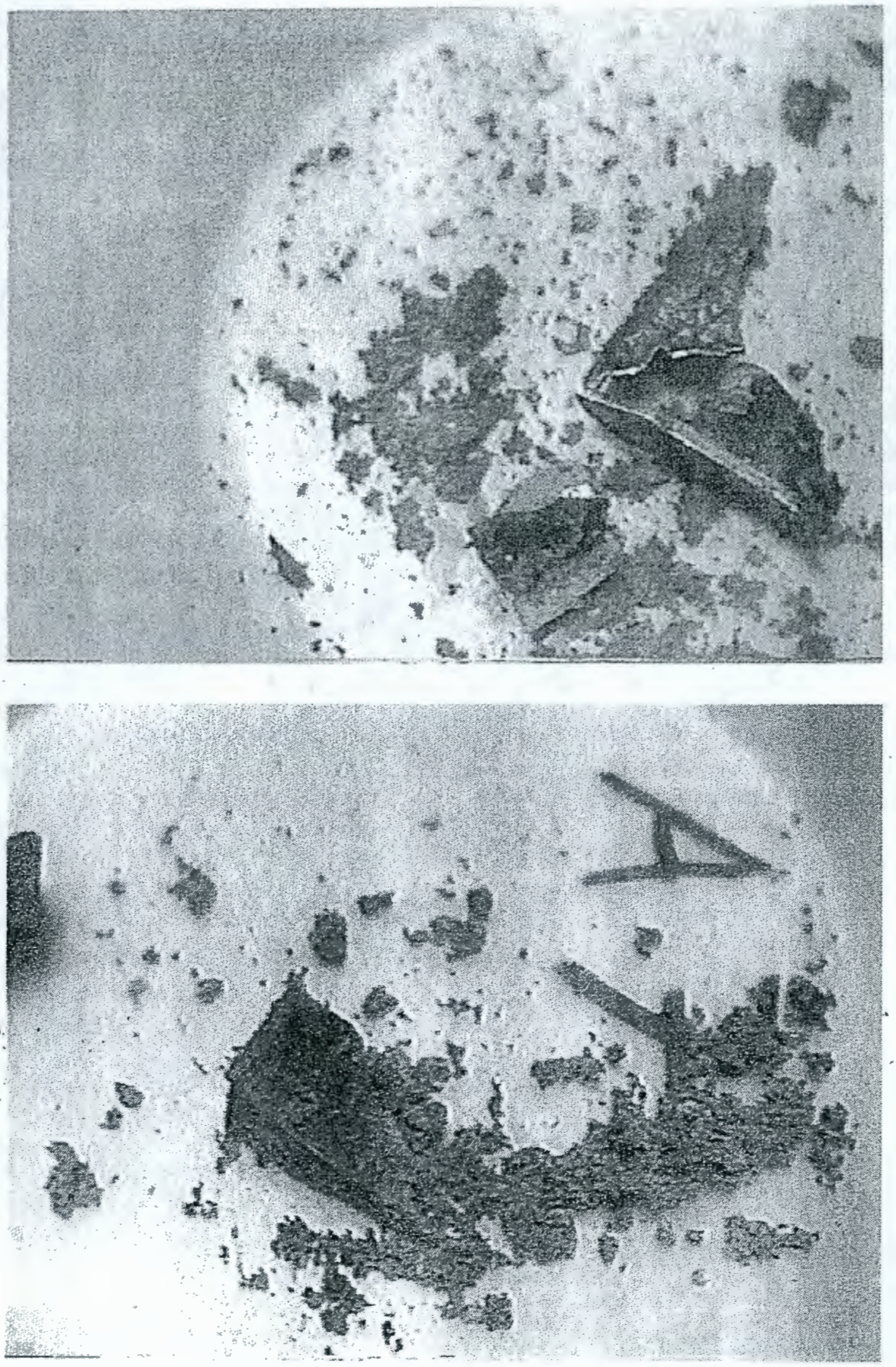


Figure E-1. Fractured Irradiated Metallic Uranium Fuel Particles After Cutting Fragment In a Bolt Cutter Under an Argon

particles will be required to more clearly determine whether fracturing will occur and how much it will enhance the size reduction rate.

As discussed above, little relevant quantitative data are available to assess the mechanical fracturability of irradiated uranium metal. Consequently, in estimating the grinding/milling processing rates, the potential of fracturing to enhance or dominate the rate of size reduction was not included. As a result, the assessment of the processing rates to achieve the required K Basin sludge particle size reduction (provided below) is based on oxidation mechanisms only.

E3.2 OXIDATION OF IRRADIATED URANIUM FUEL PARTICLES IN A GRINDING/MILLING OPERATION

Uranium metal reacts with water to form hydrogen gas and uranium oxide per Equation (1). [Some uranium hydride (<10% yield) is also formed from the reaction of uranium with water.] Likewise, uranium hydride reacts with water to form hydrogen gas and uranium oxide per Equation (2). Zirconium reacts with water to generate hydrogen and zirconium oxide per Equation (3). The reaction rate for uranium metal and water (neglecting oxide removal from metallic particles by the grinder and any fracturing of uranium particles) can be calculated using Equation (4). The uranium hydride present in the sludge is expected to be abraded off the uranium particles. While the uranium and uranium hydride should react with water at similar rates, since the uranium hydride is expected to have a much higher surface area than uranium, the uranium hydride particles are expected to oxidize faster than the uranium particles. The zirconium reaction rate with water at the grinding mill operating temperatures will be much lower than the uranium metal reaction rate and can be assumed to be negligible (i.e., zirconium particles are unlikely to be significantly altered via reaction with water, and will be removed from the grinding process essentially intact). Therefore, the size reduction rate of uranium metal particles will determine the overall grinding/milling-processing rate for the K Basin sludge.

$$U + (2+x)\,H_2O \rightarrow UO_{2+x} + (2+x)\,H_2\uparrow \text{ Where } x < 0.25 \qquad (1)$$

$$UH_3 + 2H_2O \rightarrow UO_2 + 7/2\,H_2 \qquad (2)$$

$$Zr + H_2O \rightarrow ZrO + H_2 \uparrow \qquad (3)$$

$$\text{Log } K = 7.634 - (3016/T) \text{ for water temperatures up to 373 K} \qquad (4)$$

where, K = Reaction Rate in mg wt gain/cm^2/hr and T= Temperature in K, (Reilly 1998)

Temperature and operation of the grinder will control the uranium and water reaction rate. The temperature will be controlled near 80°C. At 80°C, about 20 hours will be required for uranium particles to react to a depth of 10 μm [based upon Equations 1 and 4 from Reilly (1998)]. About 267 days are projected to be required to completely oxidize a 6350-μm-diameter spherical uranium metal particle. The 267-day reaction period for a 6350 μm uranium particle is conservative because actual uranium particles are likely to be irregular in shape (and possibly cracked) with significantly greater surface area than a perfect sphere (see Figure E-2).

The rate of uranium oxidation that will be achieved in the vibratory grinding mill is likely to differ from those reported by Reilly (1998). In the corrosion (oxidation) of bare uranium metal in distilled water at temperatures up to 80 °C, a thin protective oxide film forms on the uranium surface. As the film grows it becomes unstable and begins to break down to give way to black, powdery UO_2. Eventually, the entire surface is coated with the unprotective UO_2 layer, and the corrosion rate becomes linear with time. Consequently, an induction period of an indeterminable length is observed, and the true corrosion rate is approached only gradually (Tipton 1960). In the vibratory grinding mill, the surface of the uranium particles will be subjected to mechanical abrasion, which will continuously expose fresh uranium metal surface area. The constant exposure to bare uranium metal may enhance the oxidation rate. However, the extent of the probable enhancement to the oxidation rate is unknown, and therefore was not included for proposes of estimating the processing rates.

E3.3 SLUDGE PROCESSING RATE

A precise determination of the time required to effectively grind all K Basin sludge cannot be determined from data available without making a number of enabling assumptions. The processing time will vary depending on the stream being processed; how much, if any uranium fracturing occurs; and how much uranium must be recycled from each batch. In the process, the discharge from the grinder will be routed through a knockout pot and a series of hydrocyclones to remove particles greater than 10 μm. These oversized particles will be recycled back to the grinder feed for additional grinding in the next processing cycle. Without data, the feed rate of fresh sludge to the process, which will be determined by the rate at which metallic uranium is recycled, cannot be defensibly determined. However, using enabling assumptions, processing rate projections can be made for preliminary estimates of equipment size and processing throughput.

The K Basin floor and canister sludge is expected to contain low concentrations of metallic uranium and mainly consists of small particles. For streams KE1, KW1, and KW3, 50 volume percent of the particles will pass through screen openings of approximately 12 μm, 7 μm, and 7μm, respectively (Pearce et al. 1998). Furthermore, the estimated metallic uranium content of these steams is small: 48 kg U for KE1 (KE1 is 0.21 wt% metallic U - dry basis); 0.87 kg U for KW1 (KW1 is < 0.1 wt% metallic U - dry basis); and 67 kg U for KW3 (KW3 is 1.9 wt% metallic U - dry basis).

Figure E-2. Irradiated Metallic Uranium Fuel Fragment from K Basin.
Note: irregular fractured surface and zirconium cladding.

Assuming a 20-hour grinding time for each batch of sludge, and based on the water uranium oxidation rate at 80°C, during each batch cycle, spherical uranium particles will decrease about 20 μm in diameter. For purposes of projecting a preliminary throughput, it is assumed that one 20-hr grinding cycle will be sufficient to process streams KE1, KW1, and KW3 with minimal recycle of oversized material. For these low-metallic uranium content streams, ~65% (volume) KE1, ~82% volume KW1, and ~72% volume KW3 are less than 20 μm (Pearce et al. 1998). Furthermore, photographs and chemical analysis of larger size particles (i.e., > 355 μm) from the KE Basin floor and Weasel Pit show that the oversized material is largely composed of organic ion exchange resin beads, inorganic ion exchange material (mordenite), paint chips, uranium oxide, quartz (silica), and albite [$Na(Si_3Al)O_8$] (Bredt 1997, Schmidt et al. 1998). These oversized materials are friable, and will likely undergo very significant particle size reduction in a 20-hr grinding cycle. Testing will be necessary to determine how much oversized material (> 10 μm) will need to be recycled from each 20-hr grinding cycle for these streams. Any amount of oversized material recycle will lower the process throughput.

It is assumed that the sludge generated from the fuel element washing operations (KE2 and KW2) will contain uranium metal particles up to 1/4-inch diameter (6350 μm). These large sludge particles will require the longest time to process. For both of these streams, it has been estimated that 50 volume percent of the particles would pass through screen openings of 1000 μm (Pearce et al. 1998). The estimated metallic uranium content of these streams is significant: 1500 kg U for KE2 (stream is 39 wt% metallic U – dry basis); and 1500 kg U for stream KW2 (stream is 90% metallic U- dry basis). With a 20-hr grinding time per cycle, for streams KE2 and KW2, very significant recycle of oversized material will be necessary. If it is assumed that under steady state conditions, the average metallic uranium particle in the grinder is ~600 μm in diameter, then for each 20-hr grinding cycle, approximately 10% of the mass of metallic uranium will be oxidized per cycle. [For comparison, if the average particle size were assumed to be 6350 μm, 1000μm, 250 μm or 100 μm, than the rate of metallic uranium oxidation per cycle would be 0.97%, 5.7%, 22%, and 49% respectively.] Based on 10% uranium oxidation per cycle, for stream KE2, 78% of the sludge in each batch would be recycled as feed to the next batch. For a feed rate of 160 kg (dry basis) total (fresh sludge + recycled sludge), the fresh sludge feed rate would only be 36 kg per batch. For KW2, which is projected to be 90% metallic uranium, 89% of the sludge in each batch would be recycled (i.e., fresh sludge feed rate per batch would be only 18 kg for a 160 kg – capacity grinder). If greater or less than 10% of the metallic uranium is oxidized per cycle for these two streams, then rate at which fresh sludge can be fed to the process will change. Testing will be necessary to determine the actual recycle rates.

Again, based on particle size reduction of metallic uranium by oxidation reactions alone, to completely oxidize a 6350-μm uranium particle, the particle will need to be recycled through the grinder for a total of ~270 days of continuous processing. This illustrates the challenge of realizing a reasonable processing rate in a grinding mill for large uranium particles if the reaction of water and uranium is the only means by which the size of the uranium particles is reduced.

If significant fracturing of the uranium particles occurs in the grinding/milling operation, and/or an enhancement to the reported uranium oxidation rates is realized (from the continuous

exposure of bare uranium metal from the grinding action), then the particle size reduction rates and processing throughput will be much greater than those estimated above.

E4.0 PROCESS FLOW SHEET DESCRIPTION

The grinding/milling alternative comprises the following process steps:

- Sludge transfer from transport container to lag storage vessel
- Sludge transfer to grinder
- Sludge grinding
- Separation, removal, and recycling of solids
- Addition of neutron absorbers
- Addition of sodium hydroxide and sodium nitrite
- Transfer of the sludge to TWRS
- Offgas treatment.

These steps are depicted in the block flow diagram shown in Figure E-3 and summarized below.

E4.1 SLUDGE TRANSFER FROM TRANSPORT CONTAINER TO LAG STORAGE VESSEL

The sludge from the K Basins is loaded in a shielded transport vessel and moved via a transport vehicle to the facility-load-in/load-out bay. The shielded transport vessel is removed from the vehicle and positioned on a rail platform for movement through the washdown area to the unloading/load-out area. There the sludge is transferred to a lag storage vessel where it is agitated to suspend the solids. The tank used to receive the sludge also serves as the feed tank to the grinder. An air inbleed to the feed tank is used to dilute and sweep hydrogen gas away as it is produced by the uranium metal- and uranium hydride-water reactions and by radiolysis. (Movement of sludge has been observed to be accompanied by hydrogen generation presumably from water reactions with freshly exposed uranium metal and uranium hydride.)

E4.2 SLUDGE TRANSFER TO GRINDER

A pump delivers the sludge from lag storage to the operating grinder. The sludge slurry is fed at the top of the grinder and allowed to fall down into the void spaces of the grinding media. A defoaming agent is added to the grinder feed stream as necessary to minimize foaming. A foaming agent compatible with TWRS waste acceptance criteria would be selected. Water is added to the slurry via the add line to keep the slurry and media covered in the grinder.

E4.3 SLUDGE GRINDING

Sweco high-amplitude vibratory grinding mills were considered for grinding/milling of K Basin sludges for this evaluation. This grinding technology was identified in Prechechtel and Turnbaugh (1998), but, as discussed previously, there are no data available that it can efficiently

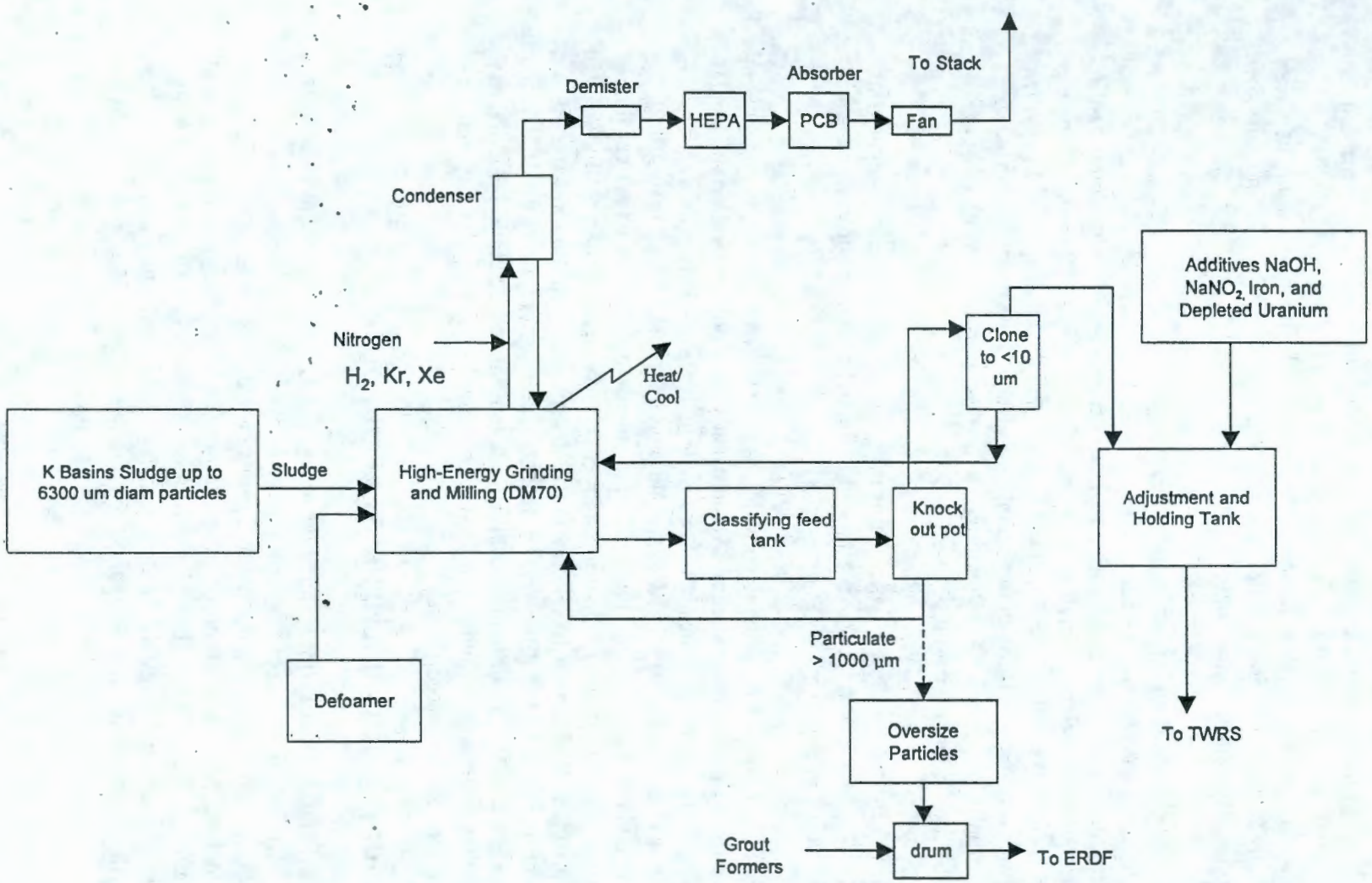


Figure E-3. Conceptual Flowchart for Grinding-Milling Option

grind the K-Basins sludge. Each unit consists of a grinding chamber and a vibrating mechanism. The polyurethane-lined grinding chamber is a vertical cylinder with a void center forming an annulus that is filled with grinding media. A cutaway of a typical grinder is shown in Figure E-4. The Sweco high-amplitude grinding mills are available in a broad range of sizes (capable of processing from 20 to 650 liters per charge). The selection of a grinding mill size was based upon criticality control considerations.

The vibration is provided by a 40-hp motor located below, and attached to, the base of the chamber. The assembly is suspended on steel springs so that all the energy is imparted directly to the grinding chamber and media. The vibrating mechanism consists of a shaft mounted in heavy-duty bearings. "Out of balance weights" are attached at each end of the shaft. The top weight causes a horizontal gyration of the grinding chamber, and the bottom weight provides a gyrating tilt. This motion creates a three-dimensional, high-frequency vibration. Based on vendor literature, virtually no vibration is transmitted to the floor during grinding (Sweco Product Brochure, "Vibro-Energy Grinding Mills," 1990).

The grinder operates as the feed is added, which helps mitigate any initial energetic reactions with uranium metal. A water heating jacket is attached to the outside of the process chamber to heat the bed and incoming slurry to 80°C.

The grinding media (aluminum oxide is being considered) is expected to wear and consequently contribute to the solids in the discharge stream. Actual wear values will depend on the final media selection, processing times, and the abrasiveness of the K Basin sludge. In vendor-conducted media wear tests, media is covered with water and the grinding mill is run for 200 hours non-stop. Typical media losses for aluminum oxide are 2.3 wt% to 3.4 wt% over the duration of the testing. For zirconium oxide grinding media, losses during wear testing (200 hr) ranged from 0.0026 wt% to 0.83 wt% (depending on which type of zirconium oxide media was used) [Personal communication, Don Rogers, D. E. Rogers Company (11/12/98)]. If aluminum oxide grinding media is selected, significant quantities of aluminum oxide could be added to the processed K Basin sludge stream. Grinding media will be replenished as needed through an addition line from the aqueous makeup area.

E4.4 SEPARATION, REMOVAL, AND RECYCLE OF SOLIDS

Opening a valve while the grinder is operating allows the ground particle slurry to flow from the bottom of the grinder/miller into a receiving tank. In the receiving tank, the processed slurry is agitated and transferred through a knockout pot to a series of hydrocyclones for particle separation. The knockout pot is used to prevent the 1000-μm or larger diameter particles from being transferred to the hydrocyclones. Particles at or greater than 10-μm diameter are removed and returned to the vibratory grinding mill for further grinding. Once the processing campaign is complete, large particles (e.g., zirconium cladding) remaining in the knockout pot are removed for grouting.

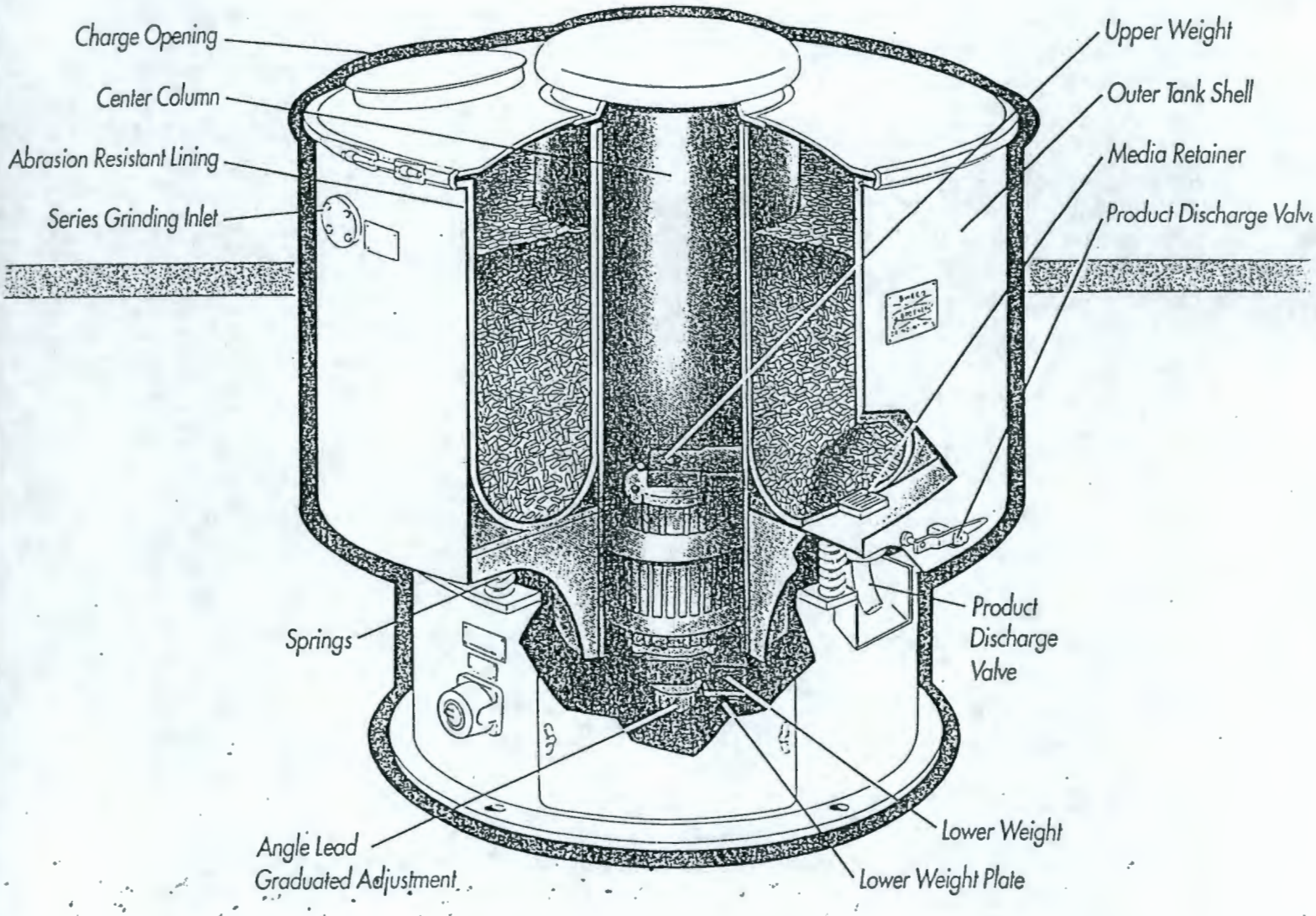


Figure E-4. Cutaway of Sweco Grinder

SWECO is a trademark of SWECO, Inc. of Los Angeles, CA

The fraction of uranium particles that are expected to be recycled back to the grinder from each batch will need to be experimentally determined. The uranium recycle rate will impact the overall process throughput and will impact the criticality control strategy.

For this process evaluation, hydrocyclones were selected to perform the particle separation/classification. Other particle screening and classifying equipment could also be considered for this application. The preliminary evaluation of vibratory grinding as an alternative treatment approach for K Basin sludge (Precechtel, 1998) included descriptions of several standard-screening techniques: stationary screening devices, vibro-energy separators, and centrifugal screen concentrators.

It is expected that the remaining oversized particles (e.g., zirconium cladding) will be partially decontaminated by the abrasive action in the grinding mill. Previous testing has demonstrated that contamination levels on the surfaces of equipment (including rusty piping and hand tools) can be significantly reduced in a vibratory finishing mill (McCoy et al. 1980, Fetrow and Allen 1981). However, in the fuel fabrication process, interdiffusion of uranium into the zirconium cladding occurs, and the trapped uranium will undergo fission and activation during irradiation. All of the activation and fission products will not be released unless the zirconium is dissolved (Swanson et al. 1985). Consequently, the oversized zirconium cladding particles from the grinding mill are likely to contain appreciable residual activity.

E4.5 ADDITION OF NEUTRON ABSORBERS

The product slurry with particles of 10 μm or less is routed to the adjustment tank. Iron nitrate and uranyl nitrate are added to the treated slurry at quantities determined by sample analysis in accordance with the TWRS criticality control strategy.

E4.6 ADDITION OF SODIUM HYDROXIDE AND SODIUM NITRITE

After addition of neutron adsorbers, sodium hydroxide is added to adjust the pH to 12, and sodium nitrite is added for corrosion control to meet TWRS requirements.

E4.7 OFFGAS TREATMENT

The gas space above the grinding/milling media is purged with nitrogen. Hydrogen gas concentrations (produced from uranium/zirconium water reactions and radiolysis) are maintained below the lower flammability limit by monitoring and dilution with nitrogen and air. The hydrogen generation rate will not be constant during processing (i.e., higher rates are expected early in the processing cycle) and will be dependent on the uranium concentration in each batch. Some radioactive species, including ^{85}Kr, ^{99}Tc, ^{137}Cs, and ^{129}I, are also expected to be released to this gaseous stream. The offgas and nitrogen are routed through a condenser and demister, heated, and then routed through a HEPA filter. As a final step, the offgas is polished through a granular activated carbon bed to ensure PCB concentration limits are met. The offgas will be monitored and sampled to verify that it complies with regulatory criteria. One offgas treatment train will support the grinders.

E5.0 DOE/FOREIGN/COMMERCIAL/PREVIOUS EXPERIENCE

As discussed previously there is no relevant experience for the grinding of irradiated uranium. The closest example is the recent size reduction testing performed at Argonne National Laboratory in which particles of metallic uranium/10% molybdenum fuel were subjected to high-energy ball milling under cryogenic conditions (Clark and Meyer, 1998). On the other hand, grinding technologies are used in the nuclear industry for oxide materials (e.g. Mox fabrication facility, grinding of sludges at West Valley)

Hydrocyclones have been tested for simulated K basin sludge separations and appear to be acceptable for their desired sand separations at larger particle diameters (around 250 μm). The hydrocyclones can be designed to separate particles at smaller diameters. Hydrocyclones have been used in industry to separate particles of a wide range of products. Separations in the range of 5 μm are routinely done.

E6.0 SAMPLING REQUIREMENTS

This section describes analytical work required to satisfy process control and product verification criteria.

E6.1 PROCESS CONTROL CRITERIA

Each batch of sludge will be sampled at the basin for accountability and process control prior to transfer to the sludge processing facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations. Particle size and particle quantity data can also be monitored with in-line instrumentation.

This process eliminates acid digestion operations and is therefore a simplified flowsheet. There are no intermediate steps that require process control laboratory analyses except as an aid to product adjustments to meet TWRS acceptance criteria. In-line instrumentation will be useful in monitoring for criticality safety from solids accumulations and particle size monitoring in the feed and product lag storage tanks.

Timeframe

Process control analysis data will be required prior to making adjustments to the product for hydroxide, nitrate, and nitrite concentrations. Batches of product will be generated daily thus data will be needed within the 4 hour turnaround time in which the analyses can be performed. The sodium hydroxide addition needed will be highly dependent on the aluminum concentration present in the resulting particulates and therefore a caustic ratio analysis will provide process information rather than product specification data.

E6.2 PRODUCT VERIFICATION CRITERIA

E6.2.1 TWRS

Waste destined for disposal in TWRS tank farms must have data to show compliance with analytes identified in the double shell tank waste acceptance criteria (Mulkey 1998). In addition, a waste fact sheet must be developed prior to shipment that includes other specific requirements to be considered. Process knowledge may provide information that can reduce direct analytical measurements but these changes require negotiation prior to material shipments. The details of the acceptance measurements required are included in the baseline process alternative and therefore are not repeated. The difference in this product is inclusion of solids in the sample intended for analyses. This additional sample preparation will increase the analytical cost, however this cost is more than offset by the savings produced in LAW glass volume by sending less sodium to TWRS.

A TWRS drafted policy sets forth additional interim criteria for the acceptance of PCBs to tank farms that ensure TSCA regulated PCBs are not received by the DST system (Interim Acceptance Criteria). This criterion is delineated in the baseline alternative and is not repeated here.

The slurry product of the grinding operation will be adjusted to comply with TWRS acceptance criteria for hydroxide, nitrate, and nitrite concentrations. Analysis of a slurry sample for hydroxide, nitrate, nitrite, metals and radionulcides (including Pu and U enrichment) will be performed on the final slurry prior to sending to TWRS.

Any unground solids >10μm separated in the hydroclone will be rerouted to the grinder and if it fails to grind will eventually be grouted along with the grinding media. This grout is expected to be <100 nCi/g and be suitable for disposal at ERDF.

Timeframe

Since a slurry batch will be produced daily, the analytical data will be required within a 24-hour period of sample receipt to minimize process perturbations. This will be taxing for the laboratory staff in that several of the radionuclide analyses require approximately 24 hours to complete when the dissolution sample preparation step is required. Analyses of the solids destined for ERDF should not require a rapid turnaround since the media and unground pieces are accumulated over time and grouted after processing is complete. As a result, this operation does not need to be completed in the 13-month processing window (which is driven by removal of sludge from basin rather than completion of disposal).

The turnaround time required to provide analytical data necessary to support the grinding and milling process alternative will be difficult to maintain but is possible. A fully dedicated staff will be required.

E7.0 APPLICATION TO K BASIN SLUDGE

This section evaluates the treated sludge against the TWRS waste acceptance criteria and against the ERDF waste acceptance criteria for the grouted product.

The organic resin beads in the K East sludge (KE1 and KE2 streams) are to be ground with the sludge for interim storage at TWRS. TWRS operations has indicated their acceptance of these organics (since they are ground to <10 um diameter and constitute less than 10 wt % of the solids in streams KE1 and KE2) without a requirement for additional monitoring of waste at TWRS (Erlandson 1999).

The grinding/milling treatment process would treat the sludge to meet the TWRS waste acceptance criteria for criticality control, elimination of pyrophoric materials, corrosion control, prevention of flammable gas retention, particle size and exclusion of TSCA regulated materials. The grinding water-oxidation step insures that essentially all of the uranium is converted to solid oxide and that all particulate sent to TWRS is at 10 μm diameter or less. Sufficient depleted uranium (as required) and iron nitrate are added to the slurry prior to pH adjustment to meet the criticality specifications. A total of 379 m^3 (100,000 gallons) solids can be added to AW-105 before exceeding the flammable gas retention requirement, this process will produce approximately 62 m^3 of solids (needs to be verified via laboratory testing). The requirements for corrosion control are met by adding NaOH and $NaNO_2$ in the neutralization step. This process eliminates pyrophoric materials by oxidizing the metallic and hydride uranium material in the grinding step. The zircaloy will be separated out in the knockout pot and stabilized in a grout matrix.

The concentration of PCBs in the sludge is likely to be reduced in the grinding process. The Sweco grinding mill considered for this application comes standard with a ~1-in. thick abrasion-resistant polyurethane liner. [Other linings, such as stainless steel, are available.] PCBs are known to sorb onto polyurethane, and polyurethane foam is used in a number of analytical PCB extraction techniques (Erickson 1992). In a previous evaluation to determine the fate of PCBs during K Basin sludge processing, several tests were conducted with PCB-spiked K Basin sludge simulant (spiked to nominally 1000 ppm PCB) using heated water (60°C/1 hr and boiling temperatures/6 hr) (Mong et al. 1998). About 20 to 70% (depending upon the PCB congener) of the recovered PCBs from this testing were found to be associated with the glass test equipment (i.e., recovered after completion of the tests via solvent washing of the test equipment). Nearly all of the remaining recovered PCB was associated with the solids from the K basin sludge simulant. These results indicate that PCBs can migrate from the sludge to a processing vessel. Given that the PCBs have a higher affinity for polyurethane than glass, it is possible that significant quantities of PCBs will collect on the liner in the vibratory grinder. However, at some point, the surface of the liner will likely become saturated, and further PCB adsorption may cease. It should also be noted that at temperatures up to 52°C, the polyurethane liner is expected to last about 13,000 hours of grinding [Personal communication, Tom Dunkar, Sweco (2/12/99)]. At higher temperatures, the life of the liner would be expected to decrease.

In addition to adsorption onto the liner, and to a lesser extent, on the other surfaces of the processing equipment, a small fraction of the PCBs may also be carried into the offgas stream in mist and vapors.

Without performing experiments, it is difficult to quantitatively estimate the extent of PCB removal from the sludge during grinding. The granulated activated carbon bed installed in the offgas system will ensure the PCB concentration in the offgas will be less than the $10\mu g/m^3$ limit.

At the end of operations, the zircaloy and grinding media will be stabilized in a grout matrix as contact handled waste and dispositioned to the ERDF.

E8.0 SAFETY CONSIDERATIONS

The proposed grinding approach has a number of safety considerations that influenced the description of the option and would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed in this facility need a significant amount of shielding (up to 75 cm of concrete for the main process vessels), hence much of the process operations would need to be performed remotely. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain ALARA. The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

Although the grinding/milling process is less complex than the baseline process, it has significant safety issues in the grinding step, which require further research, testing, modeling and analysis resolution. Thus, the process control and safety control technology is much less mature and well established than the baseline process.

E8.1 HANDLING OF PYROPHORIC PARTICLES

Metallic uranium particles are maintained under water. Much of the reactivity will be reduced by reaction in the grinder. Some metallic fines may pass the 10 μm hydroclone. However, all downstream steps are maintained under water to prevent any pyrophoric ignition events.

E8.2 OVERSIZE RECYCLE

Large pieces of metallic uranium and zircalloy-2 cladding will survive the grinding process and end up in the knockout pot for recycle to the next grinding batch. At some point, zircaloy pieces will build up in the recycle stream and need to be removed from the process. There are expected to be only about 206 kg of zircalloy-2 cladding in the material to be processed. As a result, the amount of material that must be purged from the knockout pot is small. However, it is important that the metallic uranium pieces be fully ground before separating and grouting the zircaoly pieces. A significant content of metallic uranium pieces mixed with the zircalloy cladding pieces could substantially increase the TRU content of the grout making it unsuitable for ERDF disposal. In addition, the metallic uranium particles would result in hydrogen generation in the grout and if settled to the bottom of a grout container may not be acceptable for WIPP disposal. As a result, it may be necessary to accumulate the zircaloy over the processing period, and

process the zircaloy for additional time in the grinder to eliminate entrained metallic uranium.

E8.3 CONTROL OF REACTION IN GRINDER

Control of the reaction rate in the grinder is achieved by adding the solids in a semi-batch mode. If reaction in the grinder becomes sufficiently vigorous, then addition of sludge would be halted until the reaction rate subsides. If required, the intensity of the grinding could be reduced.

Heat will be generated both through the action of the grinder and through the reaction of the uranium with water. The rate of reaction that can be expected is highly uncertain because the degree of fracturing that may occur is unknown and if fracturing is not significant, the degree of increase in corrosion rate that might be obtained is unknown. The grinding is initially assumed to occur at 80°C. Heating to this temperature is achieved through a jacket on the outside of the grinder. Cooling could also be provided through this jacket. However, if the reaction is much faster than ordinary water corrosion rates, the heat generated may quickly overwhelm the exterior cooling jacket. In this case the only way to control temperature would be to allow water to boil off and replace it with condensate or with cool water. A defoaming agent will be used in the grinder to discourage foaming of the solution in the grinder leading to the entrainment of fine solids into the offgas system.

E8.4 HYDROGEN GENERATION

The rate of hydrogen generation in the grinder is much higher than in usual process vessels. The plenum of the grinder will be maintained in a nitrogen-inerted condition. Additional nitrogen will be added as the offgas leaves the grinder to dilute the stream sufficiently such that mixing with air cannot create a flammable mixture.

The rate of hydrogen generation from the lag storage tank would be comparable to the baseline process.

As a grinder batch undergoes segregation in the hydrocyclone, some quantity of metallic uranium fines <10 micron may be passed on to downstream processes. These particles may result in a continued hydrogen generation rate which is much greater than the radiolytic hydrogen source. As a result, measures will be needed for downstream tanks similar to those implemented for the lag storage tank. The potential source from these particles has not been estimated.

E8.5 ORGANIC ION EXCHANGE RESINS

Organic Ion Exchange Resins (OIER) are fed with other sludge to the grinder and are ground up with the sludge. No particular safety concerns exist for the OIER in this option.

E8.6 CRITICALITY - PROCESS CONTROL

The criticality control on the feed to the facility is a mass based limit on a batch. The same batch-size based control is used for the batch feed to the grinder. The criticality control for the grinder has not been developed. Oversize material which does not grind is separated in either a

knockout pot or a hydroclone and returned to the grinder. Large uranium particles, which are only slightly oxidized in a single cycle, will accumulate in the knockout pot recycle. This recycle coupled with the extreme difficulty of determining what may be in the grinder at any time, introduces significant uncertainty as to the mass of fissile material in the grinder. It may be possible to take credit for the presence of the grinding media within the grinder. However, this aspect of the process needs to be developed.

E8.7 CRITICALITY - INTERIM STORAGE OF PRODUCT

After the material is ground to less than 10 microns it undergoes a hydroclone separation to remove any particles larger than 10 microns. Control of this separation is important as a consistent failure to make this separation could provide a mechanism for segregation of fissile material in the DST to which the material is sent. Depleted uranium and iron added as neutron absorbers will be precipitated using sodium hydroxide and would be expected to be very fine.

E8.8 CHEMICAL ADDITION

When the acidic iron nitrate and uranyl nitrate solutions are added to the ground sludge material, there may be a reaction with the sludge. If needed, the rate of reaction would be controlled by the rate of metal nitrate addition.

E8.9 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. However, the amount of PCBs that will be volatilized from the grinder will be minimal. The majority of PCBs would either be attached to surfaces on equipment or be attached to solids in the stream sent to TWRS

E8.10 RISK TO WORKERS

Chemical hazards, which could affect workers, include caustic (sodium hydroxide); hazardous dusts from grout formers, and depleted uranium. Physical hazards include pressurized vessels and piping, rotating equipment (pumps, and fans), vibrating equipment (grinder) vehicular traffic, and electrical hazards associated with equipment. These hazards will be addressed by an appropriately administered health and safety plan.

E9.0 MAINTENANCE

Maintenance requirements are expected to be minimal in view of the short operating life of the plant. However, features are included which allow for maintenance or change out of all, in-cell process equipment. Viewing windows and master/slave manipulators are fitted to one face of the hot cell. Inside the cell is an overhead crane with sufficient capacity to lift the heaviest piece of equipment (a grinder) should it fail. A lay down area directly under a hatch in the roof of the cell is also provided. On the second level a second crane is furnished which not only accesses the cell transfer hatch, but also will move to the load-in/load-out area.

In the event of a failure, the failed equipment piece will be flushed to the extent possible. Depending upon the failure, it will be maintained in place or changed out in the manner described. Though not expected due to the short duration of processing, the most likely failures would be the grinders, pumps, or agitators. The more passive equipment pieces are fully expected to survive for the entire mission.

E10.0 FACILITY LAYOUT

Locating the grinding/milling operation in one or both of the basins was investigated before a stand alone facility concept was selected. A grinder sized to process sludge at the rate necessary is physically too large to fit in the basin and would have to be located under water. The grinder could be located in the East Bay but only after half of the fuel and some of the racks are removed. Further, the existing crane, which services the East Bay, does not have the capacity to lift the grinder. In order to get the machine into the basin, a hole would have to be cut into the roof, and the equipment lowered through the hole into the East Bay. The grinder would be skid mounted, eliminating the need to bolt the grinder to the basin floor. The monorail would be used to move the grinder under water to the other side of the bay making room for the second grinder. Construction at the site to prepare for the grinding/milling process would impact scheduled operations in removing fuel and debris from the basin resulting in a delayed schedule.

A conceptual layout of equipment in the processing cells in shown in Figures E-5 through E-9. The main process equipment pieces are housed in a hot cell approximately 15m long x 5.5m wide x 5.5m high. The cell is serviced by an overhead crane and master-slave manipulators. The major pieces of equipment in the cell include the feed tanks, transfer pumps, the grinders, hydrocyclones, and adjustment/loadout tanks. Shield windows are provided for visual inspection during operation and in the event maintenance is required. In the event that a major piece of equipment requires change-out, a roof hatch in the cell is provided which is accessed by an overhead crane on the second level. This crane also services the load-in/load-out area. A sample cave is located adjacent to the cell for process and waste verification sample acquisition.

The bulk of the facility consist of unshielded space for support equipment such as primary and secondary closed loop cooling and heating systems, ventilation equipment, electrical distribution, manipulator repair, aqueous make up, and emergency equipment. A shipping and receiving area is also provided with drive through access for the sludge transporter and for equipment load-in/load-out.

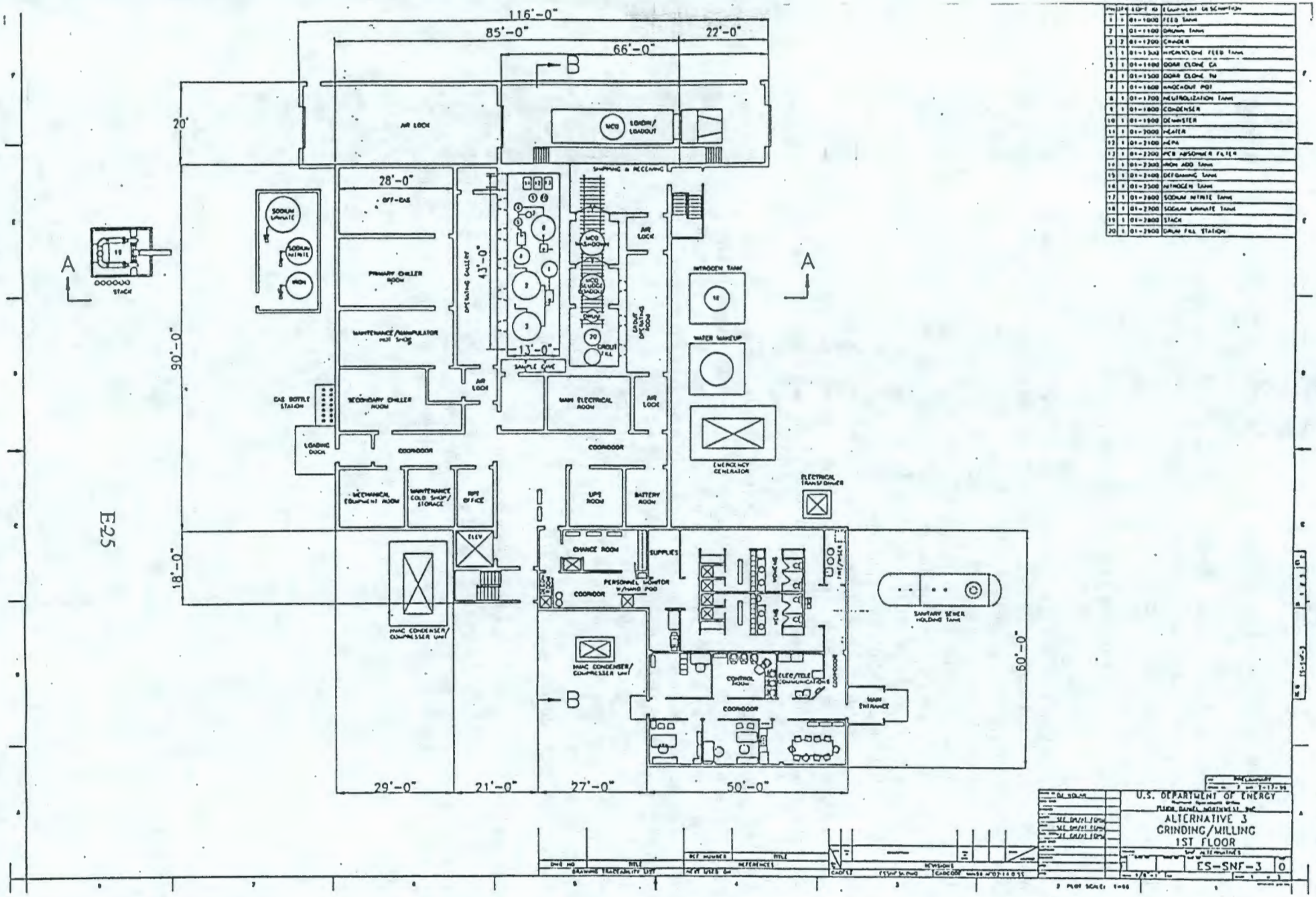


Figure E-5. 1st Floor Plan View for Grinding/Milling Process Facility

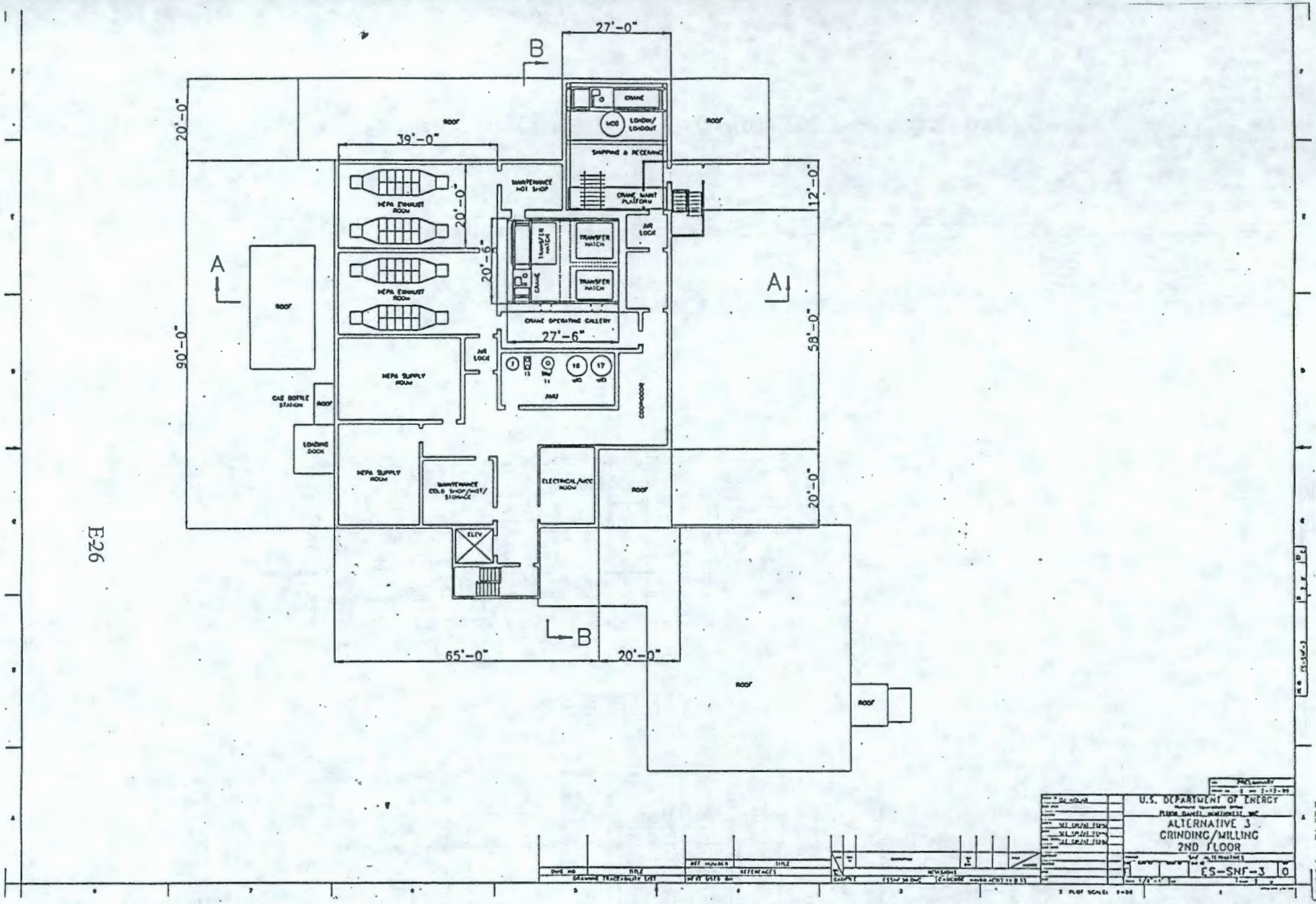
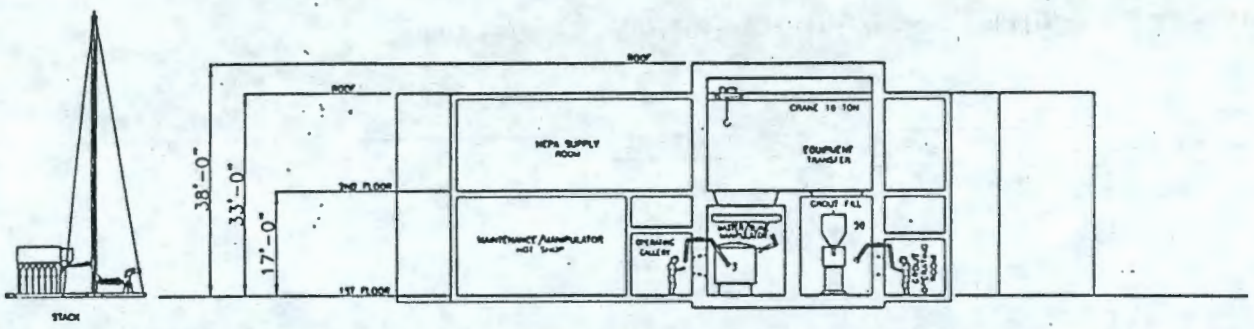


Figure E-6. 2nd Floor Plan View for Grinding/Milling Process Facility



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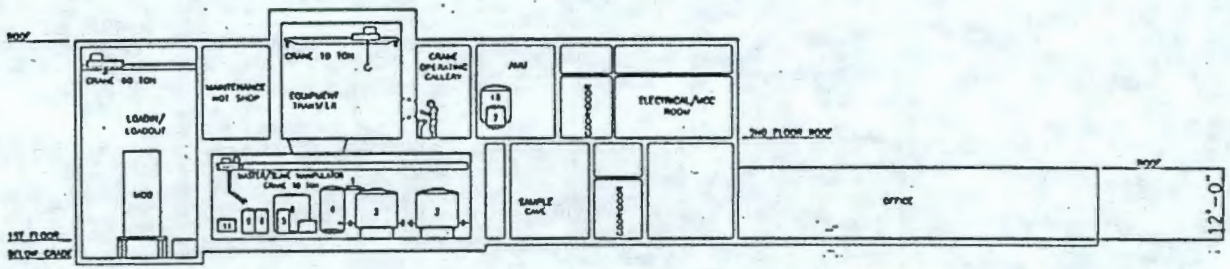

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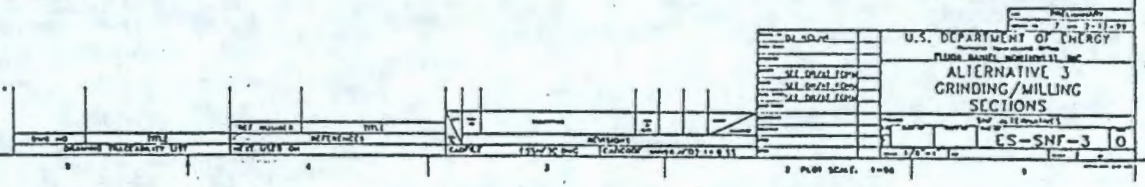


Figure E-7. Sections of Grinding/Milling Process Facility

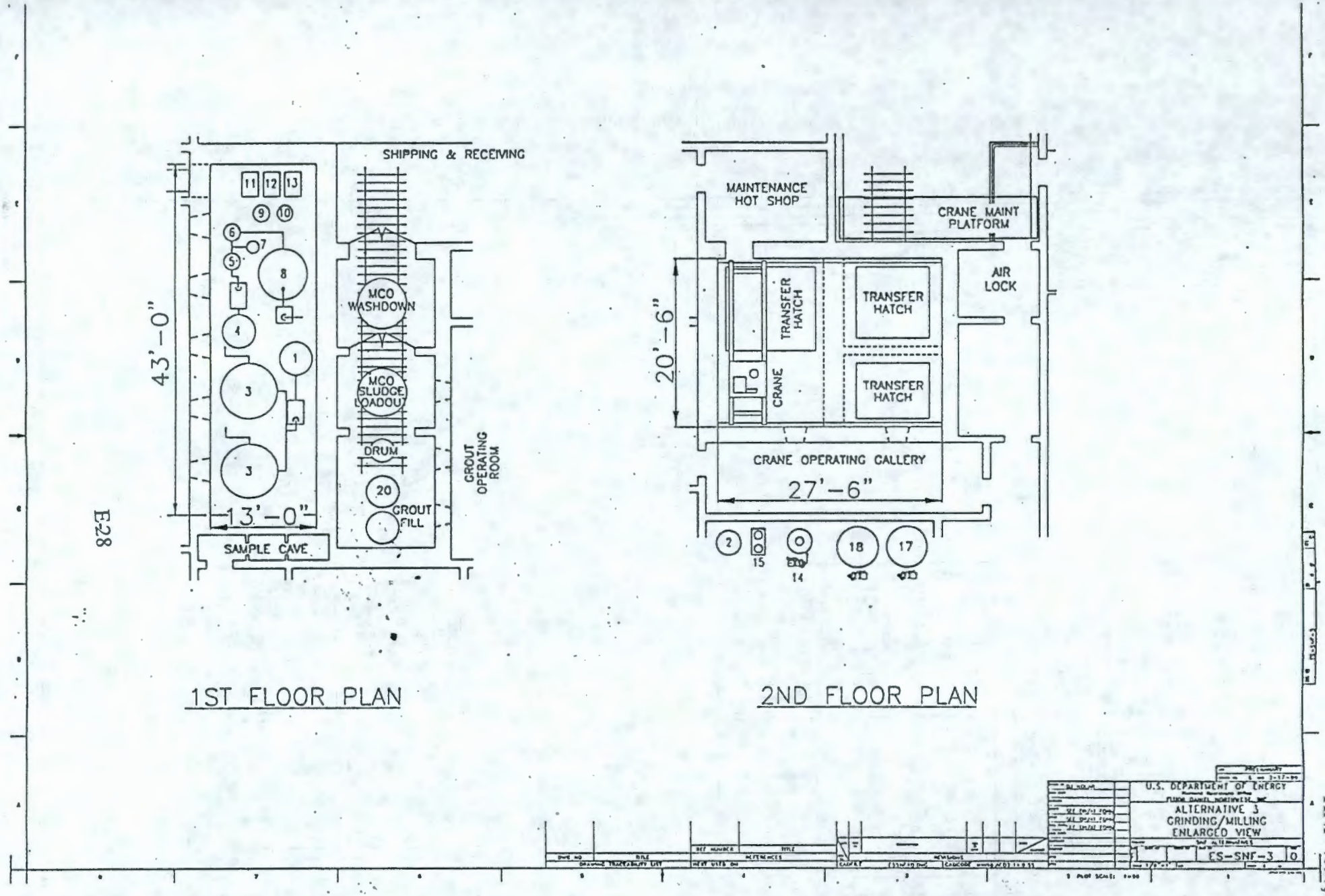
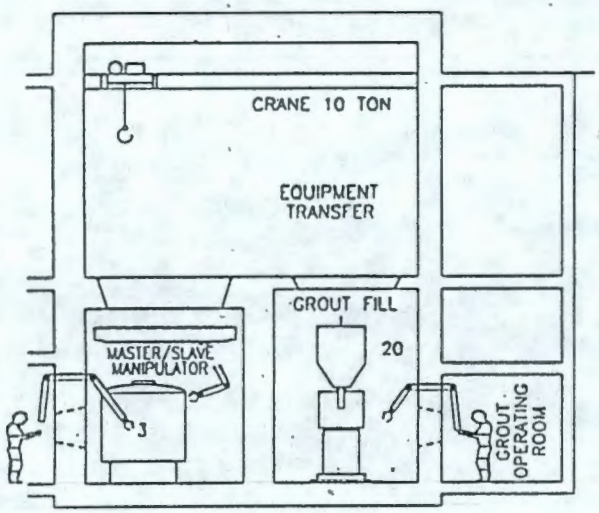
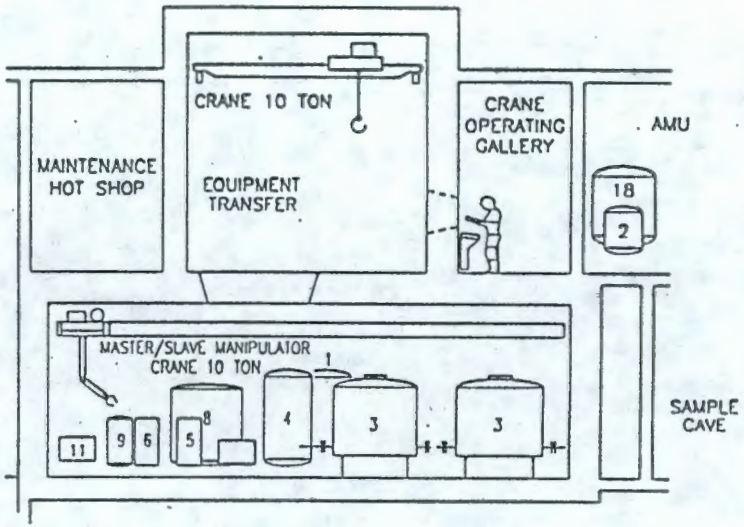


Figure E-8. Enlarged 1st and 2nd Floor Plan View of Grinding/Milling Process Area



SECTION A



SECTION B

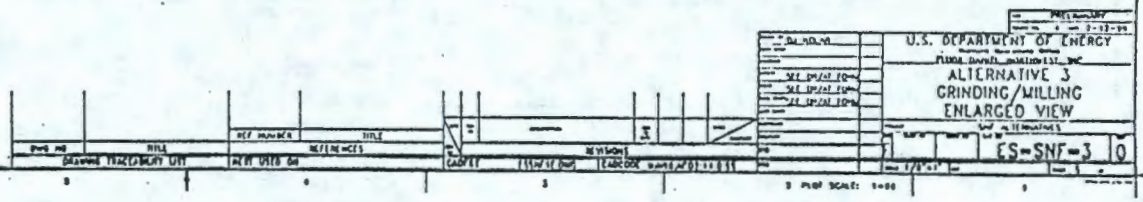


Figure E-9. Enlarged Sections of Grinding/Milling Process Area

The grinding unit is about 2.61m tall and 2.1 m in diameter. The grinder chamber is stainless steel and has a water heating/cooling jacket. The unit weighs about 7273 kg (16,000 pounds) and has a media bed weight of about 6400 kg (14,000) pounds. It has a feed port on the side, a discharge port with a valve at the bottom, and an offgas opening in the top of the unit.

E11.0 TRANSPORT AND INTERIM STORAGE

The neutralized slurry will be shipped to the AW tank farm using a specially-designed Sludge Transportation System. Modifications will be made at tank farms to enable direct transfer of the neutralized slurry from the transportation system into tank 241-AW-105 located in the 200 East Area. The offload system at tank farms is referred to as the Sludge Receiving Station.

The Sludge Transportation System consists of a trailer mounted ASME pressure vessel, designed to meet onsite shipping criteria for a Type B transportation system for highway-route controlled quantities of radioactive materials. The container is estimated to have a capacity of 7 m^3 and fit on a single-drop, flatbed trailer. The transportation system will include a pumping system capable of transferring the neutralized solution from the transport package through a transfer line into AW-105, a flexible hose for connecting the pumping system to the transfer line, and equipment for monitoring and controlling the offload process. Controls for the pumping system will be interlocked with the tank farm's Sludge Receiving Station leak detection sensors. Connections and equipment will also be provided for the TWRS supplied utilities (i.e., electrical, flush water). Container ports and closures will be sealed from the atmosphere during transport with positive closure devices that are designed to prevent unintentional opening.

The Sludge Receiving Station consists of three main elements; 1) spill retention basin, 2) male coupler for connecting to the sludge transportation system, and 3) transfer line from valve station to sludge distribution system connection. The spill retention basin is located adjacent to AW-105 and functions primarily as a leak collection system in the event that a transfer connection or line ruptures or otherwise leaks. It is assumed that any leakage will be collected in a sump and pumped back into the DST.

The male coupler contains the necessary connections to mate to the sludge transportation system and provides a terminus for the nonpermanent 1.5 inch transfer line from the tank. The transfer line provides the flowpath for the neutralized slurry to be placed in the tank. The transfer line will be aboveground and is double contained (hose-in-pipe or pipe-in-pipe) with leak detection capabilities between the inner and outer line. The leak detectors are interlocked to the pump on the shipping container to automatically stop the pump upon detection of leakage. The transfer line will have sufficient slope to prevent pooling of liquid during normal operation and concrete half-shells over the aboveground portion for shielding. Process water will be provided to flush the transport package and the receiving station pipeline after each sludge transfer. Freeze protection may also be required for winter operations.

The truck will drive onto the spill retention basin, the tractor will be uncoupled and moved away, and the trailer chocked. Operations are envisioned to include a period of time to allow the slurry

to be mixed after the trailer has been positioned on the spill retention basin. The mixer pump will be started first. While the slurry is mixing the operators will perform the connection activities. A quick-connect system is planned to minimize the time operators spend near the transportation system. The design of the connectors will accommodate the use of glovebags during the offload process.

Portable shielding, such as leaded blankets or lead bricks, will be provided for the flexible transfer hose to reduce dose rates. These shields will be placed over the flexible line before the transfer occurs. Operator stay time will be limited in this area. The transfers will be performed from a control panel on the trailer, therefore, there will be no need for the operators to remain near the flexible line for any length of time, except during the connection process.

The total volume of slurry to be sent to tank 241-AW-105 is approximately 1208 m^3. This will require 175 shipments from the treatment facility to the DST.

For this analysis it is assumed that 3 drums can be placed onto each truck shipment. It will require approximately 35 shipments to transfer the 104 drums to the CWC for storage.

E12.0 FINAL DISPOSAL

The treated sludge will be processed with TWRS waste in a high-level vitrification plant and eventually disposed of at the geologic repository. Vitrification services are currently planned to be secured from a private contractor (TWRS-P). The treated K Basin sludge will be transferred to at least two other double shell tanks prior to vitrification. One will be the TWRS feed staging tank and the other will be the vendor's staging or lag storage tank. These transfers will intimately mix the K Basin sludge with the existing tank sludge, thus masking any unique identity the treated sludge may have had.

No additional glass canisters from the high activity waste will be produced as a result of blending the treated K Basin sludge with AW-105. It has been estimated, however, that there will be an increase in the amount of glass produced from the low activity waste. This results from the dissolved sodium (5903 kg) in the treated sludge sent to AW-105 plus the sodium (13,311 kg) used to caustic leach the sludge by TWRS prior to delivery to the vitrification vendor. This quantity of sodium results in approximately 69 m^3 of LAW (see Appendix J).

The TWRS-EIS (DOE 1987) and Record of Decision delineate the selection of vitrification of high-level waste and low activity waste. At the present time, the TWRS-P contract to provide those services is not in place. The current contract with the vendor is to produce certain technical, regulatory, and business deliverables over a two-year period which will demonstrate the technical viability and economics of the privatization approach. At the end of the two-year period, the Department of Energy will review the deliverables and a path forward decision will be made either to proceed with privatization or to adopt an alternate coarse of action. No alternate strategy for treatment of tank wastes has been proposed at this time as a fall back to failure of privatization. If the decision is made, for whatever reason, not to proceed with the

TWRS-P contract for tank waste vitrification services, there is no clear end point for the basin sludge. It will remain in storage until a decision is promulgated regarding the ultimate disposition of the tank wastes.

E13.0 OPEN ISSUES

Key information needs that were identified during the course of the evaluation that could significantly impact technical and schedule viability of this alternative include the following:

- Additional studies are required to define solid/liquid separation step
- Acceptance of slurry waste by TWRS (including verification that TWRS criticality requirements can be met without co-precipitation)
- Acceptance of grouted waste by the WIPP
- Data is required to size equipment
- Data is required to determine the processing rate
- Monitoring and control strategy for uranium-in-water reactions needs to be defined
- Generally, vibratory grinders are used for the reduction of particles less than 1000 μm. If the sludge contains a substantial quantity of particles between 1000 μm and 6350 μm, longer processing times may be necessary to fracture these larger particles

E14.0 ADVANTAGES/DISADVANTAGES

The advantages of the grinding/milling process include:

- Relatively simple process with few process steps
- Equipment requirements are moderate and a very small quantity of chemicals used for this process.
- Can process silica, corrosion products, rocks from ~ 250 μm to less than 10 μm in about 2 hrs (given a homogeneous feed)
- Wide range of grinding machine sizes commercially available
- Small volume of secondary waste
- Only a minor waste stream of gasses would need to be processed from the grinding/milling operations

The disadvantages of the grinding/milling process include:

- Little or no previous experience in radioactive environment
- Generally used to process feed that is less than 1000 μm
- Product verification for TWRS waste streams requires sample and analysis of every batch.
- Vibrations may create maintenance challenges
- Large number of transfers of slurry sent to TWRS (175 shipments)

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APPENDIX F

VITRIFICATION ALTERNATIVE

APPENDIX F

VITRIFICATION PROCESS DESCRIPTION

F1.0 INTRODUCTION

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the organic ion exchange resin (OIER) beads. The OIER beads are delivered as a segregated batch for grouting in the facility with a volume increase of 3 beyond the nominal grout formulation followed by disposal at the Environmental Remediation Disposal Facility (ERDF). The OIER beads are separated to avoid contacting them with nitric acid in the dissolver. Nitrated resin if allowed to dry out could undergo an energetic reaction that could pose a safety issue.

The remaining material is delivered to the facility as two separate feed types. Feed type A consists of particles <250μm while type B consists of particles >250μm. Feed type A is delivered directly to a melter feed tank. The type B feed is fed to a dissolver. Undissolved material leaving the dissolver is removed on a 250μm screen and the remaining solution and fine solids sent to a melter feed tank. In the melter feed tank, the feed is volume reduced by boiling to remove excess water. Type B feed undergoes sugar denitration to remove excess nitrate from the feed. NO_x absorber columns treat the offgas from dissolution and sugar denitration steps to reduce emissions and recover some nitric acid for recycle to the dissolver. The feed is sampled for chemical analysis and the glass formers added based on the result of the analysis. The option is evaluated assuming a borosilicate waste glass formulation melted in a low-temperature joule-heated inconnel electrode refractory lined melter. However, an evaluation of various melter technologies would be required to select the most appropriate technology for the application. Glass is poured directly into 3m high stainless steel canisters of the type used by Defense Waste Disposal Facility (DWPF). The remote-handled glass canisters would be placed in interim storage either in modular storage units or at the Central Waste Complex (CWC) and ultimately disposed in the geologic repository.

Oversize material separated from the dissolver solution is washed with nitric acid, rinsed and then grouted into drums. It is assumed that these drums will be suitable for ERDF disposal although this assumption requires verification.

F2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Two types of constraints drive the element process selection. The first is waste acceptance, which in this alternative are the requirements that must be satisfied for

acceptance at the geologic repository. The second type is associated with the technology that is applied to satisfy the waste acceptance criteria. The requirements for CWC and repository waste acceptance are provided in section 5.0 of the main document.

Borosilicate glass is the standard high-level waste (HLW) form for the repository and the glass produced is expected to meet all waste acceptance criteria including toxicity characteristic leaching procedure (TCLP) and heat limits. The plutonium concentration limit of 2500 g/m^3 results in a small increase in glass volume over the maximum possible waste loading for high activity streams. However, while some crucible melt data exists at the high uranium content proposed for the glass resulting from high activity streams, the uranium concentration is outside the validated range of models used to predict glass properties and is outside the range of large-scale waste vitrification experience. Verification of the waste formulation would be needed. From a waste acceptance standpoint there may be a substantial effort involved in waste form qualification to get the glass accepted for disposal. In addition, there is a risk that the repository may determine that some or all of the glass produced is not HLW or spent fuel and is not suitable for repository disposal.

Interim storage of glass canisters could occur at the canister storage building, in modular storage vaults such as the NUHOMS system or at the CWC. Based on an initial evaluation, it appears unlikely that space will be available in the canister storage building. Although remote-handled material has been accepted at CWC in the past, CWC does not routinely accept remote-handled material. The best approach to interim storage at CWC has not been determined, for purposes of this study it is assumed that the canisters will be stored in NUHOMS and standalone casks

The melter feed particles larger than 250 μm undergoes dissolution. The reasons for this step include:

(1) Dissolving large particulate allows representative sampling of the feed tank for determining glass former addition and control of glass composition.
(2) the presence of up to 1/4" uranium particles would make reliable delivery of a uniform slurry feed to the melter difficult.
(3) Up to 1/4" uranium particulate would sink rapidly through the melt and end up on the floor of the melter complicating the melter behavior. Potential problems would include inclusions in the glass product, corrosion of chrome-based refractories due to highly reducing conditions, and difficulties with glass composition control resulting from major components (uranium, silicon, iron) existing in a metal pool on the melter floor.

Similarly the removal of oversize material after the dissolver allows accurate sampling of the feed tank and prevents inclusions in the melt. For particles smaller than 250 μm, it should be possible to obtain representative samples, provide a uniform feed to the melter

and melt into the glass without inclusions or settling in the melt. As a result these particles are fed without dissolution in nitric acid.
The melter is assumed to include a film cooler to keep the offgas exit clear. The film cooler introduces significant non-condensable flow to the offgas system. As a result, the melter offgas stream is not suitable for treatment in the NO_x absorber columns. For this reason, sugar denitration is performed in the feed tank and the offgas is passed through the NO_x absorber columns. With denitrated feed, the NO_x emissions from the melter are estimated to be reduced to the point that additional emission controls for the NO_x from the melter would not be required.

Multivalent metals in the glass such as iron and uranium may shift oxidation state in response to changes in melt conditions. This can result in a release of oxygen and foaming in the melter. To prevent this, additional sugar is added after sugar denitration is completed to control melter redox.

The melter glass production rate is adversely affected if excess water is present in the feed. Thus, there is a tradeoff between using a larger melter with no volume reduction in the feed tanks and performing evaporation in the feed tanks. Since the feed tanks must be heated and equipped to handle offgas from sugar denitration in any case, it was decided to provide for volume reduction in the feed tanks and use a smaller melter.

F3.0 PROCESS DESCRIPTION

In the vitrification option, the sludge is transported from the KE and KW Basins to the sludge treatment system as a slurry of 12 to 15 wt% solids in water. The treatment facility is assumed to be a new facility located on the Hanford Site. A block flow diagram of the vitrification process is shown in Figure F-1.

F3.1 FEED TYPE DISCRIMINATION IN BASIN

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate OIER beads. This results in three separate feed types being delivered to the facility: Type A (<250μm), Type B (>250μm dense particles), and organic ion exchange resins.

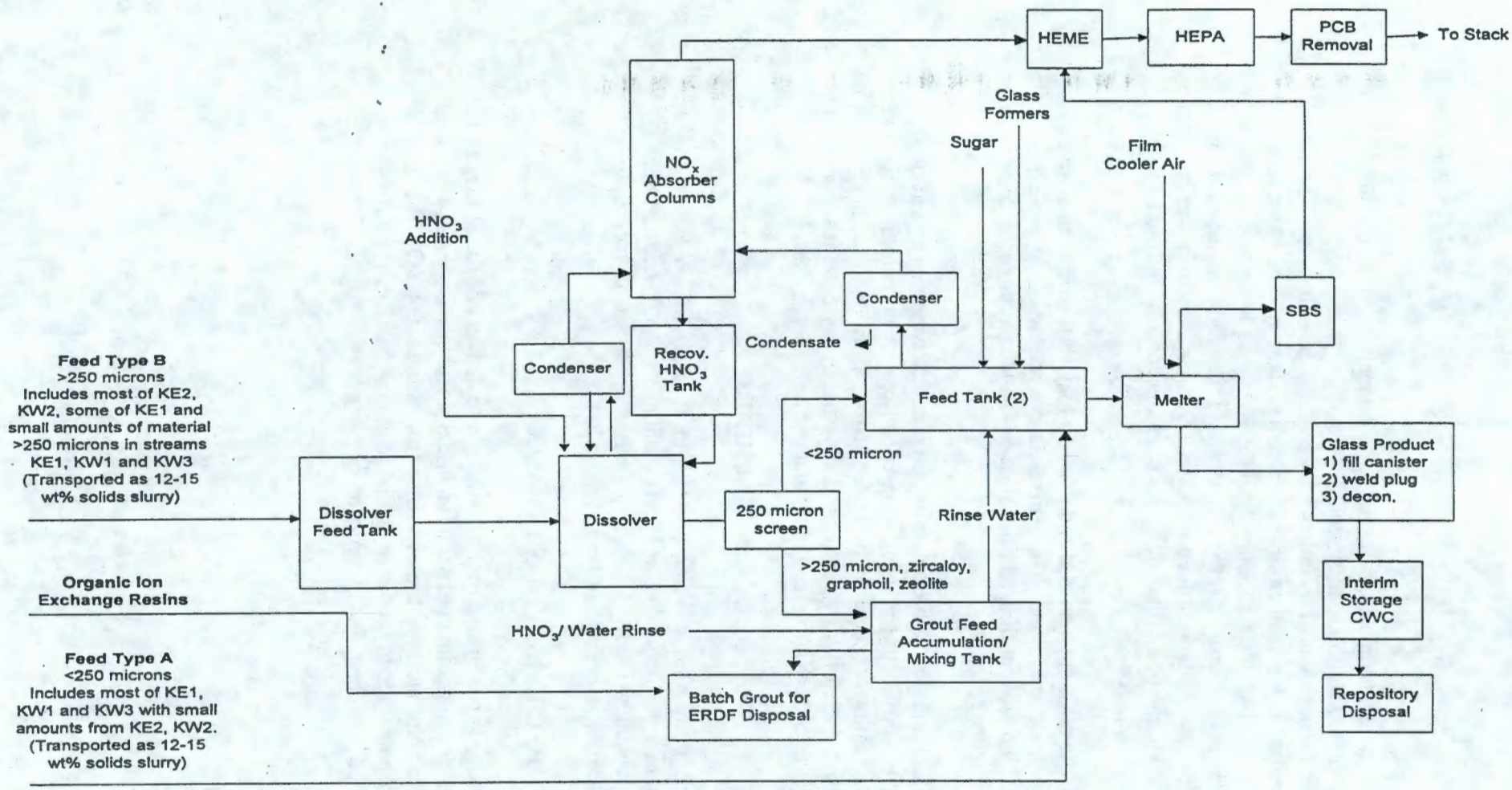

Figure F-1. Conceptual Flowchart for Vitrification Option

Feed type A will consist primarily of the majority of KE1 and nearly all of KW1 and KW3. Feed type B will consist primarily of KW2 and KE2 along with the oversize material from KE1. Very little oversize material is expected in streams KW1 and KW3 and only minor amounts of undersize material is expected to be present in KE2 and KW2.

F3.2 RECEIPT OF SLUDGE

Type A feed containing particles <250μm is delivered directly to the melter feed tank while type B feed (consisting primarily of particles >250μm) is delivered to the dissolver feed tank. Hydrogen may be generated in the feed tanks due to reaction of metallic uranium with water and also in lesser amounts due to radiolysis. A ventilation flow is maintained in the headspace of the feed tanks and the concentration of hydrogen monitored to assure flammable concentrations do not occur. It is assumed that the transfer into the plant from the transport cask will be sized to contain 160 kg dry solids and the feed tanks are sized accordingly. The dissolver feed tank would be designed to receive up to 1235 liters of slurry. The volume of the tank is selected as the slurry volume to deliver 160 kg of dry solids at 12 wt% solids. The 160 kg of dry solids is the baseline criticality limit. The feed tank offgas lines would join the main offgas line just ahead of the high-efficiency mist eliminator (HEME).

F3.3 RECEIPT OF ORGANIC ION EXCHANGE RESIN

Organic ion exchange resin (OIER) which is separated from the sludge in the basin is delivered directly to the grout-mixing tank. The resin is grouted as a separate batch of material without mixing with oversize material from the dissolver. The reason for not routing the OIER through the dissolver is to avoid contacting the resin with nitric acid which would result in nitrating of the resin. Nitrated resin, which is allowed to dry out, could undergo an energetic reaction which could pose a safety issue. In addition, not feeding the OIER to the dissolver prevents the resin from becoming loaded with Pu and Am allowing a non-transuranic (non-TRU) waste form to be produced without requiring extraordinary volume increase on grouting. It may be possible to feed the OIER to the melter. However, the impacts of the OIER on melter operation would have to be evaluated, in particular the fate of sulfur from the sulfonated groups on the cation exchange resin and the quantity of soot that may be entrained into the offgas system would need to be considered. For the current study it is assumed that the resins are not fed to the melter.

F3.4 GROUTING OF ORGANIC ION EXCHANGE RESIN

If the process stream containing the elutriated resin is directly grouted, the waste form is expected to have a TRU content of about 300 nCi/g, an organic resin content of 111 g/l and a dose rate on a 55 gallon drum of 6.9 R/hr. A nitric acid rinse prior to grouting would reduce the Cs and TRU levels although this step is not included in the current

process. Providing some dilution of the grout to reduce the concentration of organic ion exchange resin would improve the quality of the grout waste form, reduce the dose rate and potentially make the resulting package non-TRU. Assuming a volume expansion factor of 3 beyond the nominal grout formulation results in a waste form with a resin content of 37 g/l, a TRU content just under 100 nCi/g, and a surface dose of about 2.3 R/hr. It is assumed that this material is placed in drums with shielding sufficient to drop the dose to <200 mR/h and disposed at ERDF. It is estimated 154 contact handled, shielded drums would be generated for ERDF disposal.

F3.5 HNO_3 DISSOLUTION/NO_X ABSORBER

The nitric acid dissolver and associated NO_x absorber columns are the same as described for the baseline chemical dissolution process (see appendix C). Feed type B material is fed at a controlled rate to the dissolver. The sludge is pumped at a controlled rate over an eight-hour period to a dissolver which has a 6 M HNO_3 solution heated to 95°C. Additional HNO_3 at 13.2 M is added during the slurry delivery and dissolution periods to maintain the nitric acid concentration at 6 M. The uranium oxide and uranium hydride constituents in the sludge dissolve very rapidly in 6 M HNO_3. The reaction rate is controlled by continuously feeding the sludge into the dissolver at a slow enough rate (2.5 L/min or 20 kg solids/h) to maintain a stable reaction. Controlled slurry feeding of fuel pieces up to 1/4" at this rate is expected to be problematic. However, this issue is shared with the baseline process.

The dissolver temperature and vacuum, along with the NO_x concentration in the offgas, will be monitored to ensure that the reaction is under control. The concentration of xenon and ^{85}Kr in the offgas will be monitored to determine the dissolution endpoint. Internal cooling coils in the dissolver will be used to remove the heat generated by the exothermic reactions. The total time for dissolving feed B material is assumed to be 22 hours, which is the same as the baseline period for canister/wash sludge.

The primary difference in dissolver operation relative to the baseline process is in the feed to the dissolver. In the baseline, after screening and elutriation to remove resin beads, all remaining solids are fed to the dissolver. In the vitrification flowsheet, organic ion exchange resin beads are separated in a similar manner but only the oversize fraction of particles is fed to the dissolver. Sludge particles passing a 250 μm screen, primarily from KE1, KW1 and KW3 bypass the dissolver.

F3.6 SEPARATION OF UNDISSOLVED SOLIDS

After dissolution, the nitric acid solution is passed through a 250 μm screen to remove large undissolved solids. These solids would be expected to consist of zircaloy pieces, residual organic ion exchange resin, zeolite and pieces of grafoil from the gaskets used to seal KW canisters. In addition some quantity of concrete aggregate or other debris may

be present. The wind blown silica is expected to pass through the 250 μm screen. Oversize material separated from the dissolver solution would be washed by the dissolver rinse and then accumulated in a tank until sufficient material is available for a batch grouting process. An additional nitric acid and water wash would be performed on a batch prior to grouting. After washing, the liquid would be decanted through a 250 μm screen to a melter feed tank.

The separation of the undissolved solids addresses several concerns. Large particulate, such as zircaloy pieces are difficult to accurately sample in the slurry, difficult to feed uniformly in a slurry feed and may sink in the melter or result in inclusions in the product glass. While it may be feasible to feed the residual OIER leaving the dissolver to the melter, this would require that the screening following dissolution be replaced with an elutriation column which would add complexity.

F3.7 GROUTING OF UNDISSOLVED SOLIDS

Oversize material removed from the dissolver solution, after accumulation and washing, would be grouted. Grout mixing would be performed in the agitated tank used for accumulation and washing. Prior to adding dry solids, the slurry of oversize solids would be sampled and analyzed prior to grouting to determine if the grouted product is suitable for disposal at ERDF or Waste Isolation Pilot Plant (WIPP). For ERDF, the key parameter would be TRU content, for WIPP the key parameters would be fissile content, dose rate, heat content (as it relates to hydrogen generation) and polychlorinated biphenyl (PCB) content. It is assumed that this material after being slurried to 12 wt% solids and grouted would be suitable for ERDF disposal. If the material turns out to be TRU, the drums would be sent CWC for interim storage and disposed at WIPP.

The dry grout forming solids would be added to the tank and the agitator used to mix the grout. The dry solids would contain sufficient lime to neutralize the acid content of the solids which remains after the water wash. A maximum of 4 drums of grout would be produced in a batch. The discharge valve and pipe would then be rinsed with a small volume of water into an additional drum. Since the next batch of solids will initially be strongly acidic, general buildup of grout in the tank is not expected to be a problem.

It is estimated that a total of 35 drums would be produced for disposal at ERDF.

F3.8 FEED TANK SAMPLING AND ANALYSIS

After transfer of feed into the feed tank, a representative sample would be obtained. Based on analytical results the appropriate mix of glass formers for the feed batch would be determined. In addition, the target values for volume reduction, sugar addition for denitration (type B feed only) would be determined.

F3.9 FEED PREPARATION FOR FEED TYPE A

The feed tanks are assumed to be heated and equipped with a condenser. After obtaining a sample for analysis (for calculating glass formers or other process control) the solution would be volume reduced by boiling. For feed type A, the feed will not likely require significant adjustment. If transferred at 12 wt% solids, stream KE1 will, after addition of glass formers, contain 320 g glass oxides/liter. To make the feed to the melter more efficient, the volume is reduced to obtain 500 g oxide/liter and a small amount of reductant is added to assure foaming does not occur in the melter. Rheological testing would be needed to verify the pumpability of the feed at 500 g oxide per liter.

F3.10 FEED PREPARATION FOR FEED TYPE B

Feed type B requires substantially greater volume reduction due to the added volume contributed by the dissolver operations. Assuming that the target is a melter feed with 500 g glass oxides per liter[1], it is estimated that about 78% of the water initially sent to the feed tank should be evaporated.

It is estimated that about 1/3 of the nitric acid leaving the dissolver could be recovered in this condensate. The average acid content in the condensate would be 14.8 wt% with the final condensate being 37.3 wt%. The final acid concentration in the feed tank after volume reduction would be 56 wt% (calculating using only water and nitric acid masses). If desired, additional nitric acid could be recovered by additional boiling and using water (or dilute condensate from early in the volume reduction) to increase the volume prior to denitration and addition of glass forming chemicals.

The condensate from volume reduction would be routed back to the dissolver via an accumulation tank, and the desired 6 M concentration established using additional 13.2 M to achieve the 6M concentration. The melter benefits from the volume reduction in that there would be less excess water to evaporate. The requirement for reductant would be reduced (see below) and NO_x emissions would be reduced. The degree of reduction is a tradeoff between the gains in melter production rate, and recovery of nitric acid and the adverse effects on feed rheology, and increased cycle time in the feed prep tank. The capability to volume reduce the feed in the feed tank will require increases in the feed tank heating capacity and condenser chiller capacity relative to the requirements to support sugar denitration.

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[1] The optimum oxide content in the feed is a trade off between maximizing oxide loading in the slurry (i.e. minimizing water content) while maintaining acceptable rheological properties. The 500 g oxide per liter was target value for LFCM-8 which is not an acid feed.

F3.11 FEED TANK HEATING/CONDENSER SIZING

It is assumed that the heat delivered to the feed tank and the cooling capacity for the condenser is capable of producing 1 liter/min of condensate. This translates to about 38kW heat to the tank and cooling to the condenser. For type A feed, this allows volume reduction to be accomplished in about 7 hours and an overall feed preparation cycle of 26 hours which is consistent with the type A feed melter rate. For type B feed, evaporation requires about 15 hours contributing to a total feed prep cycle time of 38 hours which is longer than the melter feed time of about 32 hours. Thus, some optimization is possible by evaporating to an oxide content less than 500 g/l so that the melter is continuously evaporating.

F3.12 TYPE B FEED PREP -- DENITRATION/REDOX ADJUSTMENT

After the appropriate volume reduction, sugar would be slowly added to the solution while the solution is held near 100°C. The purpose of the sugar addition is to denitrate the solution prior to feeding the melter and to reduce NO_x emissions from the melter. Offgas from the denitration step would be routed to the dissolver offgas absorber. Bray (1963) collected data on the ability of sucrose to denitrate nitric acid solutions from Purex. The sucrose undergoes multiple hydrolysis and oxidation reactions eventually producing NO_x and CO_2. There are at least 2 hydrolysis and 3 oxidation reactions required before CO_2 is evolved. This contributes to a relatively long 6 to 10 minute induction time. The net reactions are:

$$C_{12}H_{22}O_{11} + 12\ HNO_3 \rightarrow 12\ CO + 6\ N_2O_3 + 17\ H_2O$$
$$12\ HNO_3 + 6\ NO \rightarrow 18\ NO_2 + 6\ H_2O$$
$$24\ HNO_3 + 12\ CO \rightarrow 24\ NO_2 + 12\ CO_2 + 12\ H_2O$$
$$C_{12}H_{22}O_{11} + 48\ HNO_3 \rightarrow 48\ NO_2 + 12\ CO_2 + 35\ H_2O$$

The reaction is catalyzed by uranium and iron in solution and is rapid above 85°C. The reaction is about 10% more efficient at 100°C than 85°C in terms of moles nitrate destroyed per mole sucrose added. Each mole of sucrose consumes about 20 moles of nitrate at 100°C. This consumption rate is not sensitive to acid concentration. The rate of reaction is easily controlled by controlling the sucrose addition rate. It will be desired to maintain some acid concentration in the feed to improve rheology. For purposes of this evaluation, it is assumed that the feed is 0.5 M in nitrate after the denitration step. Reduction of the nitrate to this level requires about 58 g sugar per liter of dissolver effluent (volume prior to volume reduction).

After the feed has been denitrated and cooled in the feed tank, some additional sugar will be added to offset the oxidizing effect of the remaining nitric acid and allow control the melter redox. Controlling the melter redox is important because an overly oxidized glass containing multi-valance oxides may release oxygen in response to changes in conditions

within the melt. This can result in foaming of the melt. West Valley, which uses an acid feed to the melter, uses an empirical correlation to determine the appropriate reductant (sugar) content of the feed relative to nitrate. This correlation would need to be verified for use for a different feed and melter but is useful as an approximation for pre-conceptual design. The index of feed oxidation (IFO) is adjusted to be within 2.5 and 3.4. The equation used to calculate the IFO is (Jain 1993):

$$IFO = (1-TS)(NO_3)/(TOC)$$

Where IFO= index of feed oxidation, target range 2.5 to 3.4
TS = fraction of total solids
NO_3 = wt fraction nitrate (g/g slurry)
TOC = weight fraction of organic carbon (g/g slurry)

Based on an assumed feed slurry density of 1.3 g/cm^3, neglecting solids volume, and a target IFO of 3, approximately 5.4 g sugar per/liter of dissolver effluent (volume prior to volume reduction) would need to be added prior to feeding. Combined with the sugar for denitration, the total sugar consumption is about 63.4 g sugar/liter dissolver effluent which including the effect of fine particles bypassing the dissover, results in 11,329 kg of sugar being required for processing. After the nitrate levels have been reduced and residual nitrate sugar levels adjusted, the glass forming chemicals would be added.

F3.13 OFFGAS

As in the baseline, the NO_x evolved in the dissolver passes through a condenser, oxygen enriched air (40% O_2) is added to the stream and the stream then passes through two absorber columns arranged in series which use water to absorb the NO_x. The columns are designed to remove 90% of the NO_x evolved in the dissolver. Offgas from the feed tanks during the denitration step will also be routed to the nitric acid absorber. It may be possible to coordinate the denitration step and dissolver step such that only one is producing significant offgas at any one time, thus avoiding an increase in the size of the absorber equipment compared to the baseline process. The offgas from the NO_x absorber columns would join the melter offgas, and be routed through a high-efficiency mist eliminator, leave the operating cell, be heated above its dew point, and then be routed through high-efficiency particulate air (HEPA) filters before being exhausted to the stack. Additionally, a granulated activated carbon bed may be required in the offgas system to ensure PCB concentration limits are met. At the stack, the offgas will be sampled and monitored to verify that it complies with regulatory criteria.

The melter offgas would exit the melter through a film cooler where air would be injected and then pass through a submerged bed scrubber (SBS) and then to the HEME. The film cooler would include a reamer brush to assure the offgas exit remained clear. The SBS could be replaced by an eductor venturi scrubber (EVS) which would require less space

in the cell and would have a slight draft rather than a pressure drop on the offgas line. The advantage of the SBS is that it is a passive low maintenance system which does not require a pump to operate.

The NO_x yield from the melter was assumed to be similar to that during LFCM-8 in which 65% of the nitrogen fed to the melter (primarily nitrate with some nitrite) was emitted as NO_x. For purposes of estimation, all of the feed was assumed to be 0.5 M nitrate with 500 g glass oxide per liter. Based on a feed rate of 25 liter/hr, the NO_x emission is then 0.37 kg/hr. This is less than the small-quantity emission limit of 0.91 kg/h identified in the baseline document. Processing the glass feed quantity within a single year produces 2168 kg NO_x (calculated as NO_2) which is less than the small quantity limit of 7727 kg. Thus, if the low volume/high concentration offgas streams from the dissolution and denitration steps can be routed through the absorption columns, then the melter offgas should be able to be released without treatment.

This question of whether the NO_x from the melter must be treated is important because the high non-condensable flow introduced by the film cooler would substantially reduce residence time in the absorber columns if the offgas were routed through these columns. Also, the lower concentrations of NO_x would reduce efficiency of the columns. Thus, if it were determined that the NO_x emissions from the melter required treatment, a separate treatment system may be required for this offgas stream. Most likely the additional system would be a selective catalytic reduction operation installed after HEPA filtration in a contact maintained area.

F3.14 MELTER FEED BATCH SIZE

As in the baseline, each batch of feed is initially based on 160 kg of dry solids in the feed batch. The glass oxides in a particular feed batch to the melter will vary with the waste loading in the glass. Lower waste loading streams result in larger batches of feed. The maximum feed batch size at 500 g glass oxide/liter is 977 liters for stream KW2. The smallest batch would be 398 liters for stream KW1. The time required to feed these batches at 25 liters/hr is 39 and 15.9 hours respectively. More representative times for general operation are 26 hrs for KE1 and 32 hours for KE2.

F3.15 MELTER FEEDING

The feed would be pumped through a pipe loop past the melter. A smaller diameter feed tube would deliver the feed to a single water-cooled feed nozzle penetrating into the melter plenum. Feed to the melter would be continuous. Feeding would continue for a full feed preparation tank of feed and then switches to the second tank so that feeding of the melter is nearly continuous. While feeding from one tank, the second feed tank would undergo its feed preparation cycle.

In the event that feeding cannot be maintained, the power would be reduced and the melter "idled" until feed is available. A small amount of water would be fed to the melter during idling to maintain a cold cap and reduce volatile losses from the melt.

F3.16 MELTER

For purposes of this evaluation, the melter was assumed to be an inconnel electrode, joule heated, refractory lined melter. This type of melter is common in U.S. nuclear vitrification applications. However, it may not be the best technology for this particular application. An evaluation would be needed to determine the best melter technology to use.

The melter would be operated with a cold cap of 80 to 90%. The presence of a cold cap reduces volatile losses, while less than complete coverage prevents "bridging" which can lead to melter upsets. The melter would have submerged inconnel-690 electrodes on the sides and bottom and would operate at a target temperature of 1150 C. Operating temperature would be limited to less than 1200 C to prevent damage to the inconnel-690 electrodes. If required, processing temperatures up to 1300 C could be utilized if cooling is provided to the electrodes. Electrically heated plenum heaters would facilitate initial startup and to allow startup following any upset that allows the glass to cool. The glass contact refractory for the melter would be Monofrax K-3 fused cast refractory or equivalent.

The overall size of the melter will initially be assumed to have a glass melt surface area of 0.5 m^2, glass hold up of 0.18 m^3 and have a nominal processing rate of 25 l/hr at 500 g glass oxide/liter which would result in glass pouring of 12.5 kg/hr. Each 3 m canister would require about 5.6 days to fill. At this rate, assuming feeds are not blended, it would require 72358/12.5 = 5789 hrs or 241, 24-hr days of operation to process the sludge. This scale is similar to the radioactive LFCM operated in the 324 building. For comparison the Tokai plant in Japan has an area of 0.5 m^2 and produces 9 kg/hr.

The melter would be started by melting a non-radioactive glass frit using the lid heaters. Prior to feeding the melter, a chemically similar simulant feed would be fed to the melter prior to beginning radioactive feed. As radioactive feeding is initiated, the glass in the melter will need to be disposed as radioactive waste. This will cause the first canister or two to be lower in radioactive contents and will slightly increase the volume to be disposed. All canisters are still expected to be classified as TRU.

Continuous, steady 24-hr/day operation of the melter is recommended. Shutting down for idling is possible but if processing only 8 hrs/day the required operating period will increase by more than a factor of 3 and depending on schedules, a higher capacity melter and corresponding supporting equipment would be needed. The smaller melter is

expected to be more economical for a system that will only be operated within a 13-month window.

F3.17 MELTER POURING

Pouring would occur intermittently. Glass would be poured into 3.0 m canisters through a heated overflow section which would draw glass from below the melt surface. The overflow section would be connected to a 3.0m canister by a metal bellows which would be held against the canister top by a pneumatic actuator. Pouring would be initiated by application of a vacuum to the pour spout area and pouring would be halted by releasing the vacuum. A second drain, located at the bottom of the melter would be inductively heated and would be operated when processing is complete to drain the glass from the melter. The bottom drain would have a single container (not mounted on a carousel) to receive the contents of the melter cavity. The bottom drain would only be used to remove the glass from the melter after processing or if glass needed to be removed from the melter due to a melter failure of some type.

F3.18 CONDENSATE

Condensate will be collected in the SBS and in the feed tank condensers. The amount of condensate collected will depend on the offgas flowrate, feed rate, and scrubber operating temperature. However, there will be some quantity of liquid requiring treatment or evaporation. The best approach may be to fill the cask used to deliver sludge to the facility with condensate before it returns to the basin. This water could then be discharged to the basin water treatment system. The degree of contamination in this moisture will be relatively low but will depend on the operating conditions. One option for the scrubber waste would be add it to a feed tank which would recycle volatile materials back to the melter. This recycle would increase the amount of volume reduction required during feed preparation and may not be worth the effort.

F3.19 CANISTER WELDING

Canisters would be placed on a carousel and rotated into position to receive the glass and then when full would be rotated to a cooling position and finally removed. After filling with glass and cooling in the turntable, the crane would lift a canister from the turntable and set in into the weld station. The canister neck is inspected and if required any glass or other foreign materials would be removed from neck in the region which will accommodate the plug. The plug is placed in the throat of the canister and an automated welder is placed on top of the plug. A centering device on the plug itself allows accurate positioning of the welding head. The welding head then places a fillet weld between the canister neck and the plug. The power supply for the welder is located outside the cell.

F3.20 CANISTER DECONTAMINATION

Following welding, canisters would be transferred to the decontamination cell. The decontamination cell is separated from the main processing cell to control contamination and to allow contact maintenance when all canisters of glass are removed. For purpose of the evaluation it is assumed a CeIV decontamination system is used. This decontamination method is used at West Valley. The design of the system is assumed to consist of an electrochemical cell located in a non-radioactive area that would generate the CeIV solution. The solution would be transferred to the decon tank located within the cell. After use, the spent solution would be recycled to the dissolver. The decontamination would consist of simply immersing the canister in the decontamination solution. The canister would then be removed from the decon station, swipes taken to verify decontamination, and then the canister stored until there is an air lock opening to allow the canister to be transferred out of the cell.

F3.21 CASK LOADING

A transport cask will enter the air lock on a rail transport system and the exterior air lock doors closed. The interior air lock door would then be opened and a canister retrieved from the short-term storage rack. The canister would then be loaded into the cask. The specific cask loading processes have not been developed because the specific cask system for interim storage has not been selected. It may be possible to pass canisters through a small pass through hole into a cask rather than open large air lock doors.

F3.22 SHORT TERM GLASS STORAGE

Space is included within the decontamination cell to contain up to 6 canisters (either empty awaiting transfer into the melter cell or full awaiting removal). If no interim storage location is found, it may be feasible to design interim storage capacity into the facility to accommodate the planned glass volume requiring storage. The maximum heat content in the DWPF canister is about 32 watts for KW2. This is far below the repository acceptance limit of 1500 W/canister and it is assumed that natural convection is sufficient to provide cooling to filled canisters.

F4.0 PREVIOUS DOE/FOREIGN/COMMERCIAL EXPERIENCE

The vitrification option is assumed to use a liquid-fed, low-temperature, joule-heated, refractory-l lined melter. An evaluation would be needed to determine if this technology is the best choice for vitrification of this waste stream. This section looks at previous experience with the assumed technology type for this study.

Vitrification is the baseline technology for immobilization of high-level waste and borosilicate glass is the standard HLW form for the repository. The DOE uses

vitrification to stabilize high-level waste at the DWPF and the West Valley Demonstration Project (WVDP). These melter systems are similar in that they are low-temperature inconnel electrode, refractory lined melters. The melter proposed for HWVP and currently proposed by BNFL for LLW vitrification at Hanford are also of similar design. In addition, this type of melter has been used in Germany, Japan, and China. However, the melter system described in this option is most similar to the radioactive liquid-fed ceramic melter (RLFCM) which was operated by the Pacific Northwest Laboratory in the 324 building B cell. The cell in which the RLFCM system was installed had dimensions 7.6 m x 6.7 m x 9.3 m high. Operation was performed remotely using a crane and manipulators (Holton et al. 1984). The melter was installed in 1984 and non-radioactive shakedown testing was performed in 1985[2]. The melter conducted radioactive testing related to processing of West Valley waste during Fiscal Year 1985 and processed highly radioactive cesium and strontium heat sources for the Federal Republic of Germany (FRG) during 1986[3]. The melter was joule-heated with a maximum power of 100 kW and a melt surface area of 0.53 m^2. The melter was constructed with fused chrome alumina (monofrax K-3) refractory, had air-cooled Inconel 690 plate electrodes and operated at a temperature of 1100 to 1175°C. The melter discharged via an airlift batch pour through a submerged throat and down an Inconel 690-discharge trough into canisters with maximum dimensions of 40.6 cm diameter and 2.6 m high. The melter could be started using removable silicon carbide heaters. The melter was designed to produce glass at a rate of 7 to 20 kg/h from a slurry feed of 20 to 40 liters per hour. The melter had a tank volume of approximately 190 liters and external dimensions of 1.7 m x 2.2 m x 2.1 m (WxLxH). An offgas reamer was used to keep the offgas line clear at the melter exit. Offgas was treated using an ejector venturi scrubber followed by a packed bed scrubber, a packed bed tower and HEPA filtration.

F5.0 SAMPLING REQUIREMENTS

This section describes analytical work required to satisfy process control and product verification criteria.

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[2] Run Summary of Radioactive Liquid-Fed Ceramic Melter Experiments 5 and 6. 1986. Compiled by J. H. Westsik, Jr. Unpublished PNL letter report.

[3] L.K. Holton, Jr., G. H. Bryan, R. D. Dierks, R. W. Goles, F. A. Graf, F. E. Haun, Y. B. Katayama, J. E. Surma, N. M. Thomas, G. J. Sevigny. Operating Experience in the Radioactive Liquid Fed Ceramic Melter (RLFCM). July 30, 1987. Presented at High-Level Waste Vitrification Specialists Meeting. Richland WA

F5.1 PROCESS CONTROL CRITERIA

Each batch of sludge will be sampled at the basin for accountability and process control prior to transfer to the sludge treatment facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations.

Process control data will be required to allow control of the glass oxide composition and Pu content. Constituents of concern will include fissile content along with major metals including Fe, Al, U and Si. In addition analysis for Cr, Ni and Zr to show they are less than some threshold level may be desirable. This will require a sample be taken and analyzed from a feed tank prior to adding the glass formers. In addition, the water content will need to be controlled to maintain acceptable rheology while not requiring the melter to evaporate too much water. This will be controlled by on-line instrumentation. PCB levels in the feed will not require control because the PCBs will be completely volatilized from the melter. Some sampling in the offgas to demonstrate the effectiveness of the activated carbon filter for PCB removal may be needed.

Timeframe

Process control data will be required to specify glass forming chemical additions prior to feeding the melter. Because there will be only 2 feed tanks in the process, these analyses will be required and can be performed within a 24 hour period to minimize impact on the processing rate. To provide these analyses within this required time period, a dedicated staff will be required as in the previously discussed alternative processes.

F5.2 PRODUCT VERIFICATION CRITERIA

F5.2.1 Repository – Glass Product

The glass product will require qualification as an acceptable product for final disposal at the Repository. Sufficient testing would be performed prior to processing to demonstrate that glass produced within the desired compositional envelope has suitable properties. Verification samples would then be needed to verify that the glass composition is controlled within the envelope and that glass leachability properties are within the desired range as predicted. In addition to requirements that the glass meet specific limits, there are also requirements for data reporting. Thus, there are a number of analytical requirements originating from repository waste acceptance criteria. The required data would be obtained through a combination of feed tank sampling after all glass formers have been added, and samples of the glass pour stream. The data include

- glass composition (except O) for all elementals >0.5 wt%
- radionuclides>0.05% of activity with $t_{1/2}$ > 10yrs (this should also establish dose rate<1x105 R/h and less than 1500 W/can)
- fissile content along with U and Pu isotopic ratios (this is also used to establish criticality requirement and <2500 g Pu/canister
- report content of TCLP metals
- demonstrate glass passes TCLP and PCT tests

A number of other WAC requirements should not require sampling including no free liquids, no gas generation, no explosives, no pyrophorics, no combustibles, no organics, compatibility with canister.

Timeframe

The leach procedure protocols currently in use requires up to 90 days to complete. This will be performed after the product is produced and is in temporary storage.

F5.2.2 ERDF – Grouted Drums

Solids generated as a result of processing and remaining after acid dissolution will be sampled separate from the liquid stream according to criteria established for acceptance of waste by the ERDF. Acceptance criteria for radionuclide content are based on Class C limits, ERDF performance assessment, ERDF Remedial Investigation and Feasibility Study Report, and groundwater exposure scenarios. Specific concentration limits are established for many radionuclides although most nuclides can be assumed absent.

A distribution of nuclides consistent with the irradiation history of the fuel and decay products from those parents is of concern. Only those nuclides are of concern that are insoluble in the acid digestion or sufficiently abundant that decontamination does not reduce the concentration. Most metals and organic compounds can be eliminated from concern. Other than the potential for PCB compounds, organic compounds are not present in the initial sludge and therefore can be eliminated from consideration. Zircaloy and some iron compounds are expected to be the only metals present that may not completely dissolve during the acid digestion. Grouting the solids fraction prior to transport to ERDF will immobilize and render these metals innocuous. Weekly grab samples of the separated solids fraction will be analyzed.

Timeline

The time required to perform each analysis is detailed in section (cost and schedule table). Because the samples received at the laboratory are solid, significant additional preparation is required prior to analyte quantitation. Several analyses will require 24

hours to complete even with a staff dedicated to support of this program. This additional time should not inhibit the process operations.

F6.0 APPLICATION TO K BASIN SLUDGE

Table F-1 provides the estimated data on the estimated number of 3-m DWPF canisters that would be required. The waste loading in low activity streams is limited by the maximum achievable waste loading for the glass formulation while the waste loading in the high activity streams is limited by a requirement to meet the 2500 g Pu/m^3 criteria.

Table F-1. Glass Waste Loadings and Estimated Canisters

	KW1	KW2	KW3	KE1	KE2	Total
Maximum Waste Loading (a)	0.77	0.38	0.44	0.41	0.43	
Limiting Component	Si	U	U	Fe	U	
Glass Mass at Maximum Waste Loading	2214	5039	7578	47848	9680	72359
Glass Volume at Maximum Waste Loading	0.82	1.87	2.81	17.72	3.59	26.8
Number of 3.0 m Canister at Maximum Loading	1.3	3.0	4.5	28.3	5.7	42.8
Pu, g/m^3 at maximum waste loading	387	2790	3300	456	2852	
Number of 3 m canisters, glass volume increased to comply with 2500 g Pu/m^3 limit	1.3	3.4	5.9	28.3	6.5	45.4

(a) expressed as mass fraction of glass oxides originating from sludge

F7.0 SAFETY CONSIDERATIONS

The vitrification approach has a number of safety considerations that influenced the description of the option and would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed in this facility need a significant amount of shielding (up to 75 cm of concrete for the main process vessels), hence much of the process operations would need to be performed remotely. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain ALARA. The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

F7.1 HANDLING OF PYROPHORIC PARTICLES

Large (>250 μm) metallic uranium particles are maintained under water until they are oxidized in a dissolver in a manner similar to the baseline process. Small (<250 μm) particles are maintained in a water slurry until they are fed to the melter.

F7.2 DISSOLVER CONTROL

Control of the reaction rate in the dissolver is achieved by controlling the feed rate of solids to the dissolver. The controlled feeding of up to 1/4-inch uranium particles to the dissolver is an issue that is common to all options which include the dissolver. Cooling is provided via cooling coils to control temperature. If needed, a drown tank is available to quickly add cold water to drop the temperature and reduce the acid concentration to bring a reaction under control.

F7.3 CONTROL OF SUGAR DENITRATION

The nitric acid feed undergoes sugar denitration in the feed tank. The rate of reaction is controlled by controlling the feed rate of the sugar solution.

F7.4 MIXING OF DIFFERENT FEED TYPES

Mixing of nitric acid dissolved feed with the feed that has bypassed the dissolver could result in a vigorous reaction. As a result, administrative controls will be used to prevent mixing of the different feed materials.

F7.5 ORGANIC ION EXCHANGE RESINS

Organic Ion Exchange Resins (OIER) are separated in the basin and grouted separately. Removal of the OIER eliminates concerns with the nitration of the resin structure in the dissolver. In addition, the OIER are not fed to the melter. By not feeding to the melter, sulfur emissions are reduced.

F7.6 CRITICALITY MASS LIMITS

As in other options the criticality control on the feed to the facility is a mass based limit on a batch. The same batch-size based control is used for the dissolver and feed tanks. The glass is limited to 2500 g Pu per 3-m canister to control criticality in the product container. The criticality control basis for the melter cavity itself has not been developed.

F7.7 HYDROGEN GENERATION

The rate of hydrogen generation in the dissolver feed tanks would be comparable to the baseline process. Hydrogen is also expected in the melter feed tank when processing Type A feed (<250μm) which does not go through the dissolver. A ventilation flow is maintained to dilute the hydrogen sufficiently to prevent flammable concentrations.

F7.8 MELTER PRESSURE CONTROL

A film cooler with reamer brush is included to keep the offgas exit of the melter clear. However, if the melter plenum becomes pressurized due to plugging of the line or an upset such as a steam surge, the backup vent would open and vent the gas directly to the HEME filter. This is done to prevent the migration of contamination from the melter plenum to the processing cell that would occur with a pressurized melter plenum.

F7.9 CONTROL OF NO_X OFFGAS EMISSIONS

NO_x will be generated in the dissolver and in the feed tank during the sugar denitration step. These NO_x sources will be routed to NO_x absorber columns to reduce emissions. In addition, some NO_x will be generated by feeding the nitric acid dissolved feed with residual nitric acid to the melter. Due to the high non-condensible flow created by the film cooler, this stream is not routed to the absorber columns. However, the release rate and annual NO_x release from the melter is estimated to be within small quantity emission limits for uncontrolled release.

F7.10 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. Most of the PCBs would be associated with the smaller particles in KE1 which would be fed directly to the melter. Thus, except for some fraction which would be grouted with the OIER and oversized post-dissolver material, essentially all the PCBs would be volatilized to the offgas system. No credit is taken for destruction in the melter.

F7.11 CONTROL OF RADIONUCLIDE OFFGAS EMISSIONS

Semi-volatile and particulate radionuclide concentrations in the melter offgas stream are reduced in the pocessing cell using a liquid scrubber and HEME. Radionuclides in mists leaving the dissolver or feed preparation tank are also passed through the HEME. After leaving the cell all offgas streams are passed through a HEPA filter to remove entrained particulates. Some emission of fission products in gaseous form (^{85}Kr, ^{129}I) will occur. Radionuclide emissions are not expected to exceed regulatory limits.

F7.12 RISK TO WORKERS

Risk to workers is limited due to the remote operation and maintenance approach adopted. Potential hazards workers could encounter include nitric acid, and dust from glass forming chemicals and grout formers, and electrical hazards. In addition radiation hazards will exist during the transfer of glass canisters or failed equipment out of the processing cells. These hazards will be addressed by an appropriately administered health and safety plan.

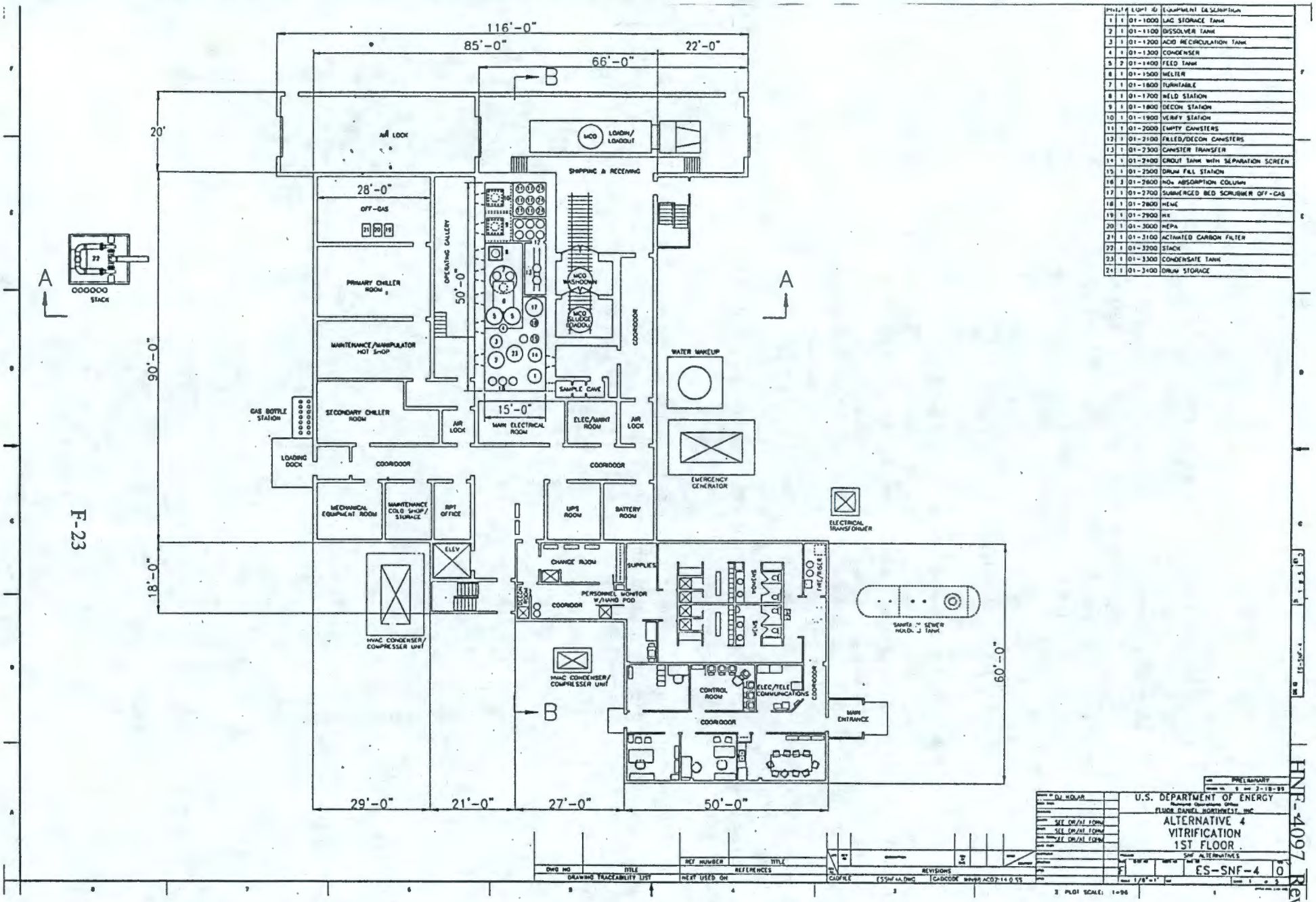
F8.0 MAINTENANCE REQUIREMENTS

It is assumed that the electrical resistance heaters will need to be remotely replaceable. Glass electrodes would not be remotely replaceable but would be conservatively designed to last the life required to complete the project. Manipulators at the wall are expected to be needed for some maintenance activities. In the event of a major melter failure, the capability to remove the melter and replace it would be included.

F9.0 FACILITY LAYOUT

A layout of major in-cell equipment was developed for the purpose of determining the approximate size of the operating cell at 15.5m x 4.6m x 8.9m. The layout is very preliminary and does not include piping, instrumentation, electrical cables etc. nor have specific maintenance operations been considered in the equipment layout. Further optimization would provide for better isolation of the sealed and decontaminated canisters from the melter cell proper prior to load out. The preliminary layout of process equipment in the processing cell is shown in Figures F-2 through F-6. Height is determined by the requirement to pick the 3 m canister out of the turntable with the crane. NO_x absorbers also use nearly the full height of the cell although these could be divided into more than two columns to reduce height if needed

Windows and a manipulator are assumed in front of the melter (access to melter top), the welding station, and the decontamination confirmation station. A window is located at the grout fill station. A crane is available in each cell for moving canisters, grout drums, and for maintenance.



1	1	01-1000	LAG STORAGE TANK
2	1	01-1100	DISSOLVER TANK
3	1	01-1200	ACID RECIRCULATION TANK
4	1	01-1300	CONDENSER
5	2	01-1400	FEED TANK
6	1	01-1500	MELTER
7	1	01-1600	TURNTABLE
8	1	01-1700	WELD STATION
9	1	01-1800	DECON STATION
10	1	01-1900	VERIFY STATION
11	1	01-2000	EMPTY CANISTERS
12	1	01-2100	FILLED/DECON CANISTERS
13	1	01-2300	CANISTER TRANSFER
14	1	01-2400	CROUT TANK WITH SEPARATION SCREEN
15	1	01-2500	DRUM FILL STATION
16	3	01-2600	NO_x ABSORPTION COLUMN
17	1	01-2700	SUBMERGED BED SCRUBBER OFF-GAS
18	1	01-2800	HEME
19	1	01-2900	HX
20	1	01-3000	HEPA
21	1	01-3100	ACTIVATED CARBON FILTER
22	1	01-3200	STACK
23	1	01-3300	CONDENSATE TANK
24	1	01-3400	DRUM STORAGE

Figure F-2. 1st Floor Plan View for Vitrification Process Facility

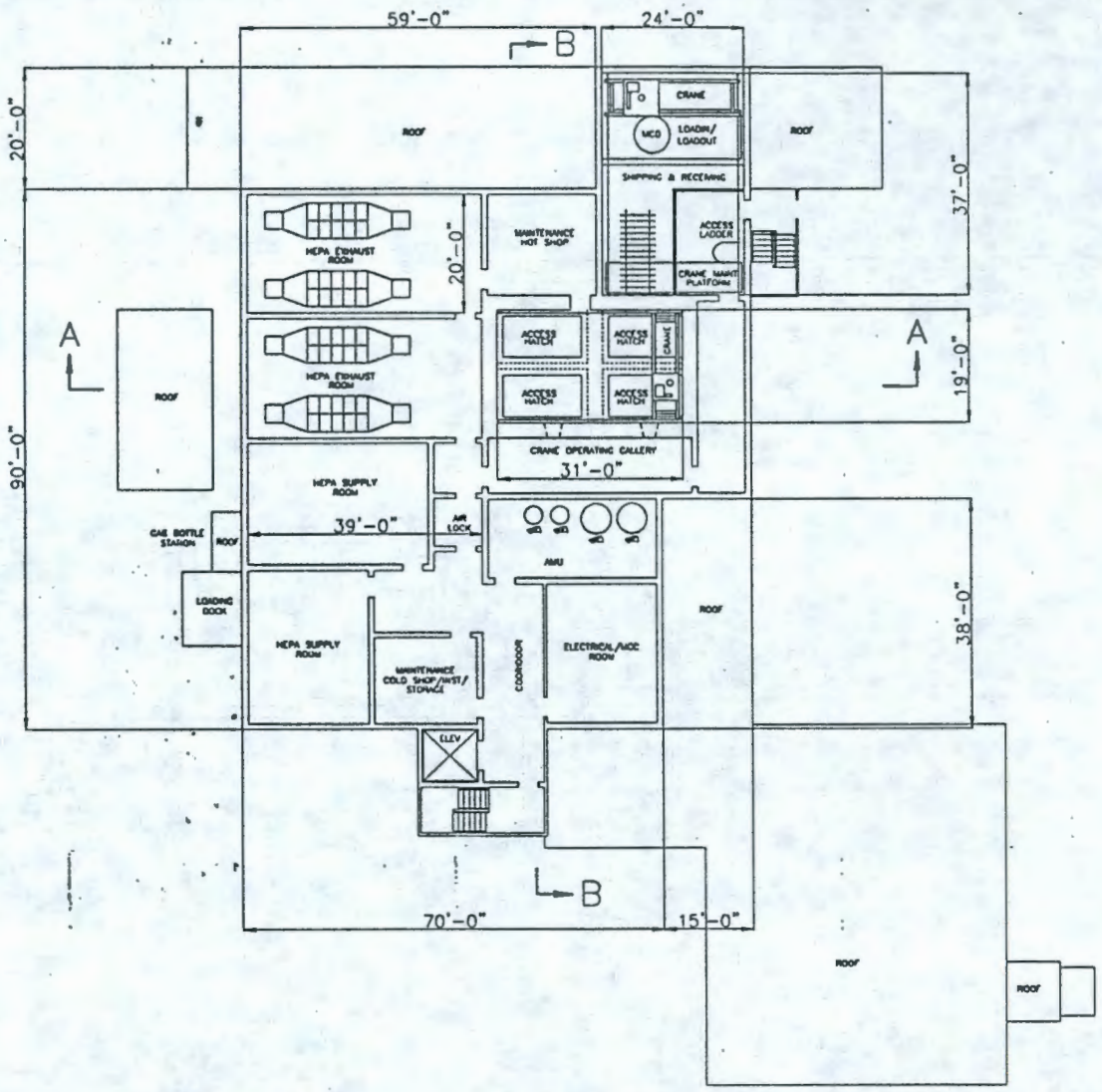
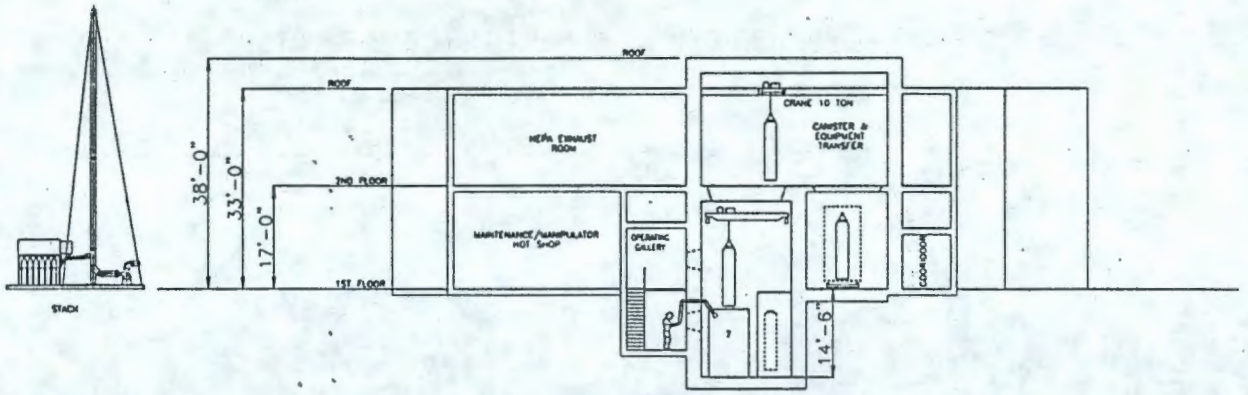
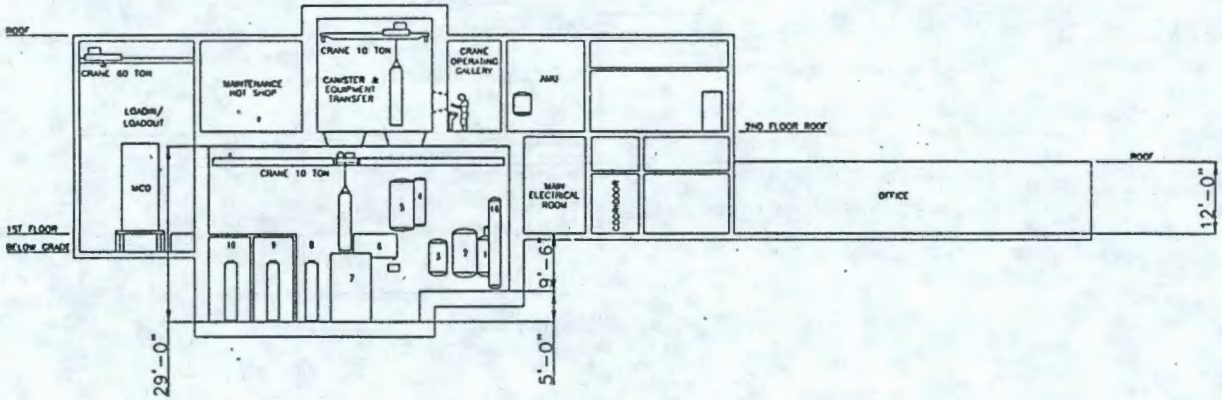


Figure F-3. 2nd Floor Plan View for Vitrification Process Facility



SECTION A



SECTION B

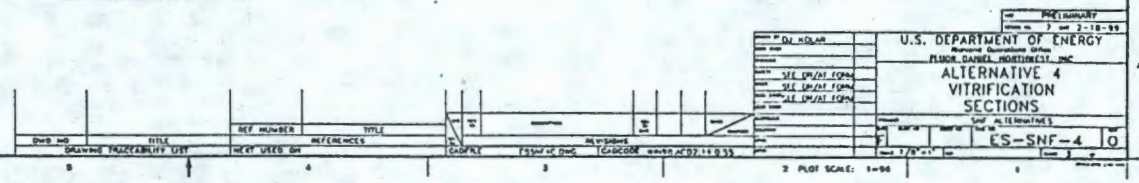
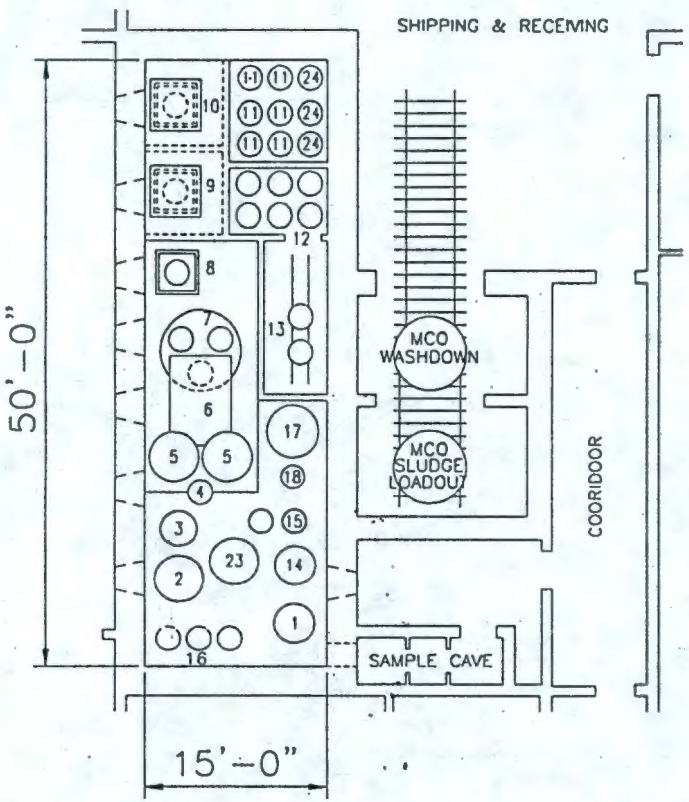
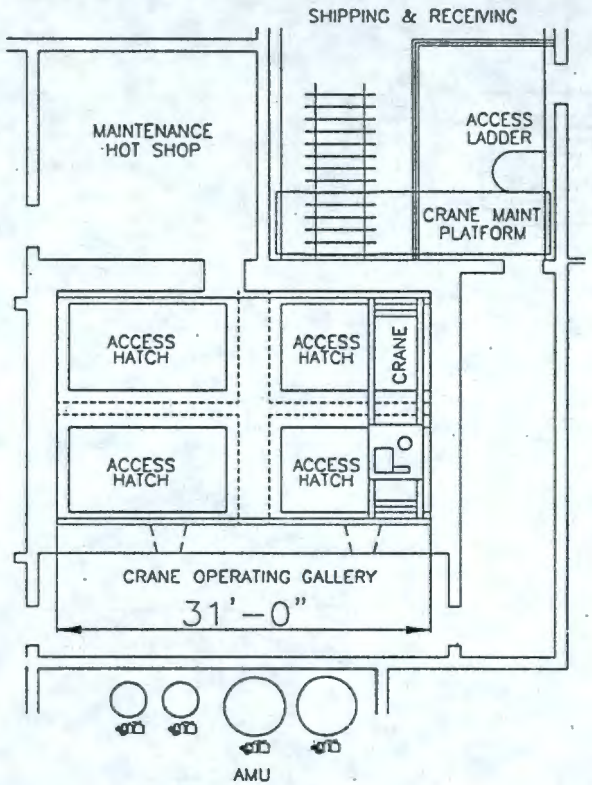


Figure F-4. Sections of Vitrification Process Facility





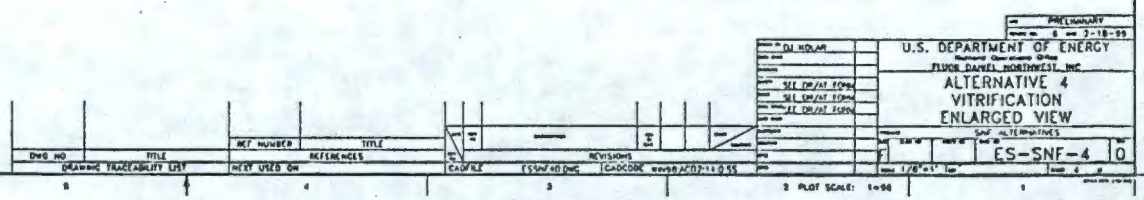


Figure F-5. Enlarged 1st and 2nd Floor Plan View of Vitrification Process Area

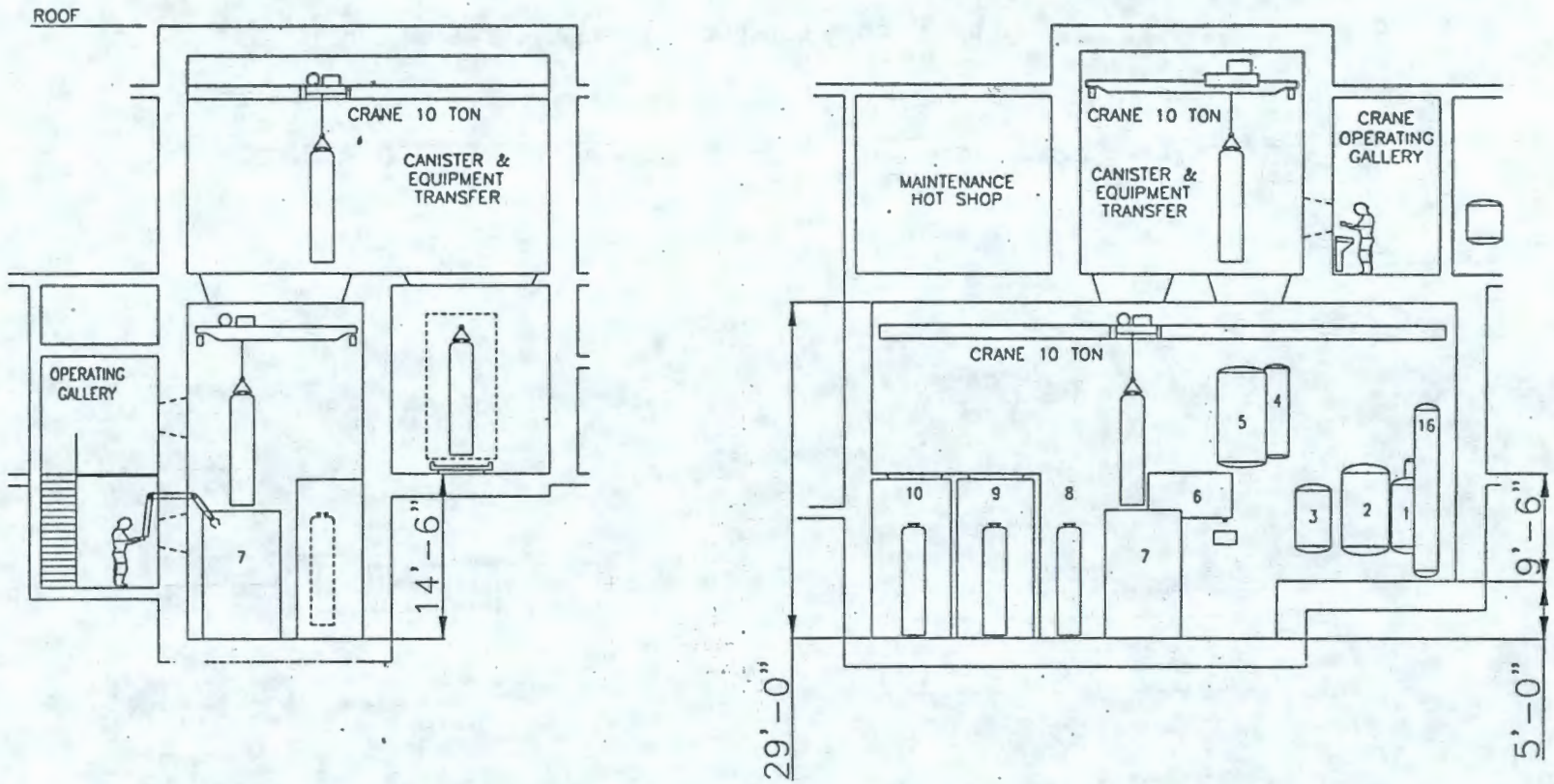


Figure F-6. Enlarged Sections of Vitrification Process Area

F10.0 TRANSPORT AND INTERIM STORAGE

This section identifies and provides a preliminary evaluation of three interim storage facilities for the vitrified glass canisters. The evaluation was conducted by reviewing reports of previous studies that have examined storage facilities for the TWRS immobilized HLW glass canisters. Options evaluated are 1) Canister Storage Building (CSB) and 2) CWC.

The interim storage facility shall support the sludge treatment schedule -- available to receive waste August 2004.

F10.1 CANISTER STORAGE BUILDING

The CSB contains three storage vaults. Each CSB vault will contain 220 storage tubes capable of holding two 4.5-m Hanford canisters or three 3-m DWPF standard canisters for a total of 440 or 660 canisters respectively per vault. Vault 1 will be used to store the SNF fuel elements and T Plant fuel elements. Current design estimates are 210 tubes will be required to store the SNF and 9 tubes will be required for storing the T Plant fuel. This would leave 1 slot available for storing sludge waste products. Therefore, Vault 1 does not provide enough slots for storage of K Basin sludge waste product and was eliminated from further consideration.

The SNF Project and project W-464 established a MOA (Hansen) that assigned CSB Vaults 2 and 3 to the IHLW Interim Storage Project. Currently, two studies are underway which address storage locations for the Phase I IHLW. One of the studies reevaluates whether the CSB remains the preferred Phase I IHLW interim storage location; the other is a proposal by the privatization contractor on construction and operation of a new facility. The data provided in these two studies will be the basis for the final decision on storage location. The decision is expected to be made in the spring. For this study it is assumed Vaults 2 and 3 are unavailable for sludge waste products.

F10.2 CENTRAL WASTE COMPLEX

Although remote-handled material has been accepted at CWC in the past, CWC does not routinely accept remote-handled material. Special arrangements would be needed for storage of the remote-handled canisters. For purposes of the current study it is assumed that if sent to CWC, the glass canisters are placed into Nuhoms cask storage systems (4 canisters per system) and standalone casks (1 canister per cask) which provide shielding to contact dose levels. The Nuhoms system and standalone casks would then be stored at CWC. Additional work is required to determine optimum storage package and location.

F11.0 FINAL DISPOSAL

Borosilicate glass is the standard HLW form for the repository and the HLW glass is expected to meet all waste acceptance criteria. As discussed previously, some volume increase may be required to meet the plutonium concentration limits of 2500 g/m^3. In addition to the 2500 g Pu/m^3 limit there is a criteria related to criticality which has not been investigated. Currently it is expected that compliance with the 2500 g Pu/m^3 limit will result in compliance with criticality requirements.

The decay heat is well below the 1500 W per canister limit and centerline temperatures should not be an issue. It is expected that the glass will pass TCLP. The glass should be able to meet waste acceptance criteria. However, the high uranium content of the high activity glasses is outside the range of large-scale waste vitrification experience. While some crucible melt data is available[4], verification of the waste formulation would be needed. From a waste acceptance standpoint there may be a substantial effort involved in waste form qualification to get the glass accepted for disposal. This issue is being investigated further.

F12.0 OPEN ISSUES AND OTHER ALTERNATIVE OPTIONS

F12.1 OPEN ISSUES

- Can the condensate be transferred to the basin water treatment system via an multicanister overpack (MCO)?

- Interface agreement with K Basin Engineering/Operations on locating elutriation columns in Basins

- The spent fuel sludge would be expected to contain noble metals. Noble metals will form a conductive sludge on the bottom of the melter and eventually lead to shorting of electrodes. This was the cause for premature failure at Pamela. Could design to accumulate or use sloped bottom with bottom drain to discharge as in Tokai plant. Need to estimate total quantity to determine best course.

- In the current canister filling assumptions, it is assumed that the 2500 g/m^3 limit on Pu for the repository satisfies criticality concerns with the glass canisters. This needs to be verified.

- Waste designation of sludge as HLW or TRU

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[4] For example see, Feng et al. Distribution and Solubility of Radionuclides in Waste Forms for Disposition of Plutonium and Spent Nuclear Fuels: Preliminary Results. *Ceramic Transactions*, American Ceramic Society, in press 1999

- Geologic repository acceptance of the glass canisters

F12.2 GLASS DISPOSAL TO WIPP OPTION

The vitrification option has been evaluated assuming that the glass canisters would be disposed of at the repository as HLW. However, the option of disposing of glass at WIPP was also considered briefly. For disposal at WIPP, the waste form qualification/disposal costs would be expected to decrease on a per canister basis. However, there are several factors that led to discarding the glass to WIPP option.

Shipment to WIPP is subject to a 325 fissile gram equivalent limit per RH canister. For the K Basin sludge material this is very restrictive. Assuming that each glass canister is filled to this maximum quantity, a total of 295 canisters would be required compared to 46 glass canisters for the repository. Assuming the melter produces a fissile-diluted glass to fill the canisters, the melter would need a melt surface area about 6.4 times larger than the melter making glass for HLW glass canisters. Alternatively, a small volume of glass could be placed into each RH canister. Due to the need to dilute or only partially fill the canisters, immobilizing the sludge in a glass form provides little reduction in the number of RH canisters sent to WIPP (295) compared to grout (364). In the grout option, the fissile content was more restrictive than gas generation in determining waste loading in the RH canister. There is no waste form leaching performance requirement for the glass disposed at WIPP. As a result, sending glass to WIPP fails to take advantage of the higher waste loading and superior waste form possible using vitrification. Neglecting for the moment the relative complexities of the preparation steps selected for large metallic uranium particles (nitric acid dissolution with sugar denitration +NO_x scrubber for dissolver offgas for glass *vs.* batch calcine in an argon-inerted cell for grout), the grout process requires less hot cell space, can be configured to require little or no canister decontamination, and produces negligible offgases or secondary wastes. These factors would be expected to more than offset a small reduction in the number of canisters to WIPP. Thus, evaluating based on current limits, it was concluded that a grout option to WIPP would evaluate more favorably than glass.

However, glass disposal to WIPP may evaluate more favorably if the fissile limit of 325 g were to be increased. There is good reason to expect that a more permissive limit is possible without compromising safety. First, shipments to the repository must also be critically safe. The same approach used for analysis of glass canisters to the repository could be used to justify a higher fissile limit (repository limit is 2500 g Pu/m^3). As a second comparison point, the batch size limit assumed for criticality control in the processing facility was 160 kg of dry solids. This limit is derived as a conservative fraction of the 612 kg of 1.25% enriched uranium to achieve criticality. Applied directly to the 160 kg, the 1.25% enrichment would suggest up to 2000 FGE may be permissible.

The fact that the glass provides a relatively homogeneous product with control of the geometric configuration would be a plus.

If relief from the 325 FGE limit is obtained, the grout waste loading could be increased but would be limited next by hydrogen generation rate. The next most limiting criteria in the glass would be the 23 Ci/l activity concentration limit. Thus, depending on where the FGE limit is set, glass may be able to produce significantly fewer RH-canisters for WIPP disposal than grout. If the glass for WIPP disposal were prepared to repository standards, the number of glass canisters would be reduced from 295 to only 46. In comparison, relaxation of the fissile limit for grout could result in a reduction from 364 to 230 canisters before the radiolytic hydrogen generation within the canisters would limit the waste loading achievable. Disposing only 46 canisters rather than 230 could cause vitrification to evaluate more favorably than grout.

F13.0 ADVANTAGES/DISADVANTAGES

Vitrification has the following advantages:

- Melter design is well-established technology. Successful demonstrations using highly radioactive waste sludges (DWPF, WVNS, PAMELA, Tokai plant, PNL, etc.)
- The waste form does not generate hydrogen and organic contaminants are removed or destroyed
- Borosilicate glass is the standard waste form for HLW and is most likely to be acceptable for repository disposal
- Good waste loadings may be achievable resulting in a low volume of waste product.
- Materials are placed in a fixed orientation and dispersibility is minimized

Vitrification has the following disadvantages:

- Rework of an off specification canister of glass is difficult
- The process uses high temperatures (1150°C) and is relatively complex
- Movement of canisters and grouted drums requires in-cell crane
- A large process cell is required and equipment may require maintenance
- Offgases are generated, requiring treatment (volatilization of radionuclides - additional complexity)
- Secondary scrubber wastes and condensate will be generated
- Decontamination step required for glass canisters
- Additional analysis is required on feed to assure proper glass formulation
- Transition from high iron to high uranium feed adds complexity to control of glass composition.

F14.0 REFERENCES

Bray L. A. 1963. Denitration of Purex Wastes with Sugar. HW-76973. Hanford Atomic Products Operation, Richland WA. First unrestricted distribution, March 1964.

Holton, L. K. Jr., D. N. Berger, W. J. Bjorkland, R. D. Dierks, June 1984. Features of a Radioactive Liquid-Fed Ceramic Melter System. PNL-SA-12282. Pacific Northwest National Laboratory.

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APPENDIX G

CALCINATION ALTERNATIVE

APPENDIX G

CALCINE PROCESS DESCRIPTION

G1.0 INTRODUCTION

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the organic ion exchange resin (OIER) beads. The OIER beads are delivered as a segregated batch for grouting in the facility with a volume increase of 3 beyond the nominal grout formulation followed by disposal at the Environmental Restoration Disposal Facility (ERDF). The OIER beads are separated to avoid contacting them with nitric acid in the dissolver. Nitrated resin if allowed to dry out could undergo an energetic reaction which could pose a safety issue.

The remaining material is delivered to the facility as two separate feed types. Feed type A consists of particles <250μm while type B consists of particles >250μm. Type A feed is delivered directly to a calciner feed tank. The type B feed is fed to a dissolver. Undissolved material leaving the dissolver is removed on a 250-micron screen and the dissolver solution sent to a calciner feed tank. The calciner is fed directly with no volume reduction or sampling. Calcine material is packaged into 1 gallon cans and placed into a 21-can shielded overpack which allows the package to be contact handled. After interim storage at Central Waste Complex (CWC), the 21-can overpack is then placed in a 10-drum overpack and placed in a TRUPACT-II for shipment to the Waste Isolation Pilot Plant (WIPP). Oversize material separated from the dissolver solution is washed with nitric acid, rinsed and then grouted into drums. It is assumed that these drums will be suitable for ERDF disposal although this assumption requires verification. The process includes NO_x absorbers which reduce emission and allow recovery of some of the nitric acid consumed in the dissolver and during feeding of dissolved type B feed to the calciner.

G2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Two types of constraints drive the element process selection. The first is waste acceptance, which in this alternative are the requirements that must be satisfied for acceptance of the waste form at the CWC for interim storage and at the WIPP for disposal. Integral with the WIPP disposal requirements are the restrictions placed on shipment of the overpack container in the TRUPACT-II cask from Hanford to WIPP.

The requirements for CWC and WIPP waste acceptance are provided in section 5.0 of the main document.

Selection of a package for calcined material is difficult. The gamma radiation from the calcine is too high to obtain a contact-handled drum using the WIPP-approved pipe

overpack containers. In addition, the fissile content in the calcine originating from high activity streams is so concentrated that compliance with the 325 FGE limit for remote handled (RH) WIPP canisters would only allow the canister to be filled about 2.7% full. Even low-activity streams could only make use of about 15% of the RH canister volume. As a result, a new package (not currently approved by WIPP) is proposed. The package consists of 21 one-gallon containers within a shielded overpack. The overpack capacity is sized to not exceed 1576 fissile gram equivalent (FGE) in the overpack for any stream. The 1576 FGE value is derived by application of the baseline mass limit criticality control to the KW2 stream. WIPP would need to approve the package and fissile limit. The safety analysis report for packaging (SARP) for the TRUPACT II would need to be revised to include the package. If WIPP does not allow movement on the fissile limit it may be necessary to repackage the calcine from high activity streams in a shielded 3-can overpack to limit the fissile content in any one overpack. The use of 1-gallon cans allows the fissile and heat content to be determined without opening the calcine container and provides flexibility for repackaging at a future date to meet whatever limit is established. The one gallon can also matches the form of other wastes currently stored at Hanford.

There are no identified issues with storage of contact-handled overpacks at CWC. Each overpack would contain 21, remote-handled one-gallon cans of calcine.

Shipment to WIPP will require that the overpack container, placed in a ten-drum overpack (TDOP) be approved by WIPP as an acceptable package configuration. There is a risk that the initial design used for the 21-can overpack will not be approved prior to using the containers to store the calcine at CWC and a risk that after filling the containers would be not be acceptable to WIPP. However, in the event that the specific package design is deemed not acceptable, the only impact is that the gallon cans would need to be overpacked into a different shielded container.

The object of the calcination process would be to drive off or destroy polychlorinated biphenyls (PCB's) to comply with the WIPP 50 ppm limit for PCBs, fully oxidize any residual metallic uranium or uranium hydride to meet WIPP and CWC restrictions on pyrophoric material, and remove nearly all of the water to assure limits associated with hydrogen generation during shipping to WIPP are met.

The process step in which larger particulate undergo dissolution in nitric acid is required because the residence time in the continuous calciner is insufficient to assure complete reaction of larger particulate. Dissolution also makes the controlled feeding of the calciner slurry easier and greatly reduces the metallic content of the feed. The option of operating the calciner in a batch mode rather than using nitric acid dissolution is discussed at the end of this appendix but was discounted due to concerns related to the large inventory of metallic uranium that might be in the calciner at any one time. The lower metallic uranium content of the calciner feed after nitric acid dissolution coupled with the small inventory in the calciner at any one time is assumed to preclude an uncontrolled exothermic reaction in the calciner so that the calciner may be fed air (rather than a controlled nitrogen-oxygen blend) without the need for an argon purge system to control a runaway exothermic reactions.

G3.0 PROCESS DESCRIPTION

In the calcination option, the sludge is transported from the KE and KW Basins to the sludge treatment system as a slurry of 12 to 15 wt% solids in water. The treatment facility is assumed to be a new facility located in the 100 Area near the K Basins. A block flow diagram of the calcination process is shown in Figure G-1. The calcining operation assumes the use of a rotary calciner. An option involving batch calcining is discussed at the end of this appendix.

G3.1 FEED TYPE DISCRIMINATION IN BASIN

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the OIER beads. This results in three separate feed types being delivered to the facility type A (<250μm), Type B (>250μm dense particles), and organic ion exchange resins.

Feed type A will consist primarily of the majority of KE1 and nearly all of KW1 and KW3. Feed type B will consist primarily of KW2 and KE2 along with the oversize material from KE1. Very little oversize material is expected in streams KW1 and KW3 and only minor amounts of undersize material is expected to be present in KE2 and KW2.

G3.2 RECEIPT OF SLUDGE

Type A feed containing particles <250μm is delivered directly to the calciner feed tank while type B feed (consisting primarily of particles >250μm) is delivered to the dissolver feed tank. Hydrogen may be generated in the feed tanks due to reaction of metallic uranium with water and also in lesser amounts due to radiolysis. A ventilation flow is maintained in the headspace of the feed tanks and the concentration of hydrogen monitored to assure flammable concentrations do not occur. It is assumed that the transfer into the plant from the transport cask will be sized to contain 160 kg dry solids and the feed tanks are sized accordingly. The dissolver feed tank would be designed to receive up to 1235 liters of slurry. The volume of the tank is selected as the slurry volume to deliver 160 kg of dry solids at 12 wt% solids. The 160 kg of dry solids is the baseline criticality limit. The feed tank offgas lines would join the main offgas line just ahead of the high-efficiency mist eliminator (HEME).

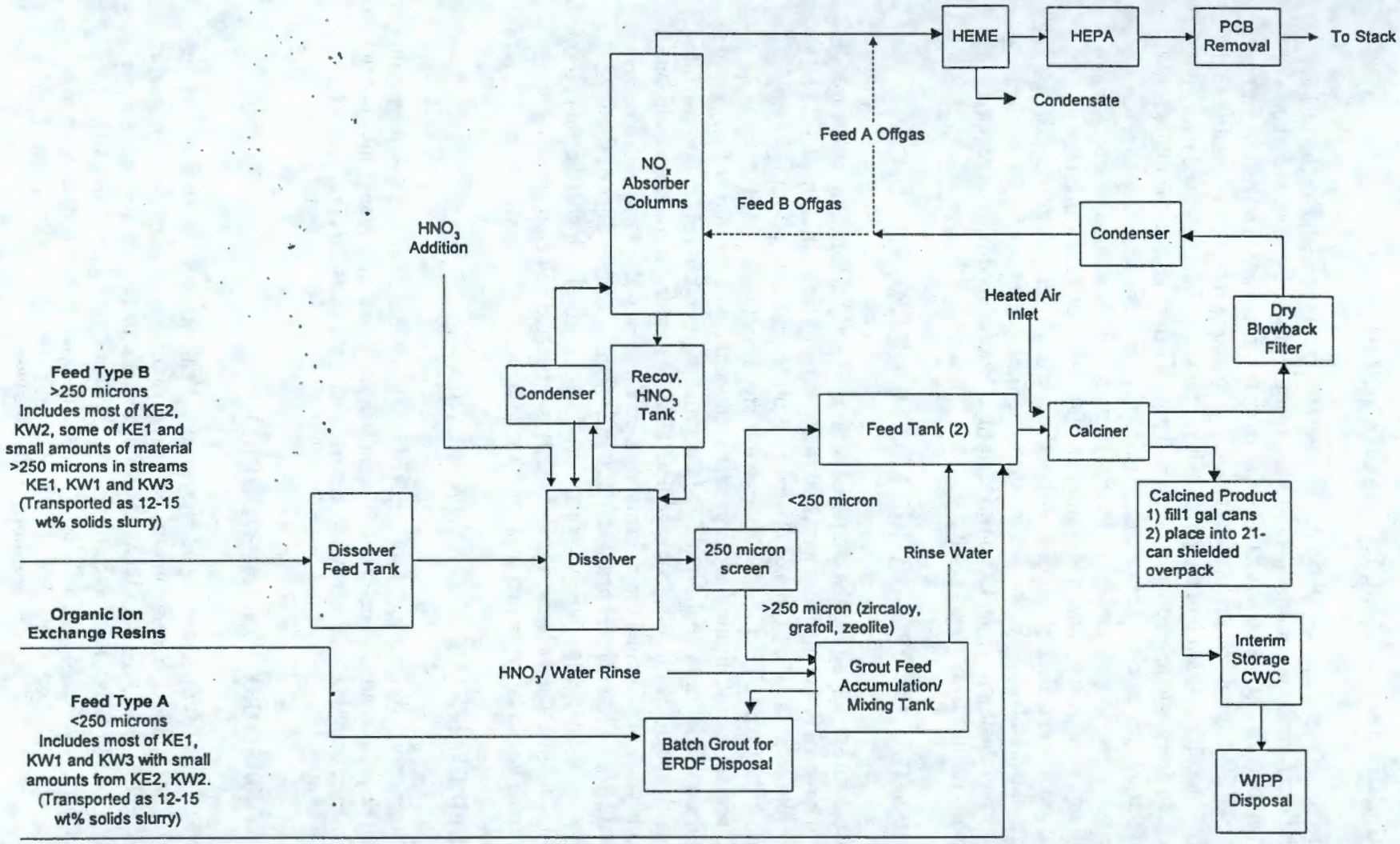


Figure G-1 Conceptual Flowchart for Calcination Option

G3.3 RECEIPT OF ORGANIC ION EXCHANGE RESIN

Organic ion exchange resin (OIER) which is separated from the sludge in the basin is delivered directly to the grout mixing tank. The resin is grouted as a separate batch of material without mixing with oversize material from the dissolver. The reason for not routing the OIER through the dissolver is to avoid contacting the resin with nitric acid which would result in nitrating of the resin. Nitrated resin which is allowed to dry out could undergo an energetic reaction which could pose a safety issue. The OIER is not processed through the calciner because there is insufficient residence time to assure complete oxidation. In addition, the resin could cause problems with the processing of sludge through the calciner and could result in sulfate-enhanced corrosion (from sulfonated groups on cation exchange resin) of the calciner tube. In addition, not feeding the OIER to the dissolver prevents the resin from becoming loaded with Pu and Am allowing a non-transuranic (non-TRU) waste form to be produced without requiring extraordinary volume increase on grouting.

G3.4 GROUTING OF ORGANIC ION EXCHANGE RESIN

If the process stream containing the elutriated resin is directly grouted, the waste form is expected to have a TRU content of about 300 nCi/g, an organic resin content of 111 g/l and a dose rate on a 55 gallon drum of 6.9 R/hr. A nitric acid rinse prior to grouting would reduce the Cs and TRU levels although this step is not included in the current process. Providing some dilution of the grout to reduce the concentration of organic ion exchange resin would improve the quality of the grout waste form, reduce the dose rate and potentially make the resulting package non-TRU. Assuming a volume expansion factor of 3 beyond the nominal grout formulation results in a waste form with a resin content of 37 g/l, a TRU content just under 100 nCi/g, and a surface dose of about 2.3 R/hr. It is assumed that this material is placed in drums with shielding sufficient to drop the dose to <200 mR/h and disposed at ERDF. It is estimated 154 contact handled, shielded drums would be generated for ERDF disposal.

G3.5 FEED TANK SAMPLING AND ANALYSIS

No sampling or analysis is assumed for the feed tanks. Instead, assay of the filled gallon cans would be performed after calcining is complete and material is placed into 1-gallon cans. If desired, complete analysis can be deferred until the material is ready to be shipped to WIPP.

G3.6 HNO_3 DISSOLUTION/NO_X ABSORBER

The nitric acid dissolver and associated NO_x absorber columns are the same as described for the baseline chemical dissolution process (see appendix C). Feed type B material is fed at a controlled rate to the dissolver. The sludge is pumped at a controlled rate over an eight-hour period to a dissolver which has a 6 M HNO_3 solution heated to 95°C. Additional HNO_3 at 13.2 M is added during the slurry delivery and dissolution periods to maintain the nitric acid concentration at 6 M. The uranium oxide and uranium hydride

constituents in the sludge dissolve very rapidly in 6 M HNO_3. The reaction rate is controlled by continuously feeding the sludge into the dissolver at a slow enough rate (2.5 L/min or 20 kg solids/h) to maintain a stable reaction. Controlled slurry feeding of fuel pieces up to 1/4" at this rate is expected to be problematic. However, this issue is shared with the baseline process.

The dissolver temperature and vacuum, along with the NO_x concentration in the offgas, will be monitored to ensure that the reaction is under control. The concentration of xenon and ^{85}Kr in the offgas will be monitored to determine the dissolution endpoint. Internal cooling coils in the dissolver will be used to remove the heat generated by the exothermic reactions. The total time for dissolving feed B material is assumed to be 22 hours, which is the same as the baseline period for canister/wash sludge

The primary difference in dissolver operation relative to the baseline process is in the feed to the dissolver. In the baseline, after screening and elutriation to remove resin beads, all remaining solids are fed to the dissolver. In the calcine flowsheet, organic ion exchange resin beads are separated in a similar manner but only the oversize fraction of particles is fed to the dissolver. Sludge particles passing a 250 μm screen, primarily from KE1, KW1 and KW3 bypass the dissolver.

G3.7 SEPARATION OF UNDISSOLVED SOLIDS

After dissolution, the nitric acid solution is passed through a 250 μm screen to remove large undissolved solids. These solids would be expected to consist of zircaloy pieces, residual organic ion exchange resin, zeolite and pieces of grafoil from the gaskets used to seal KW canisters. In addition, some quantity of concrete aggregate or other debris may be present. The wind blown silica is expected to pass through the 250 μm screen. Oversize material separated from the dissolver solution would be washed by the dissolver rinse and then accumulated in a tank until sufficient material is available for a batch grouting process. An additional nitric acid wash and water wash would be performed on a batch prior to grouting. After each wash, the liquid would be decanted through a 250 μm screen to a calciner feed tank.

The separation of the undissolved solids addresses several concerns. Separation of residual ion exchange resins is desirable due to uncertainty in the temperature and time needed to fully destroy the ion exchange resins. Surviving resin may be an issue from a hydrogen generation standpoint. In addition, the cation exchange resin beads in the mixed bed resin contains sulfonated groups which would introduce an additional uncertainty related to accelerated corrosion of the calciner tube due to formation of sulfate salts. The separation of zircaloy removes any uncertainty associated with zircaloy surviving the calcining and being considered a pyrophoric material within the calcined product. Separation of other oversize material (zeolite, graphoil, etc) will make it much easier to reliably feed a steady uniform feed to the calciner.

G3.8 GROUTING OF UNDISSOLVED SOLIDS

Oversize material removed from the dissolver solution, after accumulation and washing, would be grouted. Grout mixing would be performed in the agitated tank used for accumulation and washing. Prior to adding dry solids, the slurry of oversize solids would be sampled and analyzed prior to grouting to determine if the grouted product is suitable for disposal at ERDF or WIPP. For ERDF, the key parameter would be TRU content, for WIPP the key parameters would be fissile content, dose rate, heat content (as it relates to hydrogen generation) and PCB content. It is assumed that this material after being slurried to 12 wt% solids and grouted would be suitable for ERDF disposal. If the material turns out to be TRU the drums would be sent CWC for interim storage and disposed at WIPP.

The dry grout forming solids would be added to the tank and the agitator used to mix the grout. The dry solids would contain sufficient lime to neutralize the acid content of the solids, which remains after the water wash. A maximum of 4 drums of grout would be produced in a batch. The discharge valve and pipe would then be rinsed with a small volume of water into an additional drum. Since the next batch of solids will initially be strongly acidic, general buildup of grout in the tank is not expected to be a problem.

It is estimated that a total of 35 drums would be produced for disposal at ERDF.

G3.9 CALCINING

The continuous rotary calciner is modelled after units used in France and England to calcine an acidic waste feed prior to vitrification. The liquid feed is delivered at a controlled rate to one end of a heated metallic tube which is rotated. The water and nitric acid is driven off and the remaining solids oxidized as the material pass through the tube. The object of the calcination process is to remove nitric acid and PCBs from the product, to fully oxidize any residual metallic uranium or uranium hydride, and remove nearly all of the water to reduce or eliminate radiolytic hydrogen production.

Continuous rotary calciners are used to calcine waste prior to feeding a melter in vitrification facilities at La Hague France, and Sellafield England. The calciners used in these facilities are roughly 3 m long by 0.3 m diameter; constructed of a modified AISI 310 SS (Uranus 65) alloy, and are tilted 3 degrees. The calciners are equipped with an internal rabble bar to break material off the walls of the calciner. Residence time in the calcining zone is approximately 5 minutes. These rotary calciners normally process 50 liters/hr of acidic feed and can evaporate a maximum of 100 l/h of water[1]. The feed system on these calciners' works well for a liquid feed but would require modification for high solids slurries (Sevigny 1996). The design of the feed system would need to be reviewed to assure that it could handle the <250 micron solids without modification.

The size of the unit is assumed to be equivalent to that used at La Hauge and Sellafield. Estimates of processing times are made based on an assumed processing rate sufficient to

[1] Maximum water rate - personal communication Thierry Flament

evaporate 75 kg/hr of water in the feed. Each type A feed batch would require15.6 hours to process through the calciner. Each type B feed batch would require 28.5 hours to process. Operating 24 hours a day and 100% on-line, the total processing time would be 174 days. This translates to a required 44% on-line requirement which should be achievable.

The calciner maximum temperature is currently assumed to be 500°C. This is higher than the 400°C used at La Hague. The actual temperature selected will need to be determined based on a review of the uranium hydrate decomposition kinetics and an estimate of the hydrate-related hydrogen generation rates. Higher temperatures may be required to allow shipment to WIPP if hydrogen generation from residual hydrates is an issue. Similarly, if the H_2 generation rates are not an issue, lower temperatures may be permissible.

G3.10 OFFGAS TREATMENT / HYDROGEN CONTROL

Offgas from the calciner will be filtered through sintered metal filters with pneumatic blowback under non-condensing conditions. A capability to introduce heated air to the filter system to preheat the filters will be included. The primary purpose for this heated air capability is to prevent condensation on the filter elements during a restart leading to plugging of the filters and moisture in the calcine product. The material blown off of the filters would fall by gravity back to the calciner. In the event the calciner becomes pressurized (most likely due to clogging filters) an emergency bypass would open and the offgas would be fed directly to the condenser downstream of the filter.

A small flow of air is introduced at the entrance of the calciner. Offgas from the calciner would be monitored for hydrogen. Hydrogen may be evolved due to reaction of metallic particles with water or steam in the calciner. The airflow would be increased and the feed rate decreased if hydrogen levels approached flammable levels. Hydrogen in the calciner is not expected to be an issue because the high-uranium feed materials will have been dissolved in nitric acid (and oxidized in the process) and the type A feeds are not expected to have high metallic uranium content.

After passing through the blowback filter and condenser the routing of offgas would depend on the feed. If the feed were type A, the offgas would be routed from the condenser to a HEME and then leave the cell. If processing type B feed, the offgas from the condenser would be routed through the NO_x absorber columns before being sent to the HEME and then out of the cell. Outside the cell, the offgas would pass through a preheater, a high-efficiency particulate air (HEPA) filter and an activated carbon filter to control PCB emissions, and then a blower.

G3.11 CONTAINER FILLING BIN

The calcine discharged from the calciner will collect in the container-filling bin. The filling bin will hold about 80 liters of calcine. This will hold the approximate 160 kg solids limit used in the baseline process. This is large enough fill about 21, 1-gallon

containers. This corresponds to the number of containers in one of the proposed shielded containers, the 21-gallon overpack. Alternatively, if relief on fissile limits in a single package is not obtained this would fill seven, 3 gallon overpacks.

G3.12 FILLING OF CALCINE CANS

At the bottom of the fill bin would be star valve to control the flow of solids into the cans and a vacuum hood to control spread of contamination during filling. If solids are freely flowing, each can would be filled by a set number of rotations of the star valve. However, the ultimate control on filling each can would be provided by an operator's visual indication and manual operation. A small vacuum cleaner (shop vac type) modified to collect solids in a 1 gallon can would be used by the manipulator to clean up any spills in the filling operation. The process of filling individual cans could be automated in order to reduce the number of operations required of the manipulator.

G4.0 PREVIOUS DOE/FOREIGN/COMMERCIAL EXPERIENCE

Rotary calciners have been used at Marcoule, France on a pilot scale in a radioactive environment starting in 1978. Rotary calciners similar in scale to that proposed for use are used to treat acidic high-level waste at 50 l/hr in LaHague, France starting in 1989 and in Sellafield England starting in 1990. The LaHague calciner is capable of 70 l/hr. The calciner is equipped with graphite sealing rings that allow the calciner to be operated under a vacuum of -1 kPa (about 4" WC). These calciners operate in a continuous mode with a residence time of about 5 minutes in the calcine zone which is maintained at 400°C. The calciners are used to prepare feed for a melter.

G5.0 SAMPLING REQUIREMENTS

This section describes analytical work required to satisfy process control and product verification criteria.

G5.1 PROCESS CONTROL CRITERIA

Each batch of sludge will be sampled at the basin for accountability and process control prior to transfer to the sludge treatment facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations.

The vast majority of metallic uranium will be oxidized by nitric acid dissolution and the majority of OIER are separated and grouted separately which largely eliminates the potential for exothermic reactions occurring in the calciner. In addition, the calciner is used to evaporate the water and no sugar denitration step is performed on the feed. As a result, no process control sampling of the feed is anticipated other than what is required to assure criticality safety.

Adequate removal of moisture would be established by the temperature profile in the calciner. Similarly, adequate removal of PCBs would be assured by control of the calciner temperature profile.

PCBs are expected to be nearly completely volatilized. Some PCB sampling in the offgas may be needed to demonstrate that the activated carbon filter adequately removes PCBs from the offgas system.

Timeframe

The analyses supporting criticality safety can be completed within the 24 hours if a dedicated staff is available to proceed as soon as samples are received at the laboratory.

G5.2 PRODUCT VERIFICATION CRITERIA

Since no product will be transferred to the Tank Waste Remediation System (TWRS) from this processing alternative, the TWRS WAC and compatibility study are not required. The calcined product will, however, require qualification as an acceptable product for final disposal at the WIPP. Part of this effort would be to establish that residual waters of hydration and fragments of OIER beads (which are not successfully removed in the OIER segregation step) would not result in H_2 generation sufficient to prevent on-site shipping. Part of this effort would involve determining a bounding G-value for the calcined product which would allow shipment to WIPP to be evaluated based on measured decay heat. In addition, the lack of separated liquid, absence of flammable volatile organic carbons (VOCs) sufficient to exceed 500 ppm in the container headspace, removal of PCBs from calcine to <50 ppm, and removal of the pyrophoric characteristic should be established.

The proposed 21-can overpack container is not a WIPP approved package. The waste acceptance criteria vary with the package design. However, the key variables that will affect the acceptability can be identified.

The individual gallon cans may be characterized for fissile mass (passive active neutron interrogation) and primary radionuclides (gamma energy analysis) without opening each individual can. This passive analysis should allow compliance with the following WIPP waste acceptance limits to be established:

- fissile content
- Pu equivalent Ci content
- TRU>100 nCi/g
- Total activity <23 Ci/l (unclear if this would be applicable to shielded CH package)
- heat content, and from the G value, the expected H_2 generation

The only other characterizations that may be needed are

- Cd, Cr, Pb, Se analysis to assign EPA hazardous waste codes. WIPP accepts the hazardous waste codes so this is only a data-reporting requirement and is not

needed to determine acceptability of the package. This may be met with occasional samples at the filling station during production or if desired the samples could be taken later prior to shipment to WIPP.

- Some occasional verification sampling on parameters established during qualification may be needed, especially early in the operations.

Verification samples would be needed on relatively short turnaround in order that the process could be shut down if the product being produced is not suitable. However, the turnaround time could be longer than 24 hours. Other sampling and analysis must be completed prior to shipment to WIPP.

G6.0 APPLICATION TO K BASIN SLUDGE

Selection of Waste Package

The direct use of RH canisters was rejected for the calcine due to the very high fissile content and the relatively restrictive 325 g maximum limit. For high activity streams, this would result in canisters that were between 2.2% and 2.7% full. Even for low-activity stream KE1, the canisters would only be 15% full. If there was success in obtaining an increase in the WIPP fissile limit to the 1576 fissile gram equivalent (FGE) mass limit for the baseline process, the high activity streams could still only fill the container about 10% full to stay under the limit. Use of the higher limit would allow reasonable utilization of the RH canister (73%) for stream KE-1. However, as a result of the expected poor utilization of the container, the option of using RH-canisters was rejected. The placement in 1 gallon "paint can" type containers, allows fissile and gamma assay without opening containers and allows flexibility for future changes in overpack designs if required to obtain approval for WIPP disposal. Due to the flexibility afforded by the 1-gallon cans, the approval process for WIPP acceptance of the shielded containers can be completed long after the sludge is removed from the K basins. In addition, Hanford TRU Program Personnel have suggested that the calcine material be combined with other waste materials currently buried in caissons and processed with it.

The two key parameters for consideration with shielded containers for shipment of calcine in the TRUPACT-II will be the mass of the containers relative to allowable container weights and the fissile content of the calcine. The proposed package would not be one of the currently approved WIPP designs. However, there are several reference points that are useful:

Maximum TRUPACT-II Total Payload Weight	7265 lbs.
Maximum ten-drum overpack weight	6700 lbs
Maximum standard waste box (SWB) weight	4000 lbs
Maximum single drum weight	1000 lbs
Maximum single drum overpacked in SWB	1450 lbs

The fissile limits for approved packages are:

Maximum single drum	200 FGE
Maximum pipe component overpacked in drum	200 FGE
Maximum TDOP or SWB	325 FGE
Maximum TRUPACT-II	325 FGE
Maximum TRUPACT-II w/14 pipe components overpacked in drums	2800 FGE

Calculations were performed for each sludge composition in which the thickness of stainless steel shielding was determined to provide a package surface dose of 200 mR/hr. Calculations were performed both for a single stack of 3 cans and for a package containing three lifts of 7 cans each for a total of 21, one-gallon cans. The package weights including calcine are shown in the Table G-1.

Table G-1. Weight and Fissile Content of Filled, Shielded Calcine Containers (lbs)

	KW1	KW2	KW3	KE1	KE2
FGE in 1-gallon paint can	3.9	64.3	58.8	9.4	52.6
3, 1-Gallon Can Shielded Overpack Container					
Mass of Loaded Container	951	2357	1964	1354	1839
FGE in Loaded Container	11.7	192.9	176.4	28.2	157.8
21, 1-Gallon Can Overpack Container					
Mass of loaded container, lbs	2692	5531	4780	3555	4535
FGE in loaded package	81.9	1350.3	1234.8	197.4	1104.6

From examining the table above it appears that the 21-can overpack would be within the 1576 FGE limit determined for the baseline processing criticality control on all waste streams. Thus, if an increase in WIPP criteria could be justified, the 21 can overpack could be used for all materials. If such an increase could not be obtained, the high activity streams could be shipped in the 3 can overpack with low activity streams in the 21-can overpack. In this arrangement both of the containers would comply with the 200 g limit currently set for pipe components overpacked in drums. From a package weight standpoint all of the packages are within the allowable payload for a TDOP. The most likely configuration would be one 21-can overpack per TRUPACT-II cask.

Assumption: WIPP allows increase in the fissile limit to1576 FGE/container. All calcine is placed in gallon cans and shipped in the 21-can overpack configuration.

The estimated mass, volume and number of containers required to hold the calcine is shown in Table G-2. Included in the table is the Defense Waste Processing Facility (DWPF) 3-m canister used for vitrified HLW. It is known that the calcine would not be acceptable for repository disposal inside the 3-m DWPF canister. This container is a placeholder for a possible high-integrity container which might be placed inside a canister. However the acceptability of this approach to the repository is not currently clear.

canister. However the acceptability of this approach to the repository is not currently clear.

Table G-2. Mass, Volume and Number of Containers for Calcine Product

	Sludge Waste Stream					
	KW1	KW2	KW3	KE1	KE2	Total
Calcine Mass, kg	1707	1903	3335	19512	4116	30573
Calcine Volume, m^3	0.85	0.95	1.67	9.76	2.06	15.29
	Number of Containers					
#DWPF 3 m canisters	1.36	1.52	2.66	15.58	3.29	24.4
#1 Gallon Cans	226	251	441	2577	544	4039
# 3-can shielded overpack containers	75	84	147	859	181	1346
# 21-can shielded overpack containers	11	12	21	123	26	192

G7.0 SAFETY CONSIDERATIONS

The calcination approach has a number of safety considerations that influenced the description of the option and would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed in this facility need a significant amount of shielding (up to 75 cm of concrete for the main process vessels), hence much of the process operations would need to be performed remotely. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain as low as reasonably achievable (ALARA). The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

G7.1 HANDLING OF PYROPHORIC PARTICLES

Large (>250 μm) metallic uranium particles are maintained under water until they are oxidized in a dissolver in a manner similar to the baseline process. Small (<250 μm) particles are maintained in a water slurry until they are fed to the calciner.

G7.2 DISSOLVER CONTROL

Control of the reaction rate in the dissolver is achieved by controlling the feed rate of solids to the dissolver. The controlled feeding of up to 1/4-inch uranium particles to the dissolver is an issue that is common to all options which include the dissolver. Cooling is provided via cooling coils to control temperature. If needed, a drown tank is available to quickly add cold water to drop the temperature and reduce the acid concentration to bring a reaction under control.

G7.3 MIXING OF DIFFERENT FEED TYPES

G7.4 ORGANIC ION EXCHANGE RESINS

Organic Ion Exchange Resins (OIER) are separated in the basin and grouted separately. Removal of the OIER eliminates concerns with the nitration of the resin structure in the dissolver. In addition, the OIER are not fed to the calciner. By not feeding to the calciner, several potential problems are avoided including

- incomplete reaction in the calciner leading to gas generation in the calcine
- exothermic reactions of the resins in the calciner
- softening and sticking of the resins leading to poor flow behavior of the calcine
- potential corrosion problems in the calciner tube related to the sulfur from the sulfonated groups on the cation exchange resin

G7.5 CONTROL OXIDATION RATE/TEMPERATURE IN CALCINER

Temperature within the calciner is controlled by adjusting heating elements surrounding the calciner tube. The temperature is controlled within several independent zones. No measures are taken to try to slow the reaction of metallic uranium particles in the calciner. However, the metallic uranium content in the calciner feed is very small because the vast majority of the metallic material is processed through the dissolver. In addition, the total amount of material in the continuous calciner at any one time is small.

G7.6 CONTROLLING DISPERSION OF CALCINE

After removal from the calciner, the calcine material may be dispersible. The particles are separated from the offgas using a sintered metal blow-back type filter. The filling bin transfers solids into 1-gallon cans. The can filling operation has not been designed and would include features to limit contamination spread. However, there is a potential for the spread of contamination within the cell due to the handling of a dispersible material.

G7.7 CRITICALITY MASS LIMITS

The criticality control on the feed to the facility is a mass based limit on a batch. The same batch-size based control is used throughout the process. The can filling station and the 21-can overpack container are designed to hold approximately 1 batch of material (160 kg).

G7.8 HYDROGEN GENERATION

The rate of hydrogen generation from tanks would be comparable to the baseline process. The rate of radiolytic hydrogen generation that may occur in the calcined product has not been estimated. There may be waters of hydration remaining within the calcined product that could lead to some hydrogen generation. However, it is assumed that this rate is very small and will not interefere with the ability to ship the material to WIPP.

G7.9 CONTROL OF NO_X OFFGAS EMISSIONS

NO_x will be generated in the dissolver and in the calciner when feeding nitric acid dissolved feed. The offgas from the dissolver and the calciner will be routed to NO_x absorber columns to reduce emissions.

G7.10 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. Most of the PCBs would be associated with the smaller particles in KE1 which would be fed directly to the calciner. Thus, except for some fraction which would be grouted with the OIER and oversized post-dissolver material, essentially all the PCBs would be volatilized to the offgas system.

G7.11 CONTROL OF RADIONUCLIDE OFFGAS EMISSIONS

Particulate radionuclide concentrations in the calciner offgas stream are reduced using a dry blowback filter at the exit of the calciner. The offgas then passes through a condenser, and joins the dissolver offgas before passing through a HEME. After leaving the cell all offgas streams are passed through a HEPA filter to remove any remaining entrained particulates. Some emission of fission products in gaseous form (^{85}Kr, ^{129}I) will occur. Radionuclide emissions are not expected to exceed regulatory limits.

G7.12 RISK TO WORKERS

Risk to workers is limited due to the remote operation and maintenance approach assumed. Potential hazards workers could encounter include nitric acid, dust from grout formers, and electrical hazards. In addition radiation hazards will exist during the transfer of calcine containers and/or during movement of any failed equipment out of the cell. These hazards will be addressed by an appropriately administered health and safety plan.

G8.0 MAINTENANCE

Graphite Seals and rollers on the calciner require replacement at approximately 6-month intervals so there may need to be one scheduled shut down for calciner maintenance. The electrical heating elements would also be remotely replaceable but would probably not require replacement. To support these maintenance activities, the cell is equipped with an in-cell crane. In addition, a manipulator and window is available at the calcine can filling station. A window is placed at the grout fill station and an additional window and manipulator is located in the overpack filling area. The manipulators are used for:

- Placing 1 gallon cans under fill spout and removing when full
- Installing lids on 1-gallon cans and passing can through to overpacking station
- Operating the vacuum to clean up any spills in the filling operation
- Assisting in the replacement of calciner seals and rollers (if required)
- Assisting any maintenance on the sintered metal blowback filters (none planned)

Overpacking 1 gallon cans in the overpack
Assisting in the final D&D of the cell

The condenser, HEME and NOx columns are assumed not to require maintenance. The offgas heater, HEPA and activated carbon filter is contact maintained.

G9.0 FACILITY LAYOUT

A layout of major in-cell equipment was developed for the purpose of determining the approximate size of the operating cell. The layout is very preliminary and does not include piping, instrumentation, electrical cables etc. nor have specific maintenance operations been considered in the equipment layout. A preconceptual layout of equipment in the processing cell is shown in Figures G-2 through G-6.

G10.0 TRANSPORT AND INTERIM STORAGE

Once the shielded overpack is loaded with 21 one-gallon cans and closed up the package should be a contact-handled package. For shipment to WIPP it is intended that the shielded overpack would itself be overpacked in a TDOP and the TDOP shipped in a TRUPACT-II shipping cask. A similar arrangement could be used for shipment between the processing facility and the central waste complex. If this approach is used, the TDOP can be stored in the same manner as other contact handled waste materials until shipment to WIPP. The package arrangement would need to be approved for WIPP prior to shipment of the material to WIPP.

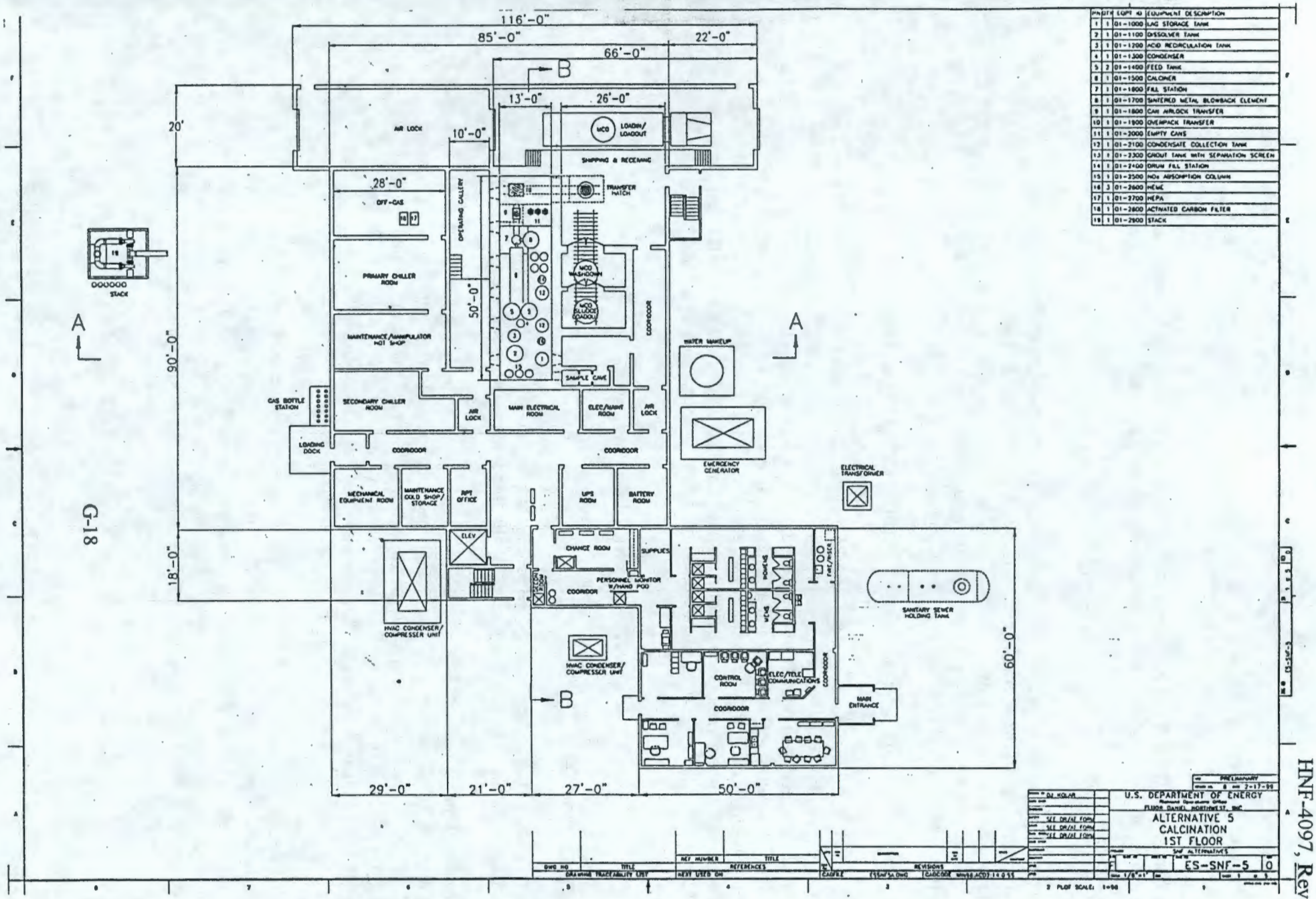
G11.0 FINAL DISPOSAL

Comparison to WIPP Waste Acceptance Criteria

The weight and fissile limits were discussed in the previous section in the process of selecting the container. A few of the potentially important waste acceptance criteria are:

Plutonium Equivalent Ci (PE-Ci)
The limit on PE-Ci per package is not clear because the package configuration is not one of the approved package configurations. However, perhaps the most applicable limits are 80 PE-Ci per drum or 1800 PE-Ci per drum when overpacked in a TDOP. The 21-can overpack is less than the drum limit in all cases. See Table G-3 below.

Total Activity (Ci/l)
The waste acceptance criteria for RH TRU limit the total activity concentration to 23 Ci/l. There is no corresponding limit for CH-TRU. It is unclear if the volume to use in this calculation should include the overpack container. High activity streams may exceed the limit if considered only on the calcine volume but would meet the limit considered on the total waste package volume. This introduces a risk that the product would not be suitable for WIPP. See Table G-3 below.



PN	QTY	EQPT ID	EQUIPMENT DESCRIPTION
1	1	01-1000	LAG STORAGE TANK
2	1	01-1100	DISSOLVER TANK
3	1	01-1200	ACID RECIRCULATION TANK
4	1	01-1300	CONDENSER
5	2	01-1400	FEED TANK
6	1	01-1500	CALCINER
7	1	01-1600	FILL STATION
8	1	01-1700	SINTERED METAL BLOWBACK ELEMENT
9	1	01-1800	CAN AIRLOCK TRANSFER
10	1	01-1900	OVERPACK TRANSFER
11	1	01-2000	EMPTY CANS
12	1	01-2100	CONDENSATE COLLECTION TANK
13	1	01-2300	GROUT TANK WITH SEPARATION SCREEN
14	1	01-2400	DRUM FILL STATION
15	1	01-2500	NOx ABSORPTION COLUMN
16	3	01-2600	HEWE
17	1	01-2700	HEPA
18	1	01-2800	ACTIVATED CARBON FILTER
19	1	01-2900	STACK

Figure G-2. 1st Floor Plan View for Calcination Process Facility

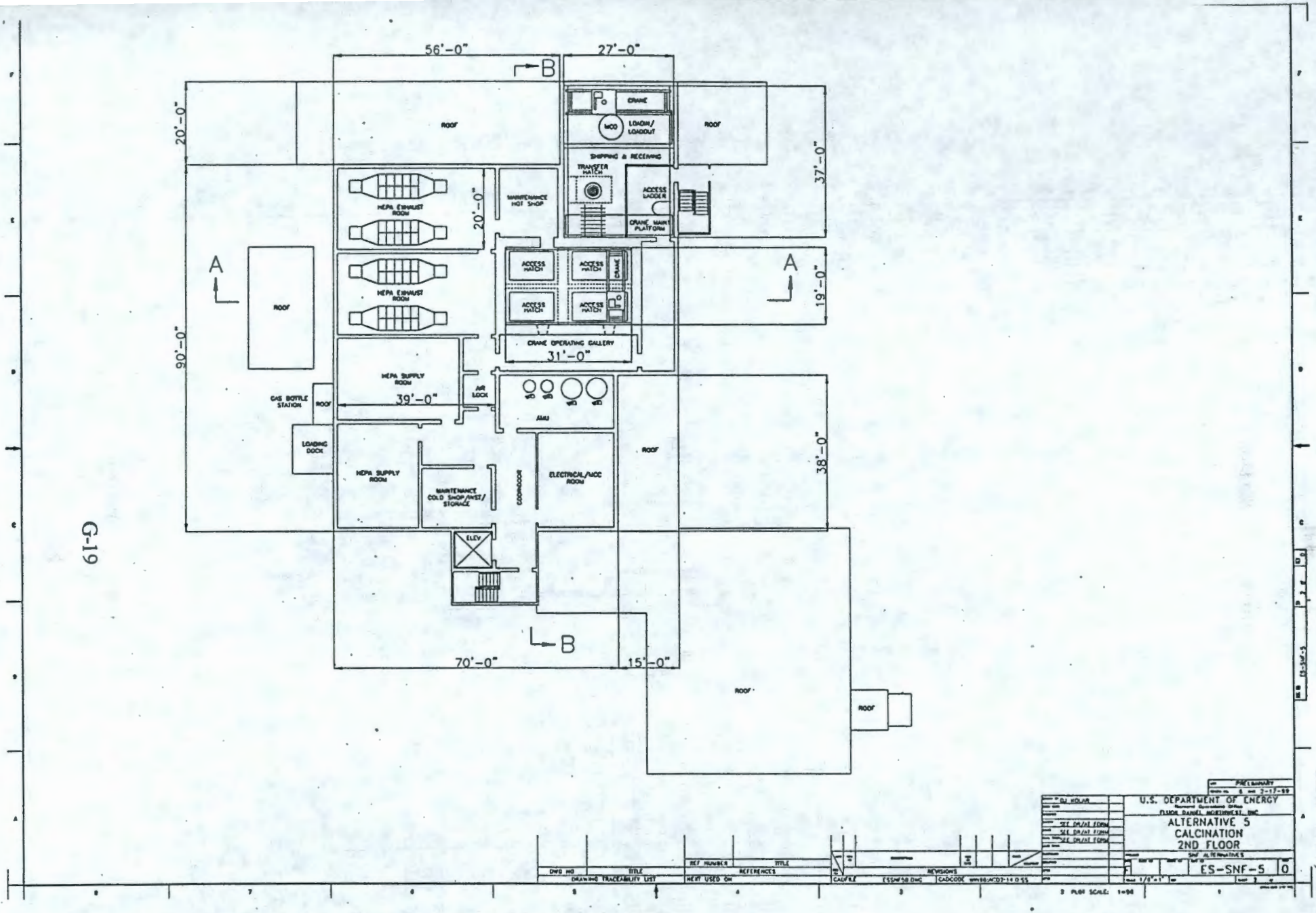
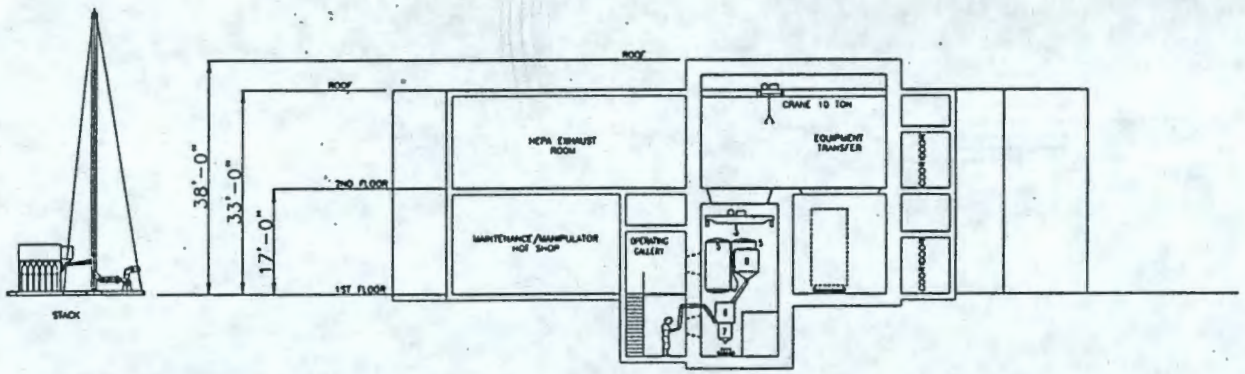
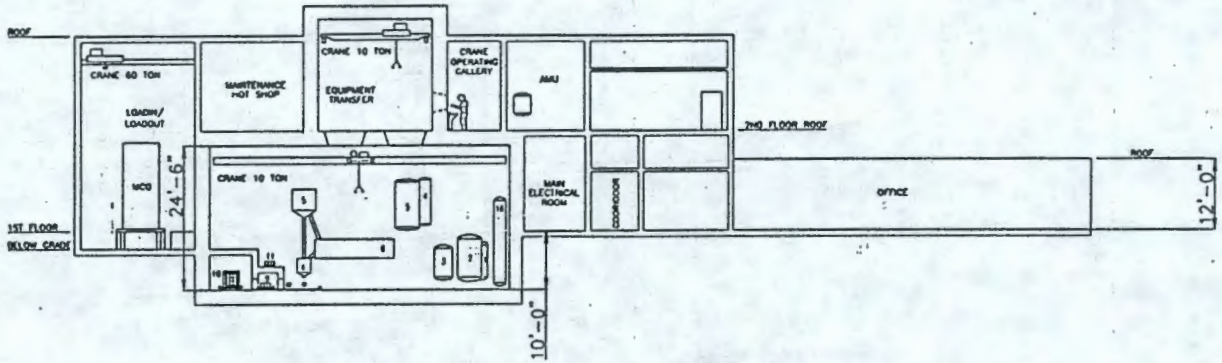


Figure G-3. 2nd Floor Plan View for Calcination Process Facility



SECTION A



SECTION B

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CALCINATION
SECTIONS
ES-SNF-5 0

Figure G-4. Sections of Calcination Process Facility

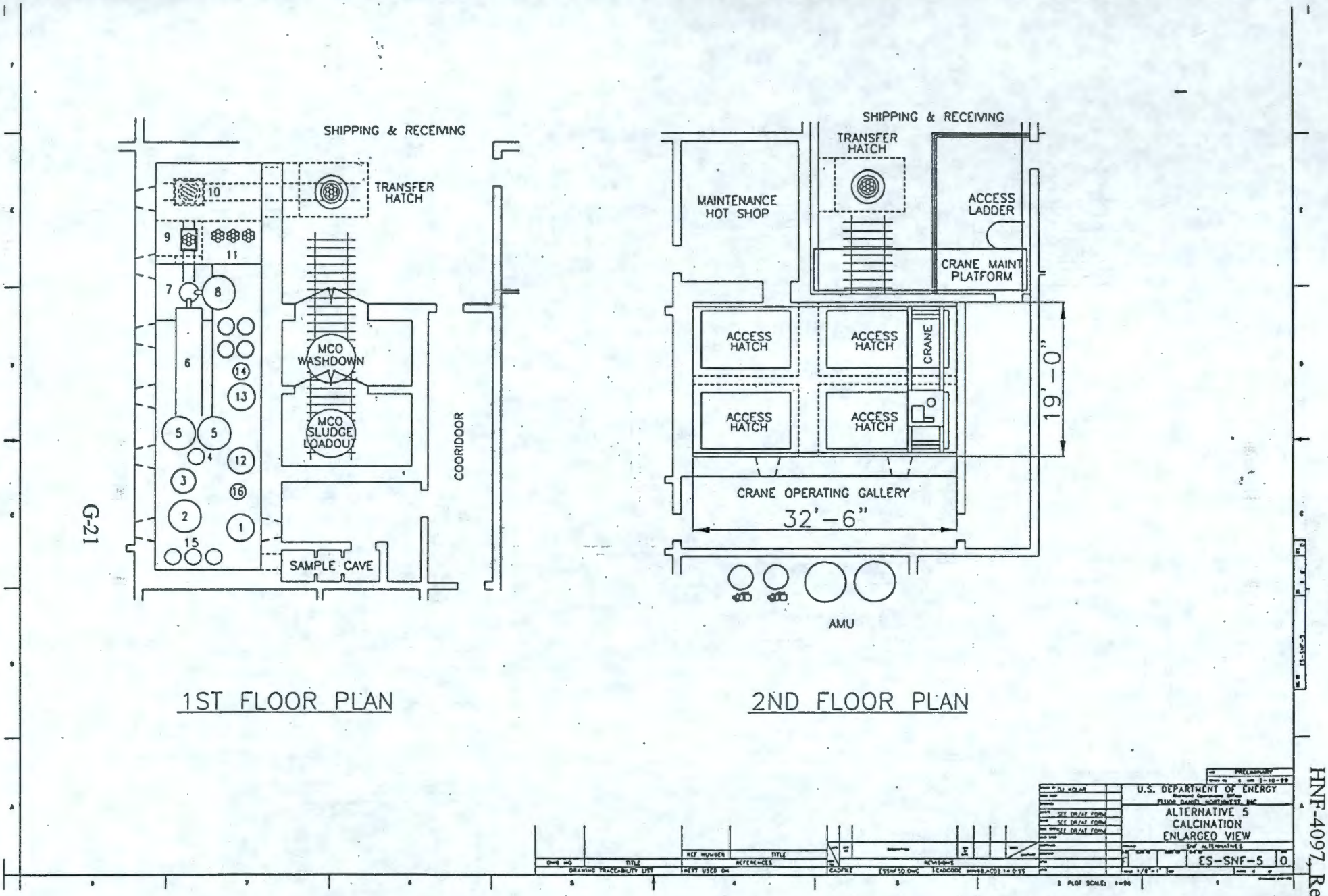
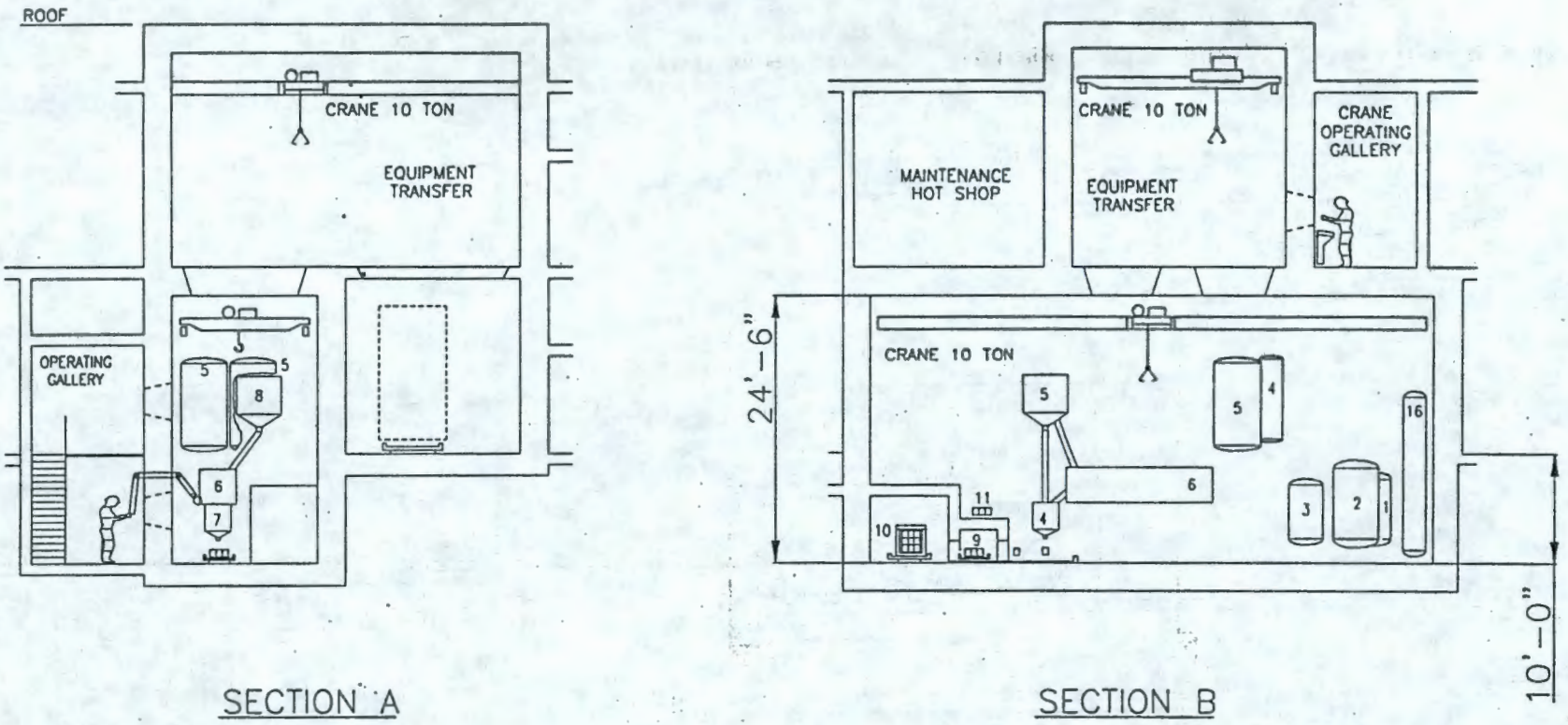


Figure G-5. Enlarged 1st and 2nd Floor Plan View of Calcination Process Area



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CALCINATION
ENLARGED VIEW
ES-SNF-5 0

Figure G-6. Enlarged Sections of Calcination Process Area

Heat/Hydrogen Generation
It is expected that relative to grout the calcine product should have greatly reduced hydrogen generation. However, the extent of hydrogen generation that may occur (due to radiolysis of water held as hydrates) has not been estimated. The acceptance limit for maximum total heat is 40 W. All packages are within the 40 W limit. Values >0.1 W/ft^3 must be reported. All heat contents exceed 0.1 W/ft^3 in the calcine and would need to be reported.

Table G-3. Comparison to Selected WIPP WAC For Calcined Product

Parameter	Limit	KW 1	KW2	KW3	KE1	KE2
PE-Ci	80 per drum or 1800 per overpacked drum	5	54	63	13	63
Total Activity(a)	23 Ci/l	4.2	45.7	54.5	7.8	42.2
Decay Heat	40 W/TRUPACT II	0.27	8.04	5.55	0.95	4.25
Decay Heat	Report >0.1 W/ft^3	0.10	2.86	1.98	0.34	1.52

(a) Values are on calcine basis. If waste package volume is considered, the package meets limit.

Other waste acceptance criteria

The calcining process should react any pyrophoric material. PCBs will be volatilized in the calciner so the calcine product so should be <50 ppm. PCBs, which are removed, will be disposed along with the scrubber waste or with the activated carbon filter bed. The 21-can overpack will be loaded in a manner designed to avoid contamination of the exterior surface. For shipment to WIPP, the 21-can overpack would then be placed in a TDOP, so contamination on the outermost container should not be an issue. The contact dose rate is limited to 200 mrem/h. The thickness of shielding on the 21-can overpack was selected to meet this criteria. If for some reason the limit is exceeded, empty gallon cans would be used as dunnage to reduce the package dose. Also, for shipments to WIPP, the 21-can overpack would be overpacked in a TDOP which would provide some reduction in dose rates.

Comparison to Repository Waste Acceptance Criteria

The calcined product is not acceptable for disposal at the repository as HLW for the following reasons:
1) The calcine is expected to be dispersible
2) The calcine is expected to fail TCLP for Cd, Cr, Pb, Se
3) The calcine will exceed the 2500 g Pu/m^3 by a factor of 2 for high activity streams
In addition, the calcine is a non-standard waste form which would require waste form qualification. However, there is a possibility that if placed inside a high integrity container the material might be acceptable as failed fuel. The initial response from HLW

program staff failed to help clarify this issue. An additional request for information is being made.

G12.0 OPEN ISSUES AND ALTERNATIVE OPTIONS

- Water Absorption after calcining

During interim storage, there may be a need for a dry storage environment. Otherwise water may diffuse into the containers (which are vented through a filter) combine with oxides to form hydrates and result in hydrogen generation. Needs to be investigated further to determine if this is an issue or not.

- Additional Information on the Batch Calcine Process

The batch calcine is an alternative that would allow the elimination of the dissolver by feeding all of the material directly to a calciner. The calciner would operate as a semi-batch drier until the full batch containing 160 kg of dry solids is loaded into the calciner. Once the full batch is loaded, the batch would be taken to temperature and held for an extended period sufficient to oxidize up to 1/4" uranium particles. The calciner would have a greater diameter than the continuous calciner and would have a cycle time on the order to about 15 hours. The batch calcine process was discarded due to the large mass of metallic uranium that would be held at high temperature at any one time. It was believed that even operating in an inerted cell, the risk presented by having such a large quantity of uranium above its air ignition temperature was unacceptable.

- *Transfer*

Transfer mechanisms need to be investigated further to determine velocity required to transfer sludge with high-density fuel pieces in operation steps prior to dissolver.

-The shipment to WIPP will require a new package to be approved

- Calcined fuel pieces from fuel wash steps are likely to be considered spent fuel and thus not acceptable for WIPP disposal. Calcine waste form may not be acceptable to the repository.

G13.0 ADVANTAGES/DISADVANTAGE

Calcination has the following advantages:

- Process is simple and technology is established for calcining other materials
- There is minimal need for up front sampling and analytical work on feed material
- One gallon cans can be rearranged in overpacks at a later date to meet FGE or other limits
- hydrogen generation rate is expected to be low
- Waste volume of product is minimized

- Product is readily reworked at a later date if needed (i.e. made into glass, grout or other)
- Overpacking cans eliminates the need for decontamination

Calcination has the following disadvantages:

- The product is dispersible
- Mechanical process will require maintenance
- Large quantity of 1 gallon cans requiring individual handling

G14.0 REFERENCES

Sevigny, G. J., 1996, Letter Report, *Evaluation of Dryer/Calciner Technologies for Testing*, PNNL-10979, Pacific Northwest National Laboratory, Richland, Washington.

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APPENDIX H

GROUTING ALTERNATIVE

APPENDIX H

GROUTING PROCESS DESCRIPTION

H1.0 INTRODUCTION

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the organic ion exchange resin (OIER) beads. The material passing the 250μm screen is combined with the OIER beads to form feed type A to the facility. The assumption on resin bead separation from the sludge in the basin is carried through to this alternative even though there is no risk of nitrating resin beads.

The oversize, heavy material from the elutriation column is feed type B to the facility. Feed type B is delivered to a screen in an argon-inerted cell where the water used for transfer is drained, the particles are calcined in batch furnaces, and the calcine pneumatically transferred to the grout feed tanks located in an adjacent nitrogen-inerted cell. The OIER beads are combined with material passing the 250μm screen in the basin and delivered as feed type A directly to a grout feed tank. The feed tanks are maintained at 100°C for 102 hours to oxidize any metallic content passing the 250-micron screen. The slurry in feed tanks is sampled, analyzed and then delivered to a mixing tank where the sludge is mixed with grout formers and pumped into remote handled (RH) canisters to meet the WIPP waste acceptance criteria. The filled RH-canisters are sent to the Central Waste Complex (CWC) for interim storage then shipped to the Waste Isolation Pilot Plant (WIPP) for final disposal.

H2.0 ANALYSIS OF CONSTRAINTS/REQUIREMENTS

Two types of constraints drive the element process selection. The first is waste acceptance, which in this alternative are the requirements that must be satisfied for acceptance of the waste form at the CWC for interim storage and at the WIPP for disposal. Integral with the WIPP disposal requirements are the restrictions placed on shipment of the RH-canister in RH-72B cask from Hanford to WIPP.

The requirements for CWC and WIPP waste acceptance are provided in section 3.1 of the main document. Although remote-handled material has been accepted at CWC in the past, CWC does not routinely accept remote-handled material. The best approach to interim storage at CWC has not been determined. However, for purposes of the study it is assumed that the RH-canisters are placed in shielded overpacks to reduce the dose rates to contact dose levels.

The most limiting WIPP waste acceptance criteria are hydrogen generation, fissile content for shipment to WIPP and the polychlorinated biphenyl (PCB) concentration in the waste form.

H2.1 WIPP HYDROGEN GENERATION LIMIT

Hydrogen may be generated either through reaction of metallic uranium with water, radiolysis of water in the grout or radiolysis of organic ion exchange resins. During an assumed 60-day shipment period, the void space in the canister must not reach 5 vol% hydrogen (flammable mixture). During shipment the RH-canister is vented to the inner containment volume (ICV) of the RH-72B cask. The restriction on hydrogen generation is sufficiently tight and the generation from metallic uranium is sufficiently high that very little metallic uranium can be tolerated. The radiolytic hydrogen source can be translated to a decay heat limit on which the process may be controlled.

H2.2 WIPP FISSILE LIMIT

The RH-72B cask used for shipment of the canister of grout to WIPP has a limit of 325 fissile gram equivalent (FGE). This limit is very restrictive relative to the fissile content of high activity sludges. It may be possible by modification of the safety analysis report (SAR) to increase this limit.

H2.3 PCB LIMIT

The final waste form should not be >50 ppm for acceptance at WIPP.

H2.4 RESTRICTION ON SPENT FUEL

WIPP does not accept spent fuel. Some fractions of the sludge, especially fuel pieces that break off during cleaning may be viewed as being spent fuel and thus the grout derived from this material would be unsuitable for disposal at WIPP. If the WIPP decision is known at the time the material is processed, the calcine from the fuel pieces could easily be containerized and stored without grouting.

These WIPP waste acceptance limits relative to the grouted waste are discussed in detail in Section H11.0.

The current process calcines oversize material prior to grouting and stirs small particulate at elevated temperature to fully react. These steps are performed to (1) eliminate pyrophoric content for WIPP acceptance, (2) reduce hydrogen generation for on site shipping, (3) prevent grout plastic volume expansion within the canister, (3) allow accurate sampling of a feed tank.

There may be some question whether the size segregation and high temperature agitation are needed for low-activity sludges. The amount of metallic material that can be

tolerated without significantly affecting the waste loading is discussed in Section H6.0. Based on the limited amount of metallic uranium that can be tolerated, it is assumed for this evaluation that low-activity steams (KE1, KW1) will need to undergo size segregation with heated stirring of fines and calcination of large particles. It is possible that further analysis may determine that this is not required, if the metallic content is less than currently estimated.

The maximum waste loading for the grout was assumed to be a volume increase factor of 1.4 applied to the volume of a 1:1 slurry (by volume) of settled sludge and water.

H3.0 PROCESS DESCRIPTION

In the grouting option, the sludge is transported from the KE and KW Basins to the sludge treatment system as a slurry of 12 to 15 wt% solids in water. The treatment facility is assumed to be a new facility located in the 100 Area near the K Basins. A block flow diagram of the grouting process is shown in Figure H-1.

H3.1 FEED TYPE DISCRIMINATION IN BASIN

Segregation of the sludge is performed in the basin prior to delivery of the sludge to the treatment facility. This segregation consists of an initial screening to separate particles >250μm followed by an elutriation of the oversize particles to separate the OIER beads. After segregation, the OIER beads are recombined with the <250 μm fraction. This results in two separate feed types being delivered to the facility Type A (<250μm) along with OIER and Type B (>250μm dense particles).

Feed type A will consist primarily of the majority of KE1 and nearly all of KW1 and KW3. Feed type B will consist primarily of KW2 and KE2 along with the oversize material from KE1. Very little oversize material is expected in streams KW1 and KW3 and only minor amounts of undersize material is expected to be present in KE2 and KW2.

H3.2 RECEIPT OF SLUDGE

Type A feed containing particles <250μm and the OIER are delivered directly to the grout feed tank (located in a nitrogen-inerted cell) while type B feed (consisting primarily of dense particles >250μm) is delivered to a 250 μm screen located in an argon-inerted cell. Any undersize material passing the screen is transferred with the liquid to a feed tank located in an adjacent nitrogen-inerted cell. After draining the water, oversize material is loaded into calcining trays within the argon-inerted cell. There are several reasons for not transferring the >250μm particles directly to a grout feed tank, including (1) to prevent settling and accumulation of pyrophoric material at the bottom of canisters which may not be acceptable to WIPP, and (2) to prevent additional hydrogen generation during shipment to interim storage and/or WIPP and (3) to allow a representative sample to be obtained from the batch such that WIPP acceptance limits can be met.

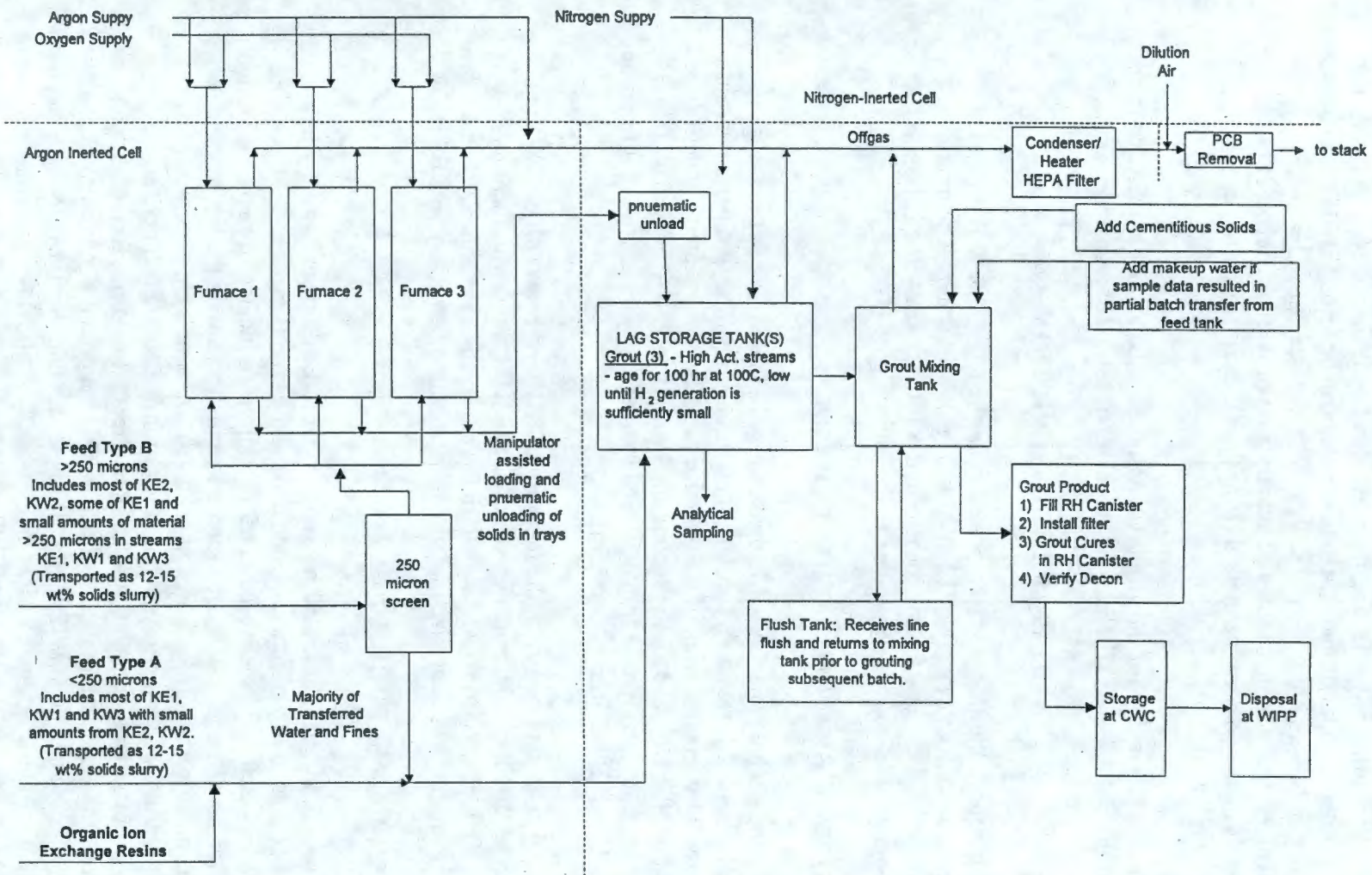

Figure H-1. Conceptual Flowchart for Grouting with Batch Calcine of Oversize Material

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Hydrogen may be generated in the feed tanks due to reaction of metallic uranium with water and also in lesser amounts due to radiolysis. A ventilation flow is maintained in the headspace of the feed tanks and the concentration of hydrogen monitored to assure flammable concentrations do not occur. It is assumed that the transfer into the plant from the transport cask will be sized to contain 160 kg dry solids and the feed tanks are sized accordingly. The feed tanks are designed to receive up to 1235 liters of slurry. The volume of the feed tanks is selected as the slurry volume to deliver 160 kg of dry solids at 12 wt% solids. The 160 kg of dry solids is the baseline criticality limit. The feed tank offgas lines would join the main offgas line just ahead of the high-efficiency mist eliminator (HEME).

H3.2.1 Expected quantity of oversize metallic uranium

To evaluate the approach, the split in metallic uranium between <250 and >250 μm is needed along with the amount of other sludge solids that might be separated along with the 250 μm metal. Based on the sources and known properties of the various sludge streams, estimates were made of the amount of uranium metal particles and other sludge solids in each stream that would be greater than 250 μm in size:

KW1 - All metallic U particles assumed > 250 μm = 0.87 kg
Similar to size data for KE1, it is assumed that 20% of the solids are greater than 250 μm in size. Total sludge solids >250 μm = 328 kg

KW2 - Entire stream is >500 μm.
All metallic U particles are assumed >250 μm = 1468 kg
Total sludge solids >250 μm = 1640 kg

KW3 - This stream has undergone a separation to remove particles >500 μm and size data indicates minimal mass >250 μm. The contribution of metallic U and diluent sludge to >250 μm size fraction is neglected.

KE1 - Metallic U particles assumed split 34 kg <250 μm, 14 kg >250 μm
Size data indicates 20% of sludge is > 250 μm.
Total sludge >250 μm = 4677 kg

KE2 - This stream has undergone a 250 μm separation in the basin so all sludge solids (3921 kg total) including 1511 kg of metallic uranium is assumed >250 μm.

The total amount of material separated for batch calcining is then 10566 kg of solids, containing 2994 kg metallic uranium requiring oxidation. The metallic uranium content can be expected to vary from 90% of dry solid content (KW2) to 0.3% (KE1 or KW1).

H3.3 BATCH CALCINE PROCESS - LOADING TRAYS

The particles retained on the 250-micron screen would be transferred to calcining trays. This is assumed to be accomplished by discharging from a shaking screen through a chute and directing the discharge chute using a manipulator. The trays are assumed to be 100 cm x 30 cm. A maximum of 12 kg of solids (dry basis) would be placed in each tray. As noted above, the vast majority of >250 μm metallic uranium will originate in streams KE2 and KW2. The sludge densities and dry solids content of the initial sludges contributing to these two streams are very different as shown below.

KE2, as-settled sludge ρ=2.359 g/cm^3, dry solids content = 1.655 g/cm^3, dry sludge is 39wt% metallic U
KW2, as settled sludge ρ=8.459 g/cm^3, dry solids content = 8.242, g/cm^3, dry sludge is 90wt% metallic U

For stream KW2, 12 kg of solids would amount to a layer about 0.5 cm thick in the tray. The thickness of the solids layer in the pan would be limited to about 2.54 cm (1-in.) thickness when treating these streams to assure adequate mass transfer of the oxygen into the layer. A thickness of 2.54 cm at a density of 1.655 g/cm^3 (i.e. the reported dry solids content of as-settled KE2) would provide the desired 12 kg loading in the tray. However, the density of 1.655 g/cm^3 for a material containing 39 wt% metallic uranium would appear to be too low so that the layer will be thinner than 2.54 cm.

For stream KE1, the solids content of the as-settled sludge is only 0.564 g/cm^3, probably due to fine flocculated solids in the sludge. It is expected that the density of the solids bed after removal of fine solids and organic ion exchange resins will be substantially higher and that the 12 kg loading with a maximum height of 2.54 cm can be achieved. The mass transfer concern in this sludge is less due to the low uranium content and lower demand for oxygen in the solids.

Assumption: The assumed total dry solids loading per tray is 12 kg.

For a total of approximately 3000 kg of metallic uranium dispersed within 10566 kg of total dry solids, loading 12 kg of solids per tray would result in 881 batches.

H3.4 BATCH CALCINE PROCESS - CALCINING CONDITIONS

After placing the trays into the oven, the sludge would undergo drying at 105°C with an argon purge, dehydriding at 400°C with an argon purge, then oxidation at 500°C with an argon+oxygen mixture. Pressure in the oven would be cycled during oxidation to aid penetration of oxygen into the layer of solids. The steps included in the calcining cycle are:

H3.4.1 Transfer from screen

Solids retained on the 250 μm screen will be transferred into a calciner tray. This transfer

may consist of a vibrating screen discharging through a tube which is positioned by a manipulator. The manipulator would be used to spread the solids out in the tray. Duration: 2 hours.

H3.4.2 Drying

The objective of this step is to remove liquid water without inducing boiling sufficient to splatter solids onto the inside of the oven. The solids will have already been drained on a screen before going into the oven. The oven would be preheated to drying temperature while the tray is being loaded. Drying would occur with an argon sweep gas through the furnace starting at a temperature 105°C. Offgases during this period would include Ar, H_2 and H_2O. The simple nature of the offgas would allow an infrared analyzer to provide a continuous indication of water rates in the offgas during drying. The furnace temperature could then be increased to obtain the desired water removal rate. As water in the offgas decays and the furnace temperature increases, the process would smoothly transition into the dehydriding step. This step is allotted 2 hours based purely on engineering judgement so there is significant uncertainty in this time.

H3.4.3 Dehydride at 400°C

The objective here is to decompose the majority of hydrides to prevent uncontrolled hydride reactions during oxidation. It does not matter if there are small amounts of residual water remaining as the temperature is ramped upward because any hydrogen generation occurring would be into an argon sweep gas in a furnace in an argon-inerted cell. This time is highly uncertain. Data related to dehydriding of K basin fuels may exist from investigation of the hot conditioning process but this data has not been reviewed. The STAR process uses a 5 to 6 hour dehydring period prior to containerizing metallic fuel elements. However, in the current process, small residuals are not believed to be a problem. The time allotted to this step is 4 hours.

H3.4.4 Oxidize at 500°C

The objective here is to fully oxidize all uranium metal particulate. The step would begin at 400°C, adding oxygen to the inlet gas and ramping up the oxygen content. Any residual hydride surviving the dehydriding step would likely react most rapidly followed by the metallic uranium. From sludges with significant uranium content, heat will be released in this step. Thermocouples attached to the bottom of the pan would monitor for hot spots and throttle oxygen content to control hot spots. There is a possibility that hot spots in the calcining tray could limit the rate at which oxygen can be introduced to the furnace. The tray temperature would be limited by the material of construction of the tray. Initially it is assumed these may be stainless steel. However, higher temperature alloys may be appropriate if local hot spots appear to be a limiting factor. The temperature would be increased up to 500°C as needed to achieve the desired oxygen consumption.

The maximum size quarter-inch particle is estimated to require 6.3 hours in dry air at 500°C to fully oxidize. Because the process would be ramped up in temperature and oxygen content, this time is increased to an assumed 8 hours. Actual termination of the oxidation cycle would be based on an observation that oxygen consumption has stopped. A purge rate of 40 slpm per oven is assumed. At the maximum oxygen content of 20%, a single oven purged at 40 slpm would provide enough oxygen to react 12 kg of U to UO_3 in about 3.6 hours. Thus, the purge rate of 40 slpm provides roughly twice the worst case stoichiometric oxygen requirement during the 8-hour reaction time. The actual oxidation cycle would be halted only after oxygen consumption has stopped. After oxygen consumption has stopped, the oven would be returned to approximately 100°C.

H3.4.5 Unload Tray

The time to cool the tray sufficient to remove it from the oven will depend largely on the oven dynamics and the design of the vacuum system. Once the oven is cooled sufficiently, the tray will be removed from the oven and the contents pneumatically transferred using a vacuum cleaner type device to a bin above a feed tank in the nitrogen inerted cell. The manipulator would be used to guide the end of the hose. During transfer, the argon would be drawn into the suction tube and pass through the dividing wall between the two cells, pass through the vacuum filter, be discharged back to the argon cell. There is a potential for mixing of the atmospheres in the two cells during transfer of solids. As a result the second cell is nitrogen inerted to prevent oxygen ingress into the argon-inerted cell. After transfer from the pan is complete, the solids would be dumped into the feed tank prior to chemical analysis of the feed. The time allotted to ramp the oven temperature down sufficient to remove the pan and then to transfer the solids is 2 hours. There is significant uncertainty in this estimate and depending on the dynamics of the furnace this might take somewhat longer than 2 hours.

The following cycle times are assumed for the ovens

Load tray with particles, insert tray into furnace	2 hr
Drying at 105°C under argon atmosphere	2 hr
Dehydride at 400°C under argon atmosphere	4 hr
Oxidize with Ar/O_2 mixture	8 hr
Unload tray and remove particulate	2 hr
Total Cycle Time	18 hr

The processing time provided (13 months)(30.4 days/mo)= 395 days. A series of 3 furnaces operated in parallel and operating 56% of the time would allow the sludge to be processed within the 13 month (395 day) window.

H3.5 CYCLE TIME UNCERTAINTY

As discussed above, there is significant uncertainty in some of the cycle time estimates for the batch calcining process. An evaluation of the dynamics of a particular furnace and the heat and mass transfer rates within the furnace would be needed to confirm that

cycle times are realistic. If the actual cycle time is longer than the estimate shown here, the impact would be to either increase the required 56% on-line requirement during the 13-month processing window, or for significant increases in cycle time, require that one or more furnaces be added to the facility

H3.6 FEED TANK - SAMPLING AND ANALYSIS

After undersized slurry has been transferred to the feed tank and any calcined material is added, the slurry would be sampled and analyzed to determine the radiolytic heat generation and the fissile content (and for some sludges PCB content). If heat and fissile limits (or in some cases PCB concentrations) do not limit the waste loading, the slurry will be allowed to settle and some fraction of the water decanted until the volume of slurry is about twice the initial as-settled sludge volume. Alternatively, additional calcine material could be added to the feed tank. If there are no constituents limiting waste loading, approximately 1/2 of a feed tank would be transferred to the mixing tank. If the analysis of the slurry indicates that decay heat or fissile content is limiting the waste loading, then a smaller quantity of slurry would be transferred to the mixing tank and additional dilution water would be added to the mixing tank to form a slurry that will meet waste acceptance criteria.

H3.7 FEED TANK - REACTING UNDERSIZE MATERIAL

There is possibility that some quantity of metallic uranium may be present in undersized material transferred as slurry to the feed tank. At 100°C, the time to fully react a 250-micron metallic particle is 102 hours. It is expected that the high activity sludge will probably require agitation for the full 102 hours while this may not be needed for low-activity sludges. However, the hydrogen generation rate from the tank would be monitored in all cases and there would be an identified rate (to be determined) below which the material could be grouted. The threshold value would be determined by on-site shipping limitations for hydrogen generation. Because shipment to WIPP would occur much later, the small metallic pieces would be expected to fully react prior to shipment to WIPP.

H3.8 GROUT MIXING

It is assumed that sufficient solids are added to the slurry in the mixing tank to result in a volume increase factor of 1.4. Approximately 618 liters of slurry would be grouted in each batch to form 865 liters of grout, which in a single transfer would be placed, into a WIPP RH Canister with a maximum volume of 890 liters.

Weigh cells on the feed tank will verify the amount of material transferred, and would be used to control transfers of slurry into the mixing tank. The control of transfers to the mixing tank is important for the high activity streams where dilution is used to comply with limits on fissile content of the grout. For low activity streams this will be a simple batch transfer. A gravimetric (loss-in-weight) solids feeder located above the cell will add dry cementitious material to the mixing tank based on the volume of slurried sludge

transferred to the mixing tank. A knife valve will be installed as a "crash" valve, which could be operated if the solids feeder were to experience fluidization of the solids. The agitator will mix the material as the solids are transferred to produce the grout. The dry solids would include Portland cement but may also include fly ash, clays, or other additives that may be specified during formulation development.

H3.9 PROCESS COOLING

The feed tanks and mixing tank will be equipped with external plate coils to provide cooling in order to dissipate the heat input from the agitator. The chiller providing cooling to the platecoils would be located outside the cell.

H3.10 HYDROGEN CONTROL

The plenums of the feed tanks and mixing tank would be nitrogen inerted. The offgas leaving the feed tanks would be independently sampled, high-efficiency particulate air (HEPA) filtered and withdrawn from the cell for GC analysis of hydrogen. The hydrogen monitoring allows the hydrogen generation rate to be verified as acceptable for on-site shipment prior to mixing the grout as well as assuring that flammable mixtures are not obtained within the tank plenum spaces. If hydrogen were detected above desirable levels in a particular vessel the offgas flow would be increased, the level of agitation decreased and cooling provided to the tank.

H3.11 OFFGAS SYSTEM

The main offgas flow from vessel ventilation would join the minor flow from the calcining furnaces, pass through a condenser and HEME and then leave the cell. During filling of the canister, offgas is drawn through the fill head to avoid discharging contamination into the cell while filling the canister. This provides an additional periodic flow of displaced air that would be routed to the HEME. Outside the cell the offgas would pass through a heater and then be HEPA filtered. Due to the presence of the condenser and HEME filter, a carbon bed filter for PCB control may not be required. However, until this can be shown with certainty, a carbon bed filter is included in the conceptual layout.

H3.12 FLUSHING/CLEANING SYSTEM

A cleaning system would be included in the mixing tank. This would include spray nozzles within the tank positioned to clean the inside of the tank, the entry of the solids chute to the tank, and the grout line and fill head. A high-pressure pump supplying water to the nozzles and valving would be located outside the cell. A capability to use water or a weak acid decontamination solution would be provided. The system would be operated after each batch to prevent accumulation of grout deposits. The wash water would be flushed through the pump and fill nozzle and into a small tank. The ability to neutralize the acid decontamination solution would be provided. This flush water or neutralized

decontamination solution would be used in place of dilution water to dilute future batches.

H3.13 REMOTE-HANDLED CANISTER FILLING

There are two primary options for containers to hold the grout. The grout may be placed in remote-handled WIPP canisters or placed in shielded overpack containers for disposal at WIPP as contact-handled waste. The primary option being analyzed is the use of the RH canisters because currently approved WIPP packages do not provide sufficient shielding to allow disposal of the sludge in contact-handled (CH) packages. The shielding required and resulting package weights for CH packages would introduce significant risk to the CH option. However, some discussion of the alternate CH package option is provided at the end of this appendix.

The containers to be filled would be WIPP RH canisters, which have a height of 121 inches, a diameter of 26 inches and a maximum internal volume of 0.89 m^3. It is assumed that each canister is filled with grout to a volume of 0.865 m^3 or roughly 97% full. The normal WIPP RH canister, which can be used to overpack drums, has a filter which screws into the inside of the canister neck. The welding to close the canister then must be done remotely to install the entire top canister assembly. Instead of using this approach it is proposed that the design be modified to allow the filter to be screwed into the neck from the outside, and that the welding of the top of the canister be performed during canister fabrication. These are superficial changes in the package and are not expected to introduce risk to the option.

The empty canister is placed into a space below the cell on a trolly and rolled underneath the cell. A lift presses the neck of the canister against a sealing gasket. The shield plug is then lifted using manipulators to expose the throat of the canister to the cell environment. The fill head is then inserted into the neck of the canister. The fill head consists of a centrally located grout injection pipe and a concentric shroud through which air is drawn. The purpose of the shroud is to prevent the spread of contamination as air is forced out of the canister by the grout filling operation. The fill head is connected to a flexhose which allows the head to be moved between the canister neck (fill position) and a flush receipt tank (flush position) for cleaning.

H4.0 PREVIOUS DOE/FOREIGN/COMMERCIAL EXPERIENCE

Even if the type of material processed in the STAR facility are somewhat different (fuel element and fuel element pieces compared to sludge), the calciner and the inerted cell concept are important relevant foreign experience, which can be used for the design of the sludge facility.

Grouting for waste stabilization is a very well established technology. Within the Department of Energy (DOE) complex, grout (Saltstone) is used at SRL to immobilize low level waste (LLW) into large concrete vaults. Floor sludges from a fuel storage basin

at Hanford (N Basin) were previously stabilized and disposed in a grout matrix[1] (Pearce, 1998). Numerous other DOE applications exist. Grout is also used outside the US for LLW stabilization.

Within the commercial power industry grout has been used extensively to stabilize LLW. A number of commercially available vendors are identified in DOE/LLW-240 *Commercially Available Low-Level and Mixed Waste Treatment Technologies.*

H5.0 SAMPLE REQUIREMENTS

This section describes analytical work required to satisfy process control and product verification criteria. The product from this process operation will be grouted for transfer to the Central Waste Complex in anticipation of final disposal at the WIPP.

H5.1 PROCESS CONTROL CRITERIA

Each batch of sludge will be sampled for accountability and process control prior to transfer to the sludge treatment facility. An in-line monitor will be used to assess the heterogeneous sludge for fissile material content as verification of criticality safety during processing operations.

Grout feed tanks will be sampled and analyzed to allow control of the key parameters pertinent to meeting WIPP waste acceptance criteria. Process control data will be required to control:

- fissile content < 325 g per RH canister
- decay heat content < 3.7 Watt per RH canister
- PCB content < 50 ppm in final grout (exceeding may be acceptable but would require application of a risk based approach to limit rather than simple 50 ppm limit)

In addition, the hydrogen generation rate from a feed tank will be monitored to assure that the rate from reacting metallic uranium is sufficiently small that on-site shipment will not be impacted. It is expected that on-site shipment will be somewhat less restrictive than the limit derived from the assumed 60-day shipping period to WIPP. The heat content would still be used to establish the WIPP radiolytic hydrogen source.

Timeframe

Process control data for the indicated components above will be required for grout feed loading. It is expected that a sample turnaround time of 24 hours can be achieved and this is sufficient to avoid slowing the processing rate using the proposed 3 feed tanks. To

[1] Letter T.E. Logan, Project Manager, N Area Project, Bechtel to P.M. Pak, Senior Project Manager, DOE-RL, **Decision on N Basin Sediment Disposal, May 12, 1998.** Correspondence #058172, job #22192, contract# DE-AC-06-93RL12367.

provide these analyses within this required time period, a dedicated staff will be required as in the previously discussed alternative processes.

H5.2 PRODUCT VERIFICATION CRITERIA

The grout product will require qualification as an acceptable product for final disposal at the WIPP. This qualification can be performed in advance of process operations and is not considered in the cost or schedule sections since the extent of testing required is not currently defined. Part of this qualification would be to:

- Demonstrate that the proposed grout formulation does not separate liquid
- Establish the "G"-value for the grout to allow H_2 control based on decay heat
- Establish feed flammable VOCs <500 ppm in container headspace
- Establish that calcine process and hot water stirring eliminates pyrophoric characteristic

The key acceptance criteria of concern (Fissile content, heat content, PCBs) will be obtained as part of the process control sampling. All waste acceptance analysis will be based on a pre-grouting sample. No sampling of the grout after mixing is proposed. The additional waste acceptance criteria include:

- Cd, Cr, Pb, Se analysis to assign EPA hazardous waste codes (these analysis would be performed on the control sample but would not need to be reported quickly)
- Thermal power<300 Watts/canister (satisfied by control sample for heat content)
- Pu equivalent Ci<1000 per canister (this is determined largely by Pu isotopes and Am-241 which would be obtained as part of fissile content determination)
- Total activity <23 Ci/l (establish based control sample data used to establish decay heat)
- TRU>100 nCi/g (establish by Pu and Am isotopic determined for fissile content)
- Some occasional verification sampling on parameters established during qualification may be needed

Timeframe

Most data would be obtained as part of process control sampling. Other data such as toxic metal content would not be time critical.

H6.0 APPLICATION TO K BASIN SLUDGE

This section evaluates the grouted product against the WIPP waste acceptance criteria and provides the projected number of RH-Canisters that may be generated if the grout is adjusted to meet the waste acceptance criteria.

H6.1 DETERMINATION OF THE MAXIMUM ALLOWABLE HYDROGEN GENERATION SOURCE TERM

For the grouted waste form, a key waste acceptance criteria that may limit the waste loading for grout is the hydrogen generation rate from the grouted container. The RH-

canister is fitted with a filter to allow hydrogen to escape from the canister. During shipment to WIPP, the hydrogen is released to the inner containment volume (ICV) of the NuPac 72-B cask. The hydrogen concentration in the void volume of the canister or in the NuPac 72-B cask ICV must remain less than or equal to 5-volume % during an assumed 60-day shipping period. The NuPac 72-B cask SAR provides hydrogen release rates for the filter at 333 K and 244 K of 1.16×10^{-4} and 6.74×10^{-5} mole/((s)(mol fraction)) respectively. The inner containment volume has a volume of 493 liters[2]. The internal volume in the RH-canister is 0.89 m^3 and the grout is assumed to occupy 0.865 m^3 for a void volume of 25 liters. Based on this data, a simple simulation was conducted, assuming hydrogen generation rates and determining if the 5 volume% limit was met. The simulation was conducted at 333 and 244 K. In both cases it was assumed that the cask was filled at the listed temperature and remained at the temperature over the 60-day period. The results of the simulation indicate the maximum hydrogen generation rates are:

244 K (-30C)	2.34E-7 mole/second
333 K (-60C)	1.78E-7 mole/second

The 333 K result was the most conservative result because the moles of gas present in the cask is reduced by the high temperature and this effect is more important than the reduced filter release rate. A slightly more conservative result might be obtained by assuming the cask is at 60°C when filled and then is shipped at -30°C. However, for purposes of the evaluation it is assumed that the limit is **1.78E-7 mole/s**.

H6.2 SELECTION OF "G(H_2)" VALUE

The G (H_2) value is a parameter that describes the molecules of hydrogen generated per 100 eV of energy absorbed as radiation. The radiolytic hydrogen yield differs between beta/gamma and alpha radiation with alpha radiation typically producing higher yields. Hydrogen is generated by the radiolytic decomposition of water. The hydrogen yield from waters held as hydrates in crystals is much lower than "free" water. In addition, some organic materials can have higher gas generation rates than aqueous materials. Inorganic minerals may absorb radiation without generating hydrogen. In addition, some fraction of the gamma radiation may escape the container and be absorbed outside the package (by the cask in the shipping case). For alpha radiation, some fraction of the radiation does not escape the particle and is not available to cause radiolysis. In addition, in some materials, matrix depletion is experienced where the hydrogen source from a package declines over time due to the hydrogen generation capability of the source being depleted. It is not expected that matrix depletion would be observed for the water in the grout matrix. Some effect might be observed for ion exchange resins.

Because a large fraction of the heat source is due to Cs-137 and Sr-90 with a half-life of approximately 30 years some fraction of the decay heat will be lost prior to shipping to WIPP. It may be possible to justify an on-site shipping period far shorter than 60 days

[2] See pages 3.6.9-9 and 3.6.9-10 of NuPac 72-B cask SAR, 2/92

for placement in interim storage. Because the ultimate date of shipment to WIPP is uncertain, no credit is taken for a reduction in activity prior to shipment.

> Assumptions: For purposes of estimating hydrogen generation, all gamma radiation is assumed to be absorbed within the package and all alpha radiation is assumed to escape the particles and be available to cause radiolysis. No matrix depletion is assumed to occur. No decay of heat generating radionuclides prior to shipment to WIPP is accounted for. These are all conservative assumptions.

The effective beta-gamma G values of cementitious grouts were reviewed previously and a bounding G value of 0.35 was selected[3]. The NuPac 72-B SAR (see pg 3.6.8-100) reviews a number of G values for alpha radiolysis in cements and concretes. The highest G value determined from a variety of sources was 0.60.

Some sludges (stream KE1 in particular) are contaminated with organic ion exchange resins. The NuPac 72-B SAR provides a bounding G value for ion exchange resins of 1.7. The gas generation from ion exchange resins was reviewed by Marusich (1994) for beta-gamma radiation related to K basin ion exchange columns, modules and cartridge filters. Based on this review, a value of 0.5 was selected. For alpha radiation, this value was increased by a factor of 3.5 to provide a value of 1.8

This results in the selected G values for this study of:

ion exchange resin	beta-gamma = 0.5	alpha = 1.8
bulk grout	beta gamma = 0.36	alpha = 0.6

Examining all sludge streams together, beta-gamma radiation accounts for roughly 70% of the heat source while alpha accounts for roughly 30%. This ratio varies by stream but for purposes of the study the variability in mixture between beta/gamma and alpha radiation is neglected. For stream KE1, which has the highest ion exchange resin content, the final grout form has roughly 5.8 wt%[4] resin in the final waste form. Linear weighting by mass the alpha and beta-gamma contributions for grout without ion exchange resin results in an estimated G value of 0.432. Including the exchange resin results in a value of 0.459. Because the values with and without exchange resins in the grout are similar, a single value of **G = 0.46** was selected for all grouts in this study.

Based on the G value of 0.46 and the maximum gas generation rate of 1.78E-7 mole/s, the maximum allowable heat value in a single RH canister is estimated to be **3.73 Watts**.

H6.3 HYDROGEN GENERATION IN GROUT FROM METALLIC URANIUM

If metallic uranium is immobilized within the grout, it would be expected to continue to react with water in the pores of the grout and generate hydrogen. An estimate of the rate

[3] Whyatt, G. A., Gas Generation and Release from Double Shell Slurry Feed (DSSF) Grout Vaults. February, 1991. Letter report to WHC, HGTP-90-02-01. Pacific Northwest Laboratory

[4] assumes "nominal" grout which is 1:1 dilution from as-settled state and then volume increase of 1.4 to account for solids addition. The wt% would decrease as the grout is diluted to meet hydrogen limits.

of hydrogen generation was prepared to determine the amount of unreacted uranium that might be tolerated.

Reilly (1998) provides an expression defining the rate constant of the reaction between metallic uranium and liquid water as a function of temperature. Part of the expression is a "reactivity enhancement factor" that increases the calculated rate based on the expression. For metallic uranium (no hydride inclusion) a value of 3 is recommended for a design basis and a value of 10 recommended for a safety basis. For purposes of this evaluation the design basis value of 3 was selected. Based on the maximum allowable hydrogen generation rate of 1.78E-7 mol/s, the quantity of different sized metallic uranium particles that can be tolerated can be calculated. This was performed for a variety of temperatures and sizes assuming spherical particles of solid metallic uranium (density =18.95 g/cm^3). A few results are summarized in the table below.

Mass of Metallic Uranium Corresponding to Maximum Hydrogen Generation Rate for RH Canister Shipment to WIPP

	Grams of Metallic Uranium Corresponding to Maximum H_2 Rate	
	Temp = 20°C	Temp = 60°C
200 micron	98.3	5.7
6350 micron (quarter inch)	3120	181

Smaller particles have a larger impact on hydrogen generation (for the same mass uranium) than larger particles but will fully react in a shorter time. Small particles, which fully react prior to shipment to WIPP, may not affect the acceptability for shipment to WIPP. Thus, the on-site shipping limitations may be the limiting factor for the amount of small metallic uranium that can be present. Assumptions used for on-site shipping between the plant and CWC are likely to be less restrictive in terms of the assumed time between departure and arrival and this may increase the amount of uranium metal that may be tolerated. However, in interpreting the numbers in the table above it should be noted that the maximum hydrogen generation value must be split between the metallic uranium and the radiolytic source. For example if dilution were performed to the point that 90% of the hydrogen limit is generated from the radiolytic source, this would reduce the allowable metallic uranium by a factor of 10 so that only about 18 grams as 1/4 inch particles would be tolerable at 60°C. The reaction rate continues to increase with temperature. Thus, if metallic uranium is present, there may need to be an analysis to determine what the highest possible temperature would be during shipment and to determine an allowable quantity of uranium surface area. The potential problem from hydrogen generation from metallic particulate is resolved by holding feed particles <250μm at 100°C in the feed tank for up to 102 hours (or until hydrogen generation stops) and by batch calcining the oversized material.

The amount of allowable metallic uranium is of particular importance to the determination of whether low-activity streams may be directly grouted without particle segregation or holding at elevated temperate. The amount of metallic uranium estimated by Pearce et al. (1998) to be present in the low activity streams extrapolates using the

nominal grout formulation to 360 g/RH canister for KE1 and 58 g/RH canister for KW1. Thus, it appears likely that some treatment prior to grouting may be required, at least for stream KE1 that is the majority of the volume. However, it should be recognized that the quantity of metallic uranium in these streams is highly uncertain. If hydrogen generation is less than expected after transfer to the feed tank, then the material can be grouted without unnecessary delay.

H7.0 SAFETY CONSIDERATIONS

The grouting approach has a number of safety considerations that influenced the description of the option and would need to be considered in the conceptual design. Preliminary shielding calculations show that the radioactive streams to be processed in this facility need a significant amount of shielding (up to 75 cm of concrete for the main process vessels), hence much of the process operations would need to be performed remotely. The batch calcination process, although remotely operated, is a manual process combining dispersable material with a thermal hazard. Thus, the potential for worker exposure is greater than for the other alternatives. A combination of administrative and physical controls will be utilized to assure that personnel radiation exposures remain as low as reasonably achievable (ALARA). The facility would include filtration of the in-cell atmosphere and the capability to retain liquid spills or leaks.

The grouting process is less complex than the baseline process; it has some safety issues in the batch calcination step which require further assessment. A similar process to the batch calcination process has been used in France (i.e., STAR), and a similar process is being used to stabilize plutonium packages in the Plutonium Finishing Plant (PFP) at Hanford. Thus, although the process control and safety control technology is less mature than the baseline process, lessons can be learned from operating experience with similar processes.

H7.1 HANDLING OF PYROPHORIC PARTICLES

Measures are required to prevent ignition of pyrophoric metallic uranium pieces. Oversized particles received in the facility are screened out of the stream and placed into pans for batch calcination in small furnaces. Ignition of particles during this step is precluded by maintaining an argon-inerted atmosphere in the cell. Air ingress from the larger adjacent cell containing the grout feed and mixing tanks is prevented by maintaining the larger cell under a nitrogen inerted cell.

Care will need to be taken in handling the unoxidized particles to assure that any spilled particles are cleaned up and placed into the ovens. Otherwise, an accumulation of particles could ignite when the argon-inerted atmosphere is eventually removed from the cell.

The inerted cell approach to preventing ignition of pyrophoric particles is specific to the grouting option. All other options evaluated prevent ignition of pyrophoric particles by maintaining the particles under water and making all transfers as a slurry.

H7.2 CONTROL OXIDATION RATE IN FURNACE

The oxidation rate within each furnace is controlled by controlling the furnace temperature, and the flow of argon and oxygen through the furnace. By limiting the amount of oxygen that is available to be consumed, the rate of heat generated is bounded. The worst case scenario for loss of control of the oxidation rate is limited by the fact that the oven itself is located within an argon-inerted cell. Opening a hot oven during a cycle would tend to stop the reaction due to ingress of the argon from the cell into the furnace.

H7.3 CONTROLLING DISPERSION OF CALCINE

The calcine after removal from the furnace may be dispersible. The particles are removed using a "vacuum cleaner" type transfer which should limit losses of dispersible material within the cell. However, there is a potential for the spread of contamination within the cell due to the handling of a dispersible material.

H7.4 HOT-WATER OXIDATION/H_2 GENERATION

The feed passing the 250 μm screen is transferred to feed tanks where it is stirred at 100°C for about 100 hours until the hydrogen generation subsides. The rate of reaction of the metallic uranium with water to generate during this oxidation step will be greater than observed in the typical storage tank due to the elevated temperature. However, the small metallic uranium content within the fine fraction of solids will prevent excessive gas generation. The hydrogen is removed and diluted by a nitrogen purge of the plenum. However, because the cell in which the tank is located is itself nitrogen-inerted, the potential for hydrogen ignition is minimal.

H7.5 CRITICALITY MASS LIMITS

As in other options the criticality control on the feed to the facility is a mass based limit on a batch. The same batch-size based control is used throughout the process. When calcined material is transferred to a feed tank, the material will either be added to a new feed tank that would receive only calcined material, or combined with the batch from which it was initially separated.

H7.6 ORGANIC ION EXCHANGE RESINS

Organic ion exchange resins (OIER) are separated in the basin and are delivered directly to a grout feed tank. Nitric acid is not used in the grouting process. In addition, there are no concerns with the sulfur content of the resin beads contributing to enhanced corrosion of the calciner pans.

H7.7 CONTROL OF PCB OFFGAS EMISSIONS

The offgas system includes an activated carbon filter to remove PCBs from the offgas. However, the quantity of PCBs in the offgas are expected to be small. Most of the PCBs would be associated with the smaller particles in KE1 and would end up in the grout.

H7.8 CONTROL OF RADIONUCLIDE OFFGAS EMISSIONS

Offgas from the batch calciners are combined with offgas streams from the hot water oxidation/lag storage tanks and the grout mixing tank before being HEPA filtered. The HEPA filter is expected to remove essentially all entrained particulate. Some emission of fission products in gaseous form (^{85}Kr, ^{129}I) released during oxidation of the metallic fuel particles will occur. Radionuclide emissions are not expected to exceed regulatory limits.

H7.9 RISK TO WORKERS

Risk to workers is limited due to the remote operation and maintenance approach adopted. Potential hazards workers could encounter include exposure to dust from grout formers, and radiation hazards during the transfer of filled grout canisters or removal of failed equipment out of the processing cells. These hazards will be addressed by an appropriately administered health and safety plan.

H8.0 MAINTENANCE REQUIREMENTS

A low-capacity crane is assumed within the cell for replacement of pumps or other small equipment. However, for replacement of large tanks the approach would be the same as in the baseline concept. Cover blocks in the top of the cell would be removed and equipment removed by a crane positioned above the cell. Some maintenance flexibility is added by the manipulators (used in the process operation) located in front of the calcine furnaces and at the container filling station. A small air lock or other arrangement is assumed which will allow movement of samples and small pieces of equipment in and out of the cell.

H9.0 FACILITY LAYOUT

A layout of major in-cell equipment was developed for the purpose of determining the approximate size of the operating cell. The layout is very preliminary and does not include piping, instrumentation, electrical cables etc. nor have specific maintenance operations been considered in the equipment layout. A pre-conceptual layout of equipment in the processing cell is shown in Figures H-2 through H-6.

Unlike the baseline, the agitator motors and pumps are placed in cell and a small crane, windows and manipulators are included in the cell. Two cells are included, an argon-

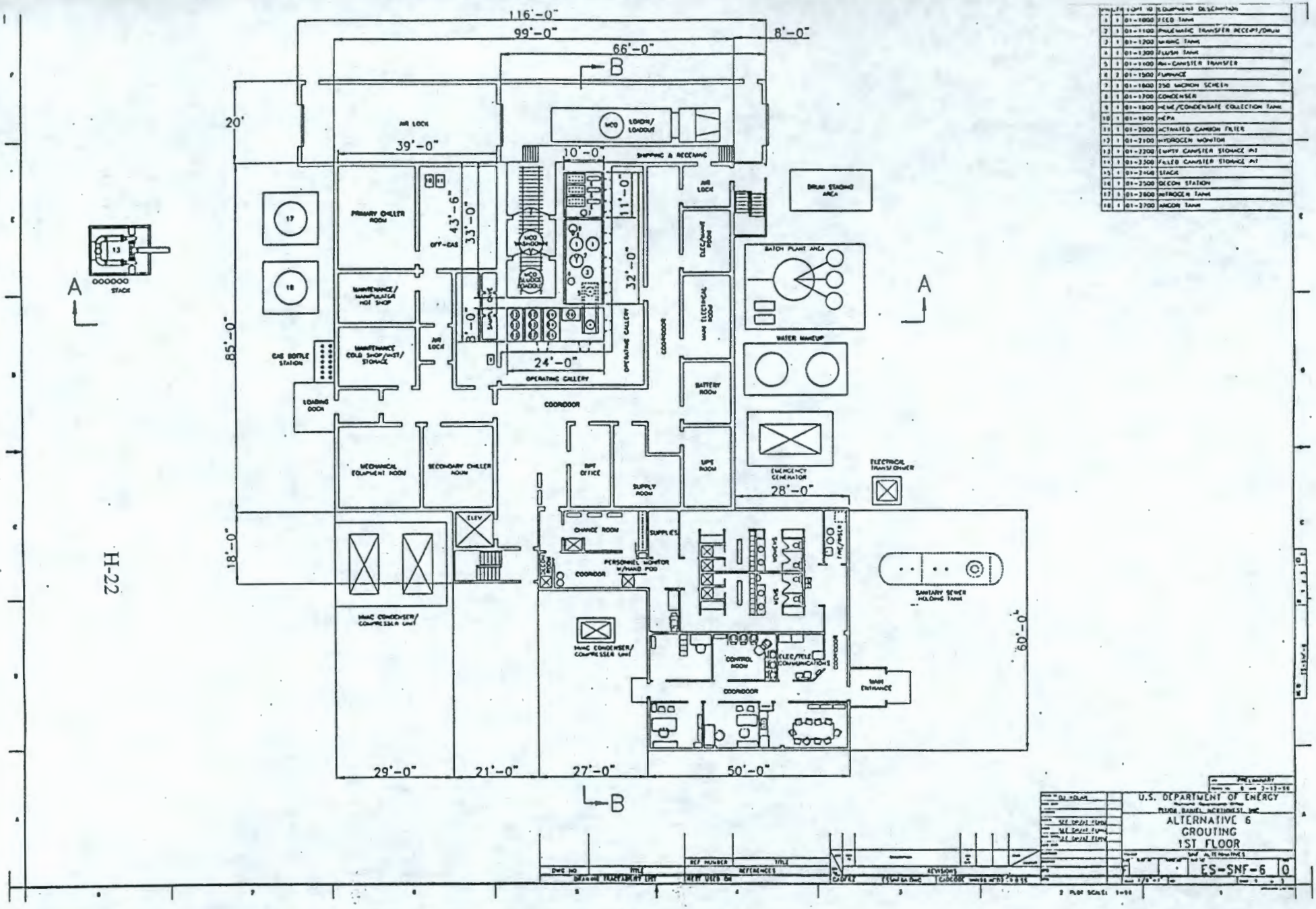


Figure H-2. 1st Floor Plan View for Grouting Process Facility

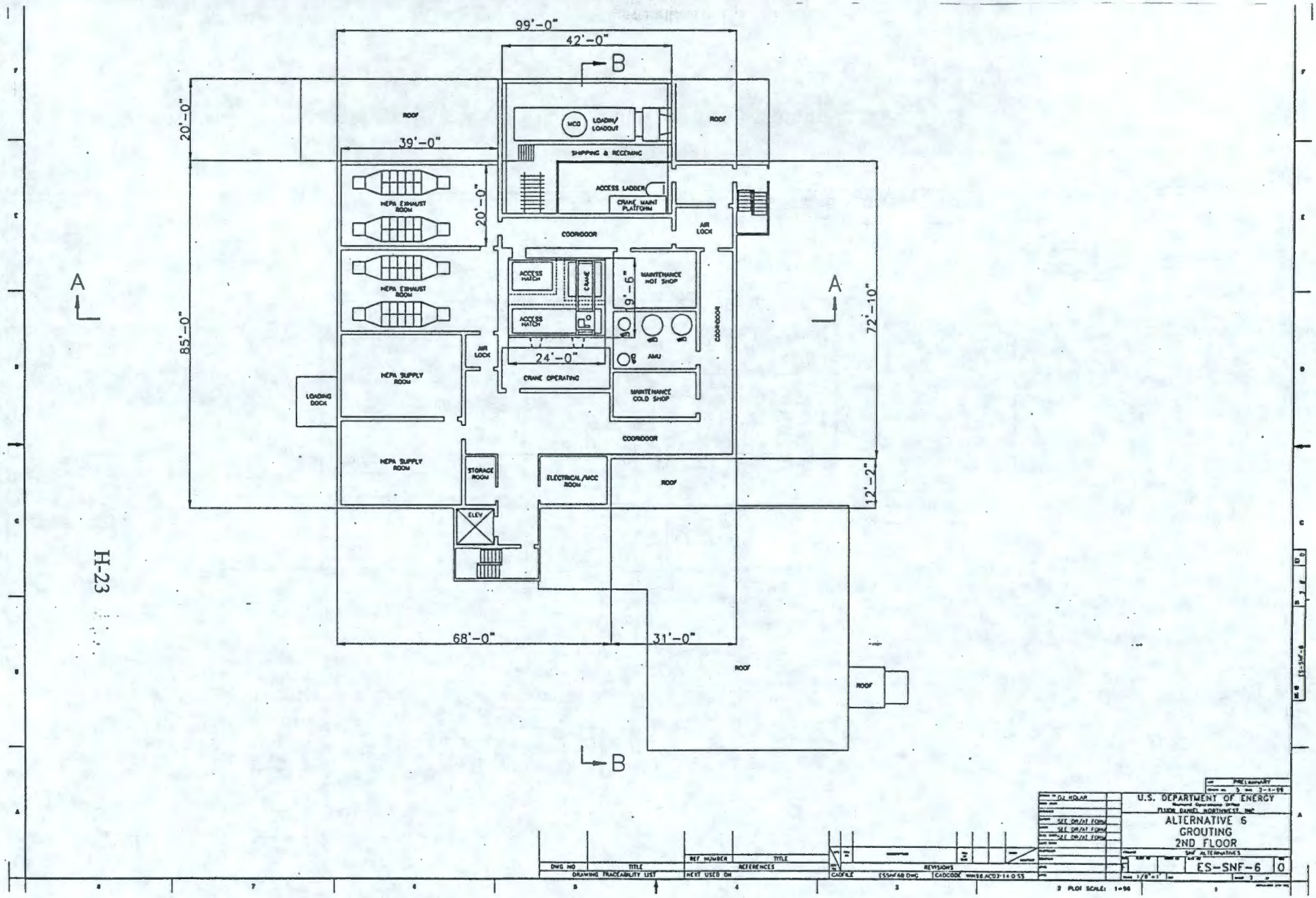


Figure H-3. 2nd Floor Plan View for Grouting Process Facility

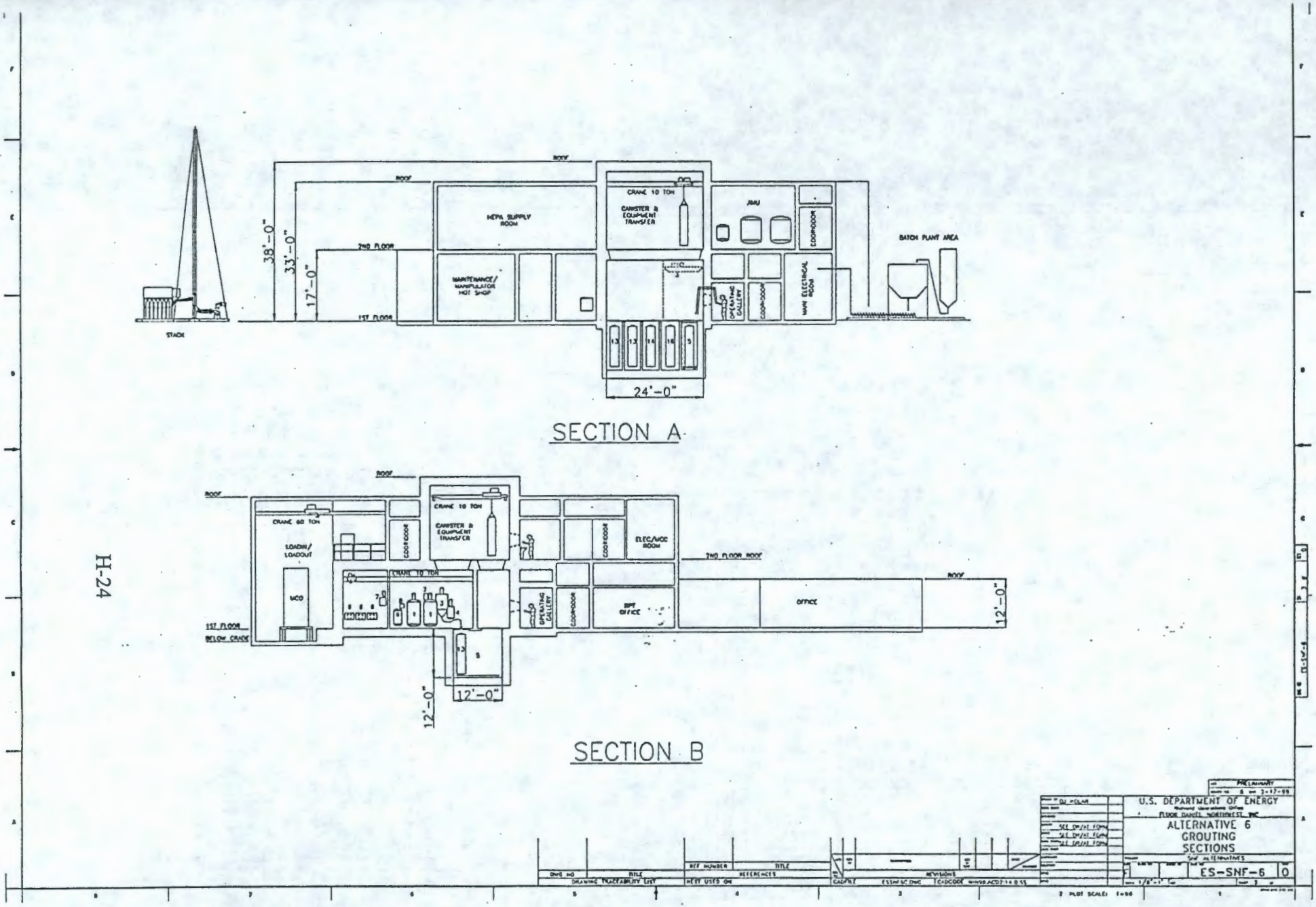
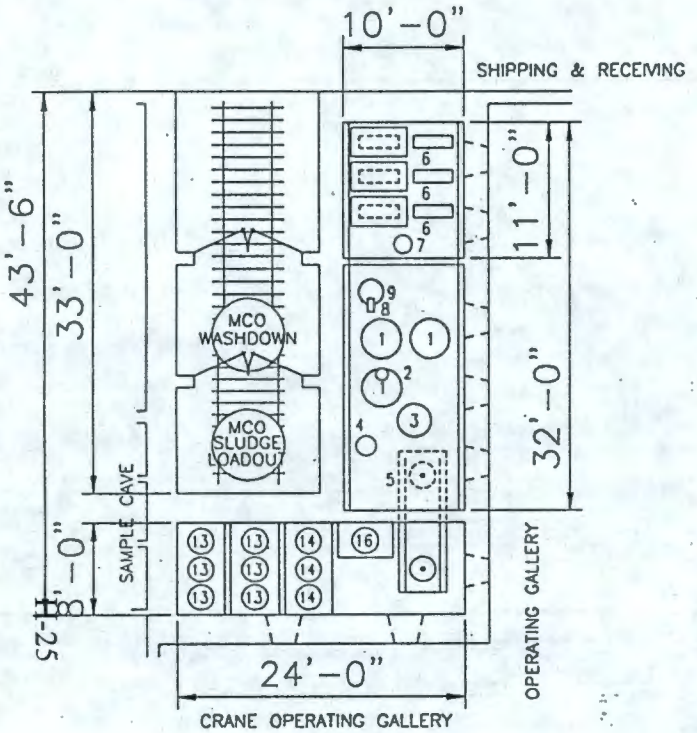
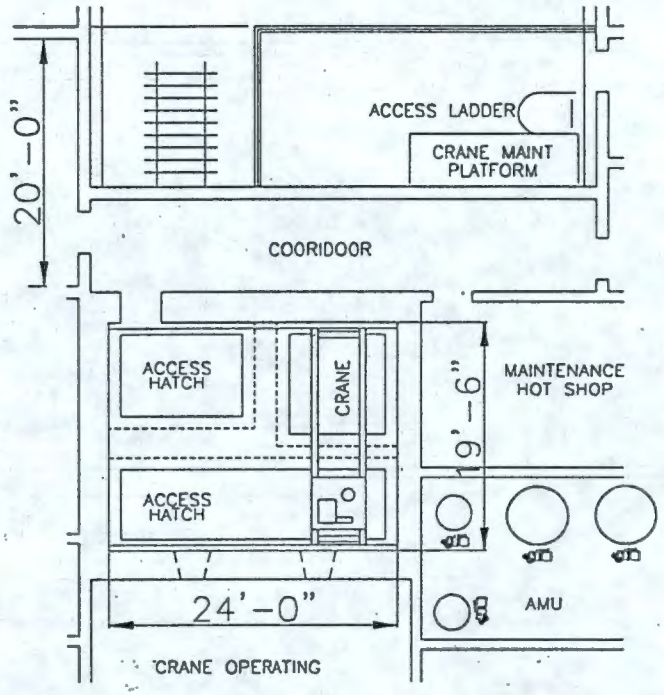


Figure H-4. Sections of Grouting Facility



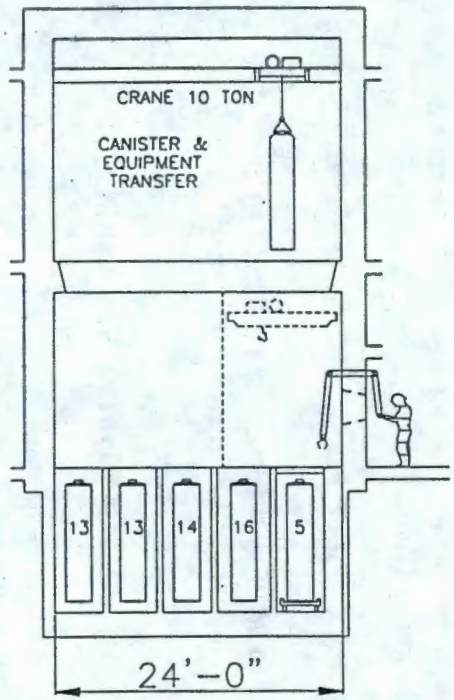
1ST FLOOR PLAN



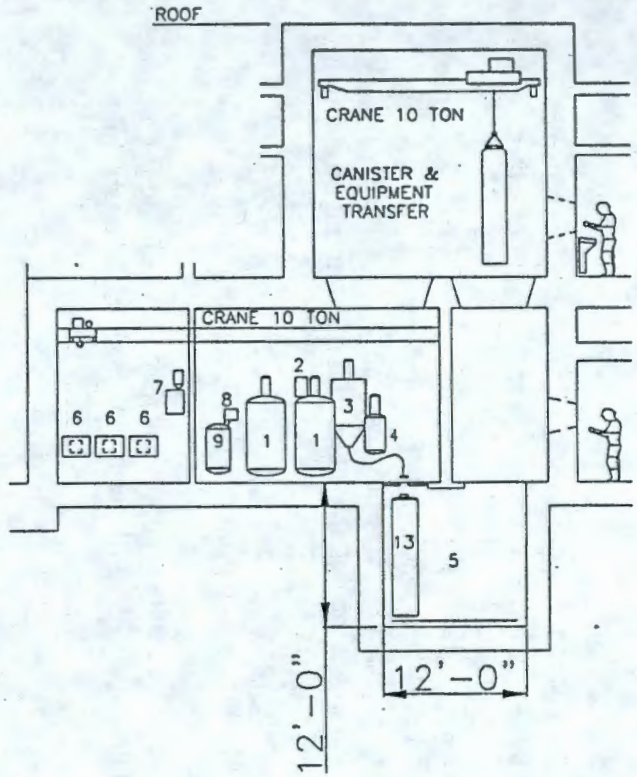
2ND FLOOR PLAN

U.S. DEPARTMENT OF ENERGY
FLUOR DANIEL NORTHWEST, INC
ALTERNATIVE 6
GROUTING
ENLARGED VIEW
ES-SNF-6 0

Figure H-5. Enlarged 1st and 2nd Floor Plan View of Grouting Process Area



SECTION A



SECTION B

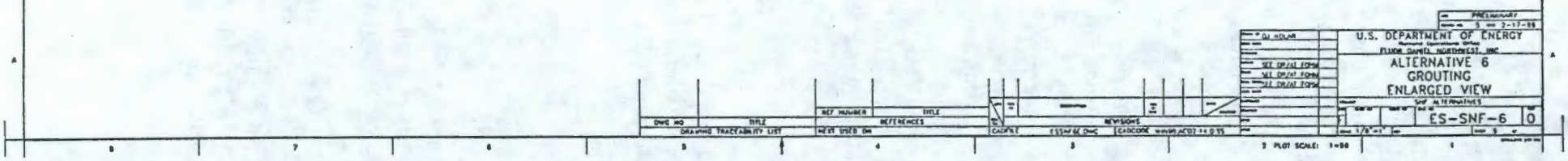


Figure H-6. Enlarged Sections of Grouting Process Area

inerted cell and a nitrogen-inerted cell. The major pieces of equipment in the argon-inert cell include a 250μm screen, and three calcining furnaces. The major pieces of equipment in the nitrogen-inerted cell include 3 feed tanks, a mixing tank, a fill head for filling canisters, a flush tank, a condenser, a HEME and condensate tank. Manipulators and windows are positioned in front of the furnaces, at the filling location and for decontamination of the canister neck area. A crane is available above the cell for canister handling for final decontamination and decommissioning (D&D).

The three in-cell manipulators may be used for:

- Transfer oversize solids to calcine trays/ empty trays using vacuum transfer
- Removing the shield plug prior to filling canister and replacing after fill is complete
- Moving fill head between the flush and fill position
- Provide maintenance for mixing tank load cells, if needed
- Provide for replacement of fill head and flex hose assembly
- Provide capability for D&D of equipment at the end of the 13-month production campaign
- Provide replacement capability on flush tank
- Decontamination of top of canister as required/verify decontamination

The initial design includes a progressive cavity pump(s) and associated piping for moving fluid from the feed tank to mix tank, mix tank to fill head, mix tank to flush tank and flush tank to mix tank.

H10.0 TRANSPORT AND INTERIM STORAGE

The grouted canisters produced will be remote-handled packages. Although remote-handled material has been accepted at CWC in the past, CWC does not routinely accept remote-handled material. Special arrangements would be needed for storage of the remote-handled canisters. For purposes of the current study it is assumed that the canisters are placed into a vented steel overpack that provides shielding to contact dose levels. This overpack would then be stored at CWC.

H11.0 FINAL DISPOSAL

Transport of the RH-canisters of grout to WIPP will occur in the NuPac-72B cask. The comparison of the grouted RH-canisters to meet WIPP criteria is discussed below for the low and high activity streams.

H11.1 COMPARISON TO WIPP WAC - LOW ACTIVITY STREAMS

For purposes of waste acceptance, the low activity streams (KW1, KE1) streams differ from the high activity stream primarily in the potential for hydrogen generation (due to radiolysis or metallic uranium reaction) and the fissile content. The table below provides

a comparison of the projected number of RH-canisters and the comparison of expected waste form properties to key waste acceptance criteria.

Nominal Grout Compared to WIPP Waste Acceptance Criteria for Low Activity Streams

	WIPP WAC Limit	KW1 Grout	KE1 Grout
Number of RH canisters	NA	15.1	134.2
Watt/canister	3.73[(a)]	0.19	0.869
Fissile Gram Equivalent/canister	325	59	181
PCB concentration, ppm	50	0	22.5
Pu Equivalent Ci/canister	1000	4	12
Total Activity Ci/l	23	0.3	0.7

(a) Actual limit is to prevent 5% hydrogen in the canister void space or Cask during a 60 day shipping period. Heat limit is derived based on an estimate of the allowable hydrogen generation rate during shipping shipping and the estimated G value for the grout.

H11.2 COMPARISON TO WIPP WAC - HIGH ACTIVITY STREAMS

Based on discussion with Hanford TRU program staff, it is very likely that pieces of fuel that break off during the fuel washing operation will be considered spent fuel and would not be suitable for WIPP disposal. Thus, an option in which all waste streams are grouted is unlikely to be acceptable. There will be a small volume of broken fuel pieces in addition to the grouted material for WIPP. In addition, the position that will ultimately be taken by WIPP for canister sludge is currently uncertain. There is a risk that the canister sludge may be judged to be spent fuel and thus unsuitable for WIPP disposal. Since the grout would not be acceptable for repository disposal and would be difficult to reprocess, this introduces substantial risk into the grouting of high activity streams. If it were determined prior to grouting that particular portions of the waste were not acceptable they could be containerized as calcine and stored.

Assuming the issue above is resolved, the nominal grout is compared to the WIPP waste acceptance criteria in the table below. Shaded boxes indicate where waste acceptance criteria (WAC) limits are exceeded.

Nominal Grout Compared to WIPP Waste Acceptance Criteria for High Activity Streams

	WIPP WAC Limit	KW2 Grout	KW3 Grout	KE2 Grout
Number of RH canisters	NA	0.6	6.1	7.7
Watt/canister	3.73[(a)]	149.4[(b)]	19.2	14.4
Fissile Gram Equivalent/canister	325	25089[(b)]	4258	3726
PCB concentration, ppm	50	0	1.34	0.17
Pu Equivalent Ci/canister	1000	998[(b)]	217	212
Total Activity Ci/l	23	78	17.3	13.1

(a) Actual limit is to prevent 5% hydrogen in the canister void space or Cask during a 60 day shipping period. Heat limit is derived based on an estimate of the allowable hydrogen generation rate during shipping shipping and the estimated G value for the grout.
(b) for consistency, the values are provided on the basis of a full canister although insufficient material is available in the stream to fill a canister.

The limits exceeded by the greatest factor in all cases are the fissile limit. There is a possibility that an argument could be made to expand the allowable fissile limit. For example, the currently assumed fissile material mass control limit for the plant is 160 kg of dry solids in any one batch. This limit was derived as a fraction of the 612 kg of 1.25% enriched fuel required to achieve criticality. If the 160 kg limit were applied to stream KW2, the derived limit would be 1576 FGE/canister. If the FGE limit were increased to about 1000 FGE/canister, it would then not be more limiting than the heat source for hydrogen control. Filling canisters at a fissile content greater than currently allowed introduces the risk that WIPP would not accept the higher limit and as a result would not allow disposal of the waste. The table below provides the number of RH canisters required to satisfy the limits with and without relief on the fissile limit. The expansion in number of canisters could be accomplished by diluting the grout, partially filling canisters or a combination of both measures. In the most extreme case (KW2 without fissile relief,) not diluting the grout results in a nearly empty canister (1.3% full or about 11.2 liters of nominal grout in the bottom of the 0.865 m^3 container). In less extreme cases (KW3 and KE2 with relief on fissile limit) the canisters would be 20 to 25% full if the grout was not diluted.

Number of RH-Canisters for High Activity Streams Diluted to Meet WIPP Waste Acceptance Criteria

	KW2	KW3	KE2	Total
Nominal (prior to dilution)	0.6	6.1	7.7	14.4
Diluted to Meet Heat Limits (assumes relief to 1000 FGE/canister)	24.0	31.4	29.7	85.1
Diluted to Meet FGE Limit (assumes no relief on FGE Limit)	46.2	79.9	88.3	214.4

H12.0 OPEN ISSUES AND OTHER ALTERNATIVE OPTIONS

H12.1 ALTERNATIVE CONTAINER: PIPE-OVERPACK PROCESS - REVISED CONTAINER

The process described here is not evaluated in detail due to the requirement that new package designs be approved by WIPP which has substantial risk. The option involves

using a heavily shielded pipe overpack component within a drum to provide a contact handled grout package.

The primary pieces of equipment in the cell that would be different form the RH-TRU canister option would be an approximately 10-ft diameter turntable with 20 brackets to hold pipe components, a modified fill system to fill containers on the turntable and an air lock/floor pass through sized to allow shielded pipe components to be lowered through the floor into a 55 gallon drum overpack. Prior to grout mixing, pipe components would be passed through the airlock and the crane would load them into the turntable and remove the lids. After transfer of the waste and addition/mixing of the grout, the pipe components would be rotated one at a time into the "fill" position of the turntable and the grout would be added to the container.

The initial concept for the fill apparatus is to have a fill head seal against the component to be filled. The head would consist of a tube to introduce the grout into the can and a dip tube to allow excess grout to be escape once the desired level has been reached. The grout would gravity flow from the mixing tank to the mixing head. Any excess grout would be dumped into the next pipe in line to be filled. A flow sensor or simple visual observation of grout entering the second container would allow the valve to be closed and the fill head moved to the next container. An alternative concept would be to evacuate a chamber of the desired volume, allow grout to fill the chamber and then drain the container into the component to be filled.

The grout would be allowed to cure 48 hours with the top removed to determine that no free liquids are present. The crane would then place the lids back on the pipe components (including an integral filter). The cover block to the pass through would be removed and the component lowered into a waiting overpack drum, and the cover block replaced. The drum would then be removed, and a lid placed on the drum manually.

The first approximation size of equipment would be a 1 m^3 mixing tank, which would fill 20, 12-inch-pipe, overpack components. For processing a total of 50.6 m^3 of sludge, a total of 142 m^3 of grout would be produced. This would require 142 batches in the mixing tank. The initial goal would be to fill a pipe component every 3 minutes during pouring which would process 20 components in 1 hour. If this rate is not achievable the batch size may need to be reexamined. However, the grout when agitated should stay fluid for several hours. Also, if the shielding required reduces the capacity of each component, this could result in a reduction in batch size. Overall production rate might be improved by adding a curing rack so that one batch of components could be curing while the next was being filled.

There may be a need for more than one pipe overpack component design, one for KE/KW floor and pit sludge and a second including additional shielding for fuel wash and canister sludge. Dose rates would be measured on the mixing tank prior to adding the grout to determine if the shielding of the planned container is sufficient. If not, some dilution of the grout may be needed on a case by case basis in order to avoid failing to

meet the 200 mrem contact dose criteria. Drums that fail to meet the criteria when overpacked would be overpacked in WIPP canisters and disposed as RH-TRU.

After the pipe components are filled and placed in the racks they would be allowed to cure for 24 hours to verify the absence of free liquids. The top cover (including a filter) would be remotely placed on each component. A 55 gallon drum overpack would be inserted into the air lock below the floor and a pnematic actuator would seal the lip of the drum against the hole in the floor. The crane would then remove the cover block, and insert the pipe component into the overpack drum and replace the cover block. The drum could then be removed. Depending on the shielding required and the impact relative to weight limitations of various packages, the shipping option may then include placing the drums inside standard waste boxes for interim storage prior to shipment to WIPP in the TRUPACT-II. The most efficient use of space in the TRUPACT-II would be to place 14 drums in the TRUPACT-II. However, in this configuration, the maximum weight of a drum is 1000 lb. In addition, there is a 7265 lb/TRUPACT-II payload limit. It may be feasible to overpack the drums in a SWB which increases the maximum drum weight to 1450 lbs while limiting the SWB payload to 4000 lbs. Thus, 3 or 4 drums in a SWB may be the best option for contact handled packages. The second overpack would eliminate concerns with exterior package contamination.

H12.2 CURRENTLY WIPP-APPROVED SHIELDED OVERPACK CONTAINERS FOR LOW ACTIVITY STREAMS

An additional possibility for shipment of grouted sludge to WIPP would be to package the grout approved pipe components with overpack drums, using dilution of the grout to allow contact handled dose rate limits to be met. The approved containers provide some shielding and can allow waste with dose rates in excess of 200 mrem/h to be shipped in a TRUPACT-II cask as CH TRU waste if the surface dose on the overpack drum <200 mrem/hr. Calculations were performed on this configuration for 6" and 12"pipe components. In either case, the grout requires dilution to comply with the contact handled dose limit. Due to the very small payload of the 6" pipe component, the 12" pipe component results in fewer containers. After dilution, stream KW1 would require 541 pipe components and stream KE1 would require 22313 pipe components for a total of 22856 drum-sized packages to handle. Compared to the roughly 150 RH canisters, it was decided that this was not an attractive disposal option for the grout.

A potential alternative to diluting the grout to meet dose limits on the pipe component package is to design a modified package which incorporates the required shielding. Such a package configuration would require WIPP approval. WIPP personnel indicated that the process would cost on the order of 3 million dollars (of which the site may only need to pay a fraction) and require 2 to 5 years to receive approval. The requirement to obtain approval introduces substantial schedule risk that the design would not be approved in time to meet processing schedules. One option would be to design the containers and process "at-risk" filling non-approved containers to remove the sludge from the basin. This, of course, carries with it substantial risk that the packages would not be found acceptable for transport and disposal at WIPP.

H13.0 ADVANTAGES/DISADVANTAGES

Grout (with calcite of oversize material) has the following advantages:

- well established and accepted technology
- minimal equipment required which reduces size of cell
- minimal energy input for type A feed
- stabilization materials are inexpensive
- simple process with minimal maintenance requirement
- low temperature process for majority of sludge volume
- limited amount of gases generated by stabilization process
- inventory in any given tray during calcining is limited

Grout (with calcite of oversize material) has the following disadvantages:

- If the waste form fails to meet criteria, reprocessing is difficult
- Water content in grout matrix results in hydrogen generation from radiolysis
- Waste volume is increased by grouting. However, where waste volume is limited by fissile or heat load values for WIPP acceptance, the volume increase is not a disadvantage.
- Flushing of mixing vessel and lines is required after each batch to prevent buildup of grout in equipment
- Batch calcining process requires an argon-inerted cell to prevent ignition when handling sludge solids
- Loading and unloading of calciner trays may be operator intensive

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APPENDIX I

PARAMETRIC COST ESTIMATE

APPENDIX I

PARAMETRIC COST ESTIMATE

I1.0 ESTIMATE BASES AND ASSUMPTIONS

For each alternative, parametric estimates developed from the process descriptions and preliminary layouts were generated for each alternative. Costs were considered for the entire life cycle of the process facility, broken down into the following major categories:

- engineering and development,
- procurement and construction,
- operations,
- decontamination and decommissioning, and
- final waste disposal.

The key elements of each process through its life cycle were identified, and the major discriminating costs for these elements were estimated. The costs obtained were parametric in nature, and do not provide a basis to establish a cost baseline. It was determined that several attributes were common to all the alternatives, and would not provide discriminating cost information. Therefore, detailed costs were **not** generated for these attributes. These attributes include:

- contingency
- escalation
- transport costs to the transport facility
- project management
- regulatory and environmental support

The specific cost information does not represent a total project or life cycle cost and therefore should not be used for budgeting purposes. It does, however, provide a suitable basis for cost comparison. Near term costs for all alternatives include engineering and development, procurement and construction, and operations.

Long-term costs include the costs of decontamination and decommissioning the processing facility. Also included are the costs for final treatment to a disposable waste form, if the treated sludge was interim stored, disposal fees, and transportation to the disposal location.

I2.0 NEAR TERM COSTS

I2.1 ENGINEERING & DEVELOPMENT

Waste Form Qualification – estimated as 50% of the final waste disposal cost. Previous PNNL studies have used this assumption. Discussions with other sites show this as a

highly variable value (something less than $8 million to approximately $350 million). The West Valley Waste Project Demonstration Project (WVDP) estimated waste qualification costs to be approximately $350 million in 1997 dollars. Exact numbers for waste qualification at Defense Waste Processing Facility (DWPF) are not readily available, but Construction Project Data Sheets indicate approximately $300 million, in as-spent dollars, were devoted to research and development. The Savannah River Site (SRS) estimates that roughly $8 million for waste form qualification for plutonium disposition (vitrified) and melt/dilute product. However, the activity for the melt/dilute is intermeshed with other technical activities and so a useful number is not available. The extent to which waste qualification testing is included in the TWRS costs is unknown. Therefore, it should be noted that there is a great deal of uncertainty associated with the assumption.

Testing/Development – estimated as an order of magnitude for the work, based on historical costs and plans for the testing supporting the chemical process development. A complexity factor was then applied to the other alternatives.

Safety Documents – a ROM estimate was obtained from the FDNW Safety Analysis group, based on previous safety documentation development (i.e., PSE, PSAR, and SAR) for similar processes and facilities. A complexity factor added to grinding/milling due to the process uncertainties.

Design – calculated as a percentage of buildings/structures/improvements to land and procurements/fabrication/installation costs based on historical data from previous projects

- Conceptual/Title I - 8%
- Title II – 20%
- Title III – 12%

I2.2 PROCUREMENT & CONSTRUCTION

Building/Structures/Improvements to Land - Utilized previous estimate (Z649SAA1) for a preprocessing facility with similar functions, similar throughputs, and also with all activities being performed under the same roof. The entire building costs were lumped together and treated as an average cost per square foot. Included in the building cost is the administrative area, mechanical room, electrical room, control room, rest rooms, change rooms, elevator, maintenance rooms and all required equipment and process rooms. The cost also includes sitework, underground utilities, fire protection, HVAC, normal electrical distribution, standby electrical distribution, uninterruptible power source, distributed control system, communication system, analytical facilities, HEPA filtration system, stack, fan house, health and physics monitoring equipment and supporting internals (process heating and cooling). Costs also include contractor overhead and profit and construction management.

Modifications at Storage Facility – Cost for options going to TWRS include modifications at AW farm (i.e., receiving station based on a previous design effort), modification of the TWRS BIO and supporting analysis. Costs of modifications at CWC were obtained from Waste Management Hanford staff and are based on acceptance documentation required to receive the waste (i.e., modification to the facility ISB, permits, etc.). (see Cost Estimate Basis Details)

Procure/Fabrication/Installation – Costs for major equipment were obtained from vendors, where possible. Historical research and estimating practices as defined in the AACE Manual indicate that equipment costs amount to roughly one fifth the total installed cost for a piece of equipment. Lacking more specific information, this rule of thumb method was used to project an "as installed" cost. Vendor quotes were compared to information obtained from previous Hanford projects (i.e., HWVP, W-041, Environmental Hot Cell Expansion) and other national and international facilities. Assumptions made for more generic equipment include:

- Tanks - Due to the variety of sizes and types of tanks, a simple cost per gallon method of costing was abandoned in favor of a graduated scale. Unless information was available to allow actual costs to be developed, or actual costs were known, the following scale of costs were applied:
  - 50 gal and less @ 112./gal
  - 51 to 100 gal @60./gal
  - 101 to 150 gal @ 50./gal
  - 151 to 250 gal @ 40./gal
  - 251 to 500 gal @ 25./gal
  - 501 to 1000 gal @ 20./gal
  - 1001 to 2000 gal @ 15./gal
  - 2001 to 5000 gal @ 12.50/gal
  - 5001 to 10000gal@ 10./gal
  - 10000 gal and up @ 7.50/gal
- Cranes - Crane costs were prorated from a recent price quote for nuclear class cranes using remote operation in a radiation zone as shown in estimate Z649SAA1.
- Manipulators – Manipulators were priced at a total installed cost of $100,000 each. The cost basis came from W-041 (completed in 1995 at 222S Labs and was a $13 million upgrade that included 8 new hot cells).
- Leaded Glass Windows - Based on historical cost data from W-041, an average installed cost per viewing window of $120,000 was used.

Vehicles/Casks – shipments to TWRS are based on information being developed in a Transport Engineering Study. Calcination factors in the cost for qualifying a new package; it was estimated that it would cost about $3.3 million for development, analysis and testing of a new package configuration and NRC review and approval.

It was assumed for estimating purposes that the glass canisters would be stored in NUHOMS systems and standalone casks. Costs were obtained from past studies

(Calmus, Baker 1996). The unit cost for a dry shielded container plus vault (NUHOMs) is about $375,000. For the pad storage units, a specially designed transport trailer would be required, estimated cost is $3 million. The unit cost for a standalone cask is $180,000 (see Cost Estimate Basis Details).

Spare Parts – estimated as a percentage of major key pieces of equipment

I2.3 OPERATIONS

Start up OTPs and Operations/Maintenance/Administration/Handling - costs were estimated based on a projected staffing profile developed with concurrence from SNF Operations. Averaged exempt and bargaining units labor rates were used (see Table I-3).

Operations at Receiving Facilities - Operations at the receiving facilities were based on projected receiving crews and the number of expected shipments to the facilities. Averaged exempt and bargaining unit labor rates were used (see Cost Estimate Basis Details).

Process Sampling and Waste Acceptance/Verification Sampling – sample costs were developed by laboratory personnel based upon the analyses assumed required for process control and product verification. The costs are predicated on the assumptions made concerning processing and the disposal route (requirements have not yet been firmly established for verification sampling). The processing alternative chosen makes a small difference in cost of the analytical support. There are uncertainties in the actual criteria required at the time processing commences; costs may be either increased or decreased. The analytical costs are based on assuming full coverage for the number of persons necessary to provide analyses on all samples received from the operation. Dedicated staff is required to meet the programmatic turnaround time of data (see Tables I-4, I-5, I-6, and I-7).

Materials/Consumables – estimated for key constituents based on the flowsheets and mass balances for each alternative (see Table I-8).

Secondary Waste Disposal – developed from volumes identified in the mass balances. Costs were obtained from the identified disposal sites (i.e., ERDF, WIPP). The estimated cost for disposal of waste at ERDF is $50 per ton. For the liners, $4,000 per liner was added. The current storage rate for CH TRU drums at CWC is $85.57 per ft3. It was assumed that all of the waste products sent to CWC would be contact handled or overpacked into shielded containers, resulting in CH packages.

For the vitrification option, the storage costs at CWC were calculated using the total estimated volume of the concrete pads required for the NUHOMs systems and standalone casks (see Cost Estimate Basis Details).

I3.0 LONG-TERM COSTS

I3.1 DECONTAMINATION AND DECOMMISSIONING

Building Demolition – costs were based on the estimated concrete volume of the building. This volume was assumed to be 18% of the gross building volume. Costs were prorated from a 1993 HWVP Clean Closure estimate (E-082-93-RWO) that was escalated 19.4% to 1999 dollars. The cost of $4,691/cy includes Part A and closure plan preparation, soil data interpretation, soil background determination, soil sampling, verification sampling, D&D work plans, design/engineering, project management, demolition and disposal costs.

I3.2 FINAL WASTE DISPOSAL

LAW Costs - Transportation/Disposal/Handling and Additional Treatment/Storage costs for the options going to TWRS are based on costs associated with the amount of Na to be processed into LAW glass (resulting from blending treated sludge with AW-105 tank waste). Process and disposal costs for LAW waste were estimated by TWRS-WDD (Taylor 1999). Cost to process sodium assuming Envelope C waste (1.15 units/MT Na) is $230,000 per unit. The cost to dispose of LAW glass is estimated to be $3,800 per m3 of glass (see Cost Estimate Basis Details).

Geologic Repository Costs - The vitrification alternative costs for disposal of the glass canisters were estimated using repository disposal fee estimates for the Hanford TWRS-EIS and estimates of the total number of canisters. Based on these calculations the disposal fee per canister was estimated at $422,000 (see Cost Estimate Basis Details).

WIPP Costs - Calcining, grouting, and all secondary costs to WIPP are estimated using costs provided by WIPP for disposal/transportation/handling. It has been pointed out by WIPP that the sites are not responsible for budgeting for transportation and disposal cost for defense TRU waste destined for WIPP. The estimate provided by WIPP is to be used for the purpose of evaluating alternative approaches for treatment. The cost (represented in Fiscal Year 1998 unescalated dollars) was developed on a per shipment basis with full operations at WIPP. The average cost per CH-TRU drum is assumed to be $750 for transportation and about $190 for disposal. The RH-TRU transportation cost is approximately $14,200 per shipment, with the disposal cost being approximately $2,500 per shipment. Each RH-TRU shipment consists of one RH-72B cask containing one canister (Dials 1997) (see Cost Estimate Basis Details).

I4.0 PARAMETRIC ESTIMATE SUMMARIES

The following tables provide the parametric estimates for the six alternatives:

- Table I-1 summarizes the near term and long term discriminating costs for all of the alternatives being considered.

- Table I-2 provides the details on major equipment costs. All costs are for installed equipment. Also included is the methodology used to calculate the spare costs used.
- Table I-3 is the estimated labor force upon which the operations costs are computed. An average exempt labor rate and an average bargaining unit labor rate was used to calculate total operations costs.
- Table I-4 provides the unit pricing and hours necessary to perform the analyses required to store sludge in AW-105 or dispose of the grouted waste at ERDF.
- Table I-5 provides an estimate of the cost to perform each analysis required to dispose of the product to the National Repository or to WIPP.
- Table I-6 presents logic of cost per analysis with the conclusion that the analytical cost for each of the processing alternatives is approximately equivalent.
- Table I-7 provides logic for specific analyses required on the product fractions not going to Tank Farms.

Table I-1. Summary of Sludge Treatment Alternative Costs

DESCRIPTION	ALT 1 BASELINE	ALT 2 SIMPL. CHEM	ALT 3 GRIND / MILL	ALT 4 VITRFICATION	ALT 5 CALCINATION	ALT 6 GROUTING
DEVELOPMENT						
- WASTE FORM QUALIFICATION	$ -	$ -	$ -	$ 10,000,000	$ 115,000	$ 3,000,000
- TESTING/DEVELOPMENT	$ 2,000,000	$ 2,000,000	$ 10,000,000	$ 5,000,000	$ 4,000,000	$ 4,000,000
SAFETY DOCUMENTS						
- SAR	$ 5,000,000	$ 5,000,000	$ 10,000,000	$ 10,000,000	$ 5,000,000	$ 5,000,000
DESIGN	$ 11,760,392	$ 11,343,288	$ 11,815,992	$ 13,116,424	$ 13,220,464	$ 14,041,504
- CONCEPTUAL / TITLE I (8%)	$ 2,352,078	$ 2,268,658	$ 2,363,198	$ 2,623,285	$ 2,644,093	$ 2,808,301
- TITLE II (20%)	$ 5,880,196	$ 5,671,644	$ 5,907,996	$ 6,558,212	$ 6,610,232	$ 7,020,752
- TITLE III (12%)	$ 3,528,118	$ 3,402,986	$ 3,544,798	$ 3,934,927	$ 3,966,139	$ 4,212,451
ENGINEERING & DEVELOPMENT	$ 18,760,392	$ 18,343,288	$ 31,815,992	$ 38,116,424	$ 22,335,464	$ 26,041,504
BUILDING/STRUCTURES/IMPROVE TO LAND	$ 21,089,000	$ 20,493,000	$ 18,525,000	$ 17,284,000	$ 17,284,000	$ 19,765,000
MODS AT STORAGE FACILITY	$ 3,310,000	$ 3,100,000	$ 3,100,000	$ 419,000	$ 256,000	$ 210,000
PROCURE/FAB/INSTALL	$ 13,011,980	$ 12,565,220	$ 15,654,980	$ 22,992,060	$ 19,067,160	$ 15,338,760
- MAJOR EQUIPMENT	$ 8,311,980	$ 7,865,220	$ 11,014,980	$ 15,507,060	$ 15,767,160	$ 15,338,760
- VEHICLES / CASKS	$ 4,700,000	$ 4,700,000	$ 4,640,000	$ 7,485,000	$ 3,300,000	$ -
SPARE PARTS	$ 259,000	$ 82,000	$ 497,800	$ 645,000	$ 595,000	$ 623,000
PROCUREMENT & CONSTRUCTION	$ 37,669,980	$ 36,240,220	$ 37,777,780	$ 41,340,060	$ 37,202,160	$ 35,936,760
- S/U OTP'S	$ 6,056,133	$ 6,092,753	$ 5,981,863	$ 6,469,520	$ 6,175,533	$ 5,881,546
- OP'S/ MAINT. STAFF/ ADMIN/ HANDLG.	$ 9,841,216	$ 9,900,723	$ 9,720,528	$ 10,512,970	$ 10,035,241	$ 9,557,512
- OP'S (based on # of transports)	$ 3,920,000	$ 4,154,000	$ 3,331,000	$ 107,000	$ 161,000	$ 610,000
- PROCESS SAMPLING	$ 400,000	$ 400,000	$ 322,000	$ 4,200,000	$ 100,000	$ 200,000
- WASTE ACCEPTANCE / VERIFICATION SAMPLG.	$ 4,000,000	$ 4,000,000	$ 4,000,000	$ 100,000	$ 4,200,000	$ 4,200,000
- MATERIALS / CONSUMABLES	$ 732,525	$ 201,000	$ 47,118	$ 545,500	$ 505,500	$ 3,662,000
- SECONDARY WASTE DISPOSAL/STORAGE	$ 32,000	$ 38,000	$ 2,300	$ 740,000	$ 280,000	$ 1,652,000
OPERATIONS	$ 24,981,874	$ 24,786,476	$ 23,404,809	$ 22,674,990	$ 21,457,274	$ 25,763,059
NEAR TERM COSTS	$ 81,412,246	$ 79,369,984	$ 92,998,581	$ 102,131,474	$ 80,994,898	$ 87,741,323
- PROCESS FACILITY	$ 13,557,000	$ 13,168,000	$ 11,906,000	$ 11,108,000	$ 11,108,000	$ 12,703,000
- MODS @ STORAGE FACILITY	$ 717,375	$ 717,375	$ 717,375	$ -	$ -	$ -
D & D	$ 14,274,375	$ 13,885,375	$ 12,623,375	$ 11,108,000	$ 11,108,000	$ 12,703,000
TRANSPORATION/DISP/HANDLING	$ 2,200,000	$ 2,000,000	$ 300,000	$ 19,412,000	$ 181,000	$ 6,080,000
ADDITIONAL COSTS TREATMENT/INT. STORAGE	$ 42,300,000	$ 35,000,000	$ 5,100,000	$ -	$ -	$ -
SECONDARY WASTE TO WIPP	$ 3,000	$ -	$ -	$ -	$ -	$ -
FINAL WASTE DISPOSAL	$ 44,503,000	$ 37,000,000	$ 5,400,000	$ 19,412,000	$ 181,000	$ 6,080,000
LONG TERM COSTS	$ 58,777,375	$ 50,885,375	$ 18,023,375	$ 30,520,000	$ 11,289,000	$ 18,783,000
TOTAL	$ 140,189,621	$ 130,255,359	$ 111,021,956	$ 132,651,474	$ 92,283,898	$ 106,524,323

Table I-2. Summary of Equipment Costs

	ALT 1 BASELINE	ALT 2 SIMPL. CHEM	ALT 3 GRIND/MILL	ALT 4 VITRIFICATION	ALT 5 CALCINATION	ALT 6 GROUTING
bridge cranes	2,250,000	2,250,000	3,500,000	3,500,000	3,500,000	3,500,000
manipulators	-	100,000	500,000	500,000	500,000	400,000
lead viewing windows	-	360,000	1,200,000	1,200,000	1,080,000	1,200,000
tanks	416,000	203,000	136,000	68,000	73,000	58,000
screen	15,000	-	-	-	-	15,000
centrifuge	1,750,000	-	-	-	-	-
hydropulse filter		80,000				
grout mixer	1,000,000	2,000,000	500,000	750,000	750,000	2,500,000
condenser	300,000	300,000	150,000	150,000	150,000	150,000
NOx absorption column	270,000	270,000	-	270,000	90,000	-
demister	90,000	90,000	90,000	-	-	-
heater	33,000	33,000	-	-	-	-
activated carbon filter	25,000	25,000	25,000	25,000	25,000	25,000
HEME filter	-	-	-	90,000	90,000	90,000
heat exchanger	-	-	-	150,000	-	-
sintered metal blowback element	-	-	-	-	200,000	-
submerged bed scrubber (SBS)	-	-	-	500,000	-	-
pneumatic transfer	-	-	-	-	-	100,000
Ar circulation loop	-	-	-	-	-	1,000,000
grinder (2)	-	-	3,888,000	-	-	-
dorr clone ca/tm	-	-	800,000	-	-	-
knockout pot	-	-	10,000	-	-	-
melter	-	-	-	1,000,000	-	-
turntable	-	-	-	1,500,000	-	-
decon station	-	-	-	2,000,000	2,000,000	2,000,000
canister transfer	-	-	-	1,500,000	1,500,000	1,500,000
overpack transfer rail	-	-	-	-	1,500,000	-
calciner	-	-	-	-	3,000,000	-
dissolver	2,000,000	2,000,000	-	1,000,000	1,000,000	-
weld station	-	-	-	1,000,000	-	-
furnace (3)	-	-	-	-	-	1,500,000
cell inert gas system (N2)	-	-	-	-	-	1,000,000
MAJOR EQUIPMENT SUBTOTAL	8,149,000	7,711,000	10,799,000	15,203,000	15,458,000	15,038,000
small tools @2% of MAJOR EQUIP	162,980	154,220	215,980	304,060	309,160	300,760
MAJOR EQUIP + SMALL TOOLS	8,311,980	7,865,220	11,014,980	15,507,060	15,767,160	15,338,760
spare parts	259,000	82,000	497,800	645,000	595,000	623,000
pumps (1/3 replacement cost)	44,000	22,000	15,000	8,000	8,000	7,000
agitators (@10% tank cost)	40,000	20,000	14,000	7,000	7,000	6,000
manipulators	-	40,000	80,000	80,000	80,000	160,000
centrifuge (10% instl'd cost)	175,000	-	-	-	-	-
melter parts (@ 10% instl'd cost)	-	-	-	100,000	-	-
grinder parts (@ 10% instl'd cost)	-	-	388,800	-	-	-
turntable (@ 10% instl'd cost)	-	-	-	150,000	-	-
decon stn (@10% instl'd cost)	-	-	-	200,000	200,000	200,000
calciner (@10% instl'd cost)	-	-	-	-	300,000	-
furnace (@10% instl'd cost)	-	-	-	-	-	150,000
weld stn (@10% instl'd cost)	-	-	-	100,000	-	-
cell inert gas system (10%)	-	-	-	-	-	100,000

Table I-3. Estimated Labor Force (2 sheets)

SUB GROUP	DISCIPLINE	RES CODE	1999 RATE	ALT 1 BASELINE E	ALT 1 BASELINE B	ALT 2 SIMPL. CHEM E	ALT 2 SIMPL. CHEM B	ALT 3 GRIND / MILL E	ALT 3 GRIND / MILL B	ALT 4 VITRFICATION E	ALT 4 VITRFICATION B	ALT 5 CALCINATION E	ALT 5 CALCINATION B	ALT 6 GROUTING E	ALT 6 GROUTING B
	PLANT MGR	DM01E	$ 55.62	1		1		1		1		1		1	
	ADMIN ASST	DG01B	$ 42.39	1		1		1		1		1		1	
	TECH/BUDGET ASST	DG06N	$ 30.51	1		1		1		1		1		1	
	CLERICAL	DG02B	$ 30.51		1		1		1		1		1		1
PLANT MGT															
	MGR/CLERICAL	DM01E	$ 55.62	0.5		0.5		0.5		0.5		0.5		0.5	
	DESIGNERS/DRAFTERS	DT02N	$ 48.90	0.2		0.2		0.2		0.2		0.2		0.2	
	PLANT ENG	DE10E	$ 57.52	0.25		0.25		0.25		0.25		0.25		0.25	
PLANT ENG															
	MGR/SUPV	DM01E	$ 55.62	1		1		1		1		1		1	
	CHEMIST	DS01E	$ 87.74	1		1		1		1		1		1	
	CHEM TECH	DT08B	$ 48.90		4		4		4		4		4		4
ANALYTICAL LAB															
	MGR/CLERICAL	DM01E	$ 55.62	0.25		0.25		0.25		0.25		0.25		0.25	
	HPT	DT05B	$ 50.04		6		6		6		6		6		6
RAD PROTECTION															
	MGR/SUPV	DM01E	$ 55.62	0.25		0.25		0.25		0.25		0.25		0.25	
	CLERICAL	DG02B	$ 30.51		0		0		0		0		0		0
	CRANE OPER	DR03B	$ 54.79		1		1		1		1		1		1
	POWER OPER	DR07B	$ 49.15		0.2		0.2		0.2		0.2		0.2		0.2
	DRIVER	DL07B	$ 40.62		3		3		3		1.5		1.5		1.5
FACILITY SVC															
COMPUTER SUPPORT		DP06E	$ 56.15	0.1		0.1		0.1		0.1		0.1		0.1	
DOC CTRL		DG06N	$ 30.51	0.1		0.1		0.1		0.1		0.1		0.1	
BUILDING SUPPORT															
	MGR/CLERICAL	DM01E	$ 55.62	0.2		0.2		0.2		0.2		0.2		0.2	
	SHIFT ENG	DE00E	67.79	4		4		4		4		4		4	
	PROCESS ENG	DE00E	67.79	3		3		2		3		3		2	
	L&E ENG	DE00E	67.79	1		1		2		2		1		1	
	MECH ENG	DE07E	72.68	0		0		2		0		0		0	
PROC & TECH															
	MGR/CLERICAL	DM01E	$ 55.62	0.1		0.1		0.1		0.1		0.1		0.1	
	QC INSPECTOR	DE11E	$ 66.71	0.5		1		0.5		1		1		1	
	QA ENGR	DE11E	$ 66.71	0.1		0.1		0.1		0.1		0.1		0.1	
QA&C															
	MGR/CLERICAL	DM01E	$ 55.62	0.1		0.1		0.1		0.1		0.1		0.1	
	EMERGENCY PREP	DE12E	$ 62.85	0.1		0.1		0.1		0.1		0.1		0.1	
	SPECIALIST	DE08E	$ 85.09	0.1		0.1		0.1		0.1		0.1		0.1	
	RAD ENG	DE08E	$ 85.09	0.1		0.1		0.1		0.1		0.1		0.1	
	CRITICALITY ENG	DE08E	$ 85.09	0.25		0.25		0.25		0.25		0.25		0.25	
	INDUST SFTY ENG	DE06E	$ 67.79	0.1		0.1		0.1		0.1		0.1		0.1	
SAFETY ENG															

Table I-3. Estimated Labor Force (continued)
(2 sheets)

ENG & SUPT																		
OPS MGR	DM01E	$ 55.62	1		1		1		1		1		1					
SHIFT MGR	DM01E	$ 55.62	4		4		4		4		4		4					
SHIFT SUPT MGR	DM01E	$ 55.62	4		4		4		4		4		4					
OPS PLANT MGR	DM01E	$ 55.62	4		4		4		4		4		4					
CLERICAL	DG02B	$ 30.51		1		1		1		1		1		1				
OPS MGT																		
PROCESS CONTROL	DR01B	$ 54.79		20		20		16		20		20		16				
OPERATORS																		
HPT	DT05B	$ 50.04		16		16		12		16		16		16				
RADIATION PROTECTION																		
PROCESS STAFF																		
PIC	DE10E	$ 57.52	1		1		1		1		1		1					
MILLWRIGHTS	DC06B	$ 50.08		1		1		4		4		4		4				
PIPEFITTERS	DC08B	$ 50.08		4		4		1		4		4		4				
RIGGERS	DL09B	$ 40.62		2		2		2		2		2		2				
DRIVERS	DL07B	$ 40.62		1		1		1		1		1		1				
MECH MAINT																		
PIC	DE10E	$ 57.52	1		1		1		1		1		1					
I&E TECHNICIANS	DT07B	$ 53.24		4		4		4		4		4		4				
ELECTRICIAN	DC02B	$ 53.24		4		4		8		8		4		4				
I&E MAINT																		
MAINTENANCE																		
TOTAL STAFFING PROJECTED (FTE)			31.3	68.2	31.8	68.2	33.3	64.2	32.8	73.7	31.8	69.7	30.8	65.7				
EXEMPT HOURS (1820 HRS X FTEs)			56,966		57,876		60,606		59,696		57,876		56,056					
BARGAINING UNIT HOURS (1820 HRS X FTEs)				124,124		124,124		116,844		134,134		126,854		119,574				
EXEMPT RATE (AVERAGE)		$ 60.36	$ 3,438,575		$ 3,493,504		$ 3,658,292		$ 3,604,362		$ 3,493,504		$ 3,383,645					
BARGAINING UNIT RATE (AVERAGE)		$ 45.48		$ 5,645,625		$ 5,645,625		$ 5,314,503		$ 6,100,917		$ 5,769,796		$ 5,438,674				
STAFFING EXPENSE PER ALT				$ 9,084,200		$ 9,139,129		$ 8,972,795		$ 9,704,280		$ 9,263,300		$ 8,822,319				

Table I-4. Cost for Analyses for TWRS and ERDF

Analyte	Hours to Complete Analysis (Liquid, Acid Sample	Cost to Perform Analysis (Liquid, Acid Sample) Dollars	Hours to Complete Analysis (Solid Sample for ERDF)	Cost to Perform Analysis (Solid Sample) (1)	Comments
Strontium-90 + Yitrium-90	16	900	24	1400	
Cesium-137	4	300	6	300	
Pu-239+Pu-240 / AEA + AT	16	1500	24	2350	
Am-241	16	2000	24	2350	
Np-237	N/R		16	2000	
Total U	4	850	8	1388	
U Isotopics	16	875	24	1060	
Neutron Absorbers and regulated metals	6	575	12	700	
Ammonia (2)	N/A		N/R		
Sodium Hydroxide (caustic demand) (3)	2	250	N/R		Process Control Only
Sodium	3	575	4	700	
TOC	4	975	4	1000	
Percent Water (5)	N/A		N/R	750	
Specific Gravity	3	185	N/R	300	
Vol Percent Solids	4	80	N/R	50	Can be in-line monitor
Nitrate/Nitrite/ Chloride	4	940	N/R	N/R	
pH (6)	1	60	N/R	N/A	
Hydroxide (7)	N/A	237	N/R	100	
Energetics (8)	4	755	5	800	

Notes For Table I-4

N/A = Not Applicable; N/R = Not Required

1) The hours and cost is calculated based on a separated solids fraction delivered for analysis. Added time and cost is attributed to sample dissolution prior to chemical analyses.
2) Ammonia will not be present in acid system and no source in sludge fraction
3) Caustic Demand should be substituted for sodium hydroxide in the acid sample
4) Sodium hydroxide is meaningless on sludge solids
5) Percent Water in a liquid sample is meaningless; may be required on settled solids fraction one-time.
6) pH required on neutralized sample for tank farm disposal.
7) Hydroxide must be performed on final slurry.
8) The definition of energetics will need clarification; organic fuel not an issue in K Basin, but will provide an indication of reactive metal species.

Table I-5. Schedule and Cost of Analyses for Repository Disposal

Analyte	Hours to Complete Analysis (Sludge)	Cost to Perform Analysis Dollars	Comments
U Total	8	1388	
U Isotopics	24	1066	
Pu-239+Pu-240			Estimated with Pu Isotopics
Pu Isotopics	24	2350	
Am-241	24	2350	
Np-237	24	2350	
Hazardous Metals	12	700	
Sr-90	24	1400	
GEA	6	300	
TOC	4	1000	
PCB	36	1800	
TCLP (1)	(2)	3000	

Note:

1) If waste form is prequalified, this requirement may be waived
2) Dependent on protocol

Table I-6. K Basin Analytical Cost Addendum

Process Alternative	Cost per Batch or Sample (K$) Process Control/ Product Criteria (1)	Cost for Process Duration Liquid / ERDF Solids (2)	Total Cost (K$) (5)
Baseline (acid)	2.6 / 9.3 = 11.9 (3) / 17.1 (4)	3,213.0 923.4	4,136.4
Shift Operation to provide Turnaround			4.357
Grout/Vitrification/ Calcine	3.7 / 14.0 = 17.7	4,779.0	4,779.0 (6)

Notes:

(1) Includes both liquid process control, product, and ERDF Solids
(2) Estimated 270 liquid product batches and 54 ERDF solids batches
(3) Liquid Fraction
(4) ERDF Fraction
(5) Includes no rework or process tests
(6) Analytical batching with greater than 24-hour turnaround is anticipated to reduce cost to $4.5M.

Table I-7 provides logic for specific analyses required on the product fractions not going to Tank Farms. The table also provides a logic for the analyses required for process control; assuming criticality is primary safety concern. Data generated to provide these process controls are assumed to be usable for product validation.

Table I-7. Justification for Specific Analyses for Grout/Vitrification/Calcine Processes

Analyte	WAC REQUIREMENT			
	FGE/PACKAGE	Radionuclides >0.05% of total	Hazard Classification	Process Control
Total Uranium				
Uranium Isotopics	X	X		X
Plutonium-239/240				X
Plutonium Isotopics	X	X		X
Americium-241	X	X		
Neptunium-237	X	X		
Metals			X	
Strontium-90		X		
Gamma Energy		X		X
TOC			X	
PCB			X	
TCLP			X	

This requirement list assumes in-line monitoring will be conducted external to laboratory operations for monitoring gaseous emissions. It also assumes water content of filled product containers will be monitored with NDA instrumentation at-line.

I5.0 COST ESTIMATES – BASIS

I5.1 ALTERNATIVE 1 – BASELINE CHEMICAL

I5.1.1 Near-Term Costs

ERDF Disposal Costs

- $50/ton [1997 $, lifecycle cost, LM Johnson e-mail]
- $4000/monolith [i.e., L14-170 liners, LM Johnson e-mail]
- weight of one L14-170 liner (empty) = 1550 lbs
- mass of concrete in 7 liners (Westra 1998) = 9357 kg = 10.3 ton
- number of drums disposed at ERDF = 46 (Westra 1998)
- weight of one 55-gallon drum = 60 lbs
- mass of concrete in 55-gallon drum (assuming density = 1.73) = 794 lbs/drum

(7 liners x 1550 lb)/2000 lb/ton = 5.425 tons
total mass of liners = 5.4 + 10.3 = 15.7 tons
(46 drums x 854 lbs/drum)/2000 lb/ton = 19.6 tons
total mass = 16 + 20 = 36 tons

Secondary Waste Disposal/Storage = (36 tons x $50/ton) + ($4000/liner x 7 liners) = $29.8K

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 19 = $16.7K

CWC Waste Acceptance

- Acceptance criteria = $30K
- NEPA documentation = $40K
- Part B modification = $30K
- ISB modification = $100K
- Waste acceptance modification = $10K

Mods @ Storage Facility = $210K (KM McDonald e:mail 1999)

CWC Handling/Disposal (waste receipt)

- $85.57/ft3 for CH-TRU drum (KM McDonald e:mail 1999)
- volume of CH-TRU drum is 7.35 ft3
- 3 drums per shipment
- Total number of drums disposed at CWC = 3 (Westra 1998)

Secondary Waste Disposal/Storage = 3 drums x 7.35 ft3/drum x $85.57/ft3 = $1887 = $2K

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 1 shipment = $ 0.88K

TWRS Waste Acceptance (waste receipt)

- Transport operations include sludge loadout, sludge transportation, and sludge offload activities
- Cost estimate for cask/vehicle and op's is based on 8 m3 cask ; 205 shipments

Mods at Storage Facility = $3100K (baseline budget)

OP's (based on # of transports) = $3900K

Vehicles/Casks = $4700K (design, develop, and fabricate)

I5.1.2 Long-Term Costs

WIPP Transportation/Handling/Disposal

- $750 for transportation (Dials 1997)
- $190 for disposal (Dials 1997)

Secondary Waste to WIPP = 3 drums x $940/drum = $2.8K

BNFL Process/Disposal

Additional Costs Treatment/Int. Storage = $42.3M (Taylor 1999)
Transportation/Disp/Handling = $2.2M (Taylor 1999)

I5.2 ALTERNATIVE 2 – MODIFIED CHEMICAL

I5.2.1 Near-Term Costs

ERDF Disposal Costs

- Total number of CH drums disposed at ERDF = 1784 (Appendix D)

(1784 drums x 854 lbs/drum)/2000 lb/ton = 762 tons

Secondary Waste Disposal/Storage = (762 tons x $50/ton) = $38K

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 595 = $524K

TWRS Waste Acceptance (waste receipt)

- Transport operations include sludge loadout, sludge transportation, and sludge offload activities
- Cost estimate for cask/vehicle and op's is based on 8 m3 cask ; 191 shipments

Mods at Storage Facility = $3100K (baseline budget)

OP's (based on # of transports) = $3630K

Vehicles/Casks = $4700K (design, develop, and fabricate)

I5.2.2 Long-Term Costs

BNFL Process/Disposal

Process Cost (estimates revised from Taylor 1999 due to revisions in flowsheet resulting in higher sodium added to sludge)

- Total amount of dissolved sodium in sludge = 123,000 kg
- Total amount of Na to caustic leach sludge = 7863 kg
- Total sodium oxide to LAW = 131,000 kg x 1.35 = 176850 kg

Units of Na processed assuming Envelope C waste (1.15 units/MT Na)
Units of Na = 1.15 x (123 + 8)MT = 151 units

M3 of glass to dispose of as LAW
(177 MT Na2O/ 0.14 MT Na2O per MT glass)/ 2.7 MT glass per m3 = 468 m3 glass

Additional Costs Treatment/Int. Storage = 151 units x $230,000/unit = $35M
Transportation/Disp/Handling = 468 m3 x $3800 = $1.8M

I5.3 ALTERNATIVE 3 – GRINDING/MILLING

I5.3.1 Near-Term Costs

ERDF Disposal Costs

- Total number of CH drums disposed at ERDF = 104 (Appendix D)

(104 drums x 854 lbs/drum)/2000 lb/ton = 45 tons

Secondary Waste Disposal/Storage = (45 tons x $50/ton) = $2,250

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 35 = $30,800

TWRS Waste Acceptance (waste receipt)

- Transport operations include sludge loadout, sludge transportation, and sludge offload activities
- Cost estimate for cask/vehicle and op's is based on 7 m3 cask ; 175 shipments

Mods at Storage Facility = $3100K (baseline budget)

OP's (based on # of transports) = $3300K

Vehicles/Casks = $4640K (design, develop, and fabricate)

I5.3.2 Long-Term Costs

BNFL Process/Disposal

Process Cost (revised from Taylor 1999 based on revised process flowsheet resulting in lower sodium additions to sludge)

- Total amount of dissolved sodium in sludge = 5903 kg
- Total amount of Na to caustic leach sludge = 13311 kg
- Total sodium oxide to LAW = 19214 kg x 1.35 = 25939 kg

Units of Na processed assuming Envelope C waste (1.15 units/MT Na)
Units of Na = 1.15 x (5.9 + 13.3)MT = 22.1 units

M3 of glass to dispose of as LAW
(26 MT Na2O/ 0.14 MT Na2O per MT glass)/ 2.7 MT glass per m3 = 69 m3 glass

Additional Costs Treatment/Int. Storage = 22.1 units x $230,000/unit = $5.1M
Transportation/Disp/Handling = 69 m3 x $3800 = $ 0.3M

Disposal cost for BNFL HLW glass = $0.0 (assumes alumina media NOT zirconia as cited in Taylor 1999)

I5.4 ALTERNATIVE 4 - VITRIFICATION

I5.4.1 Near-Term Costs

ERDF Disposal Costs

- Total number of shielded RH drums disposed at ERDF = 189 (Appendix F)

(189 drums x 2150 lbs/drum)/2000 lb/ton = 203 tons

Secondary Waste Disposal/Storage = (203tons x $50/ton) = $10.2K

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 63 = $55.4K

CWC Waste Acceptance

Mods @ Storage Facility = $210K (KM McDonald e:mail 1999)

CWC Handling/Disposal for Glass Canisters

- Assumes Nuhoms systems (4 canisters/ DSC) and Standalone casks (1 canister/cask) are needed to store 46 glass canisters
- Dry shielded container & vault unit cost = $375K (Calmus, Baker, 1996)
- Standalone cask unit cost = $180K (Calmus, Baker, 1996)
- Concrete pad (3m x 12m x 30.5 cm) unit cost = $19K (Calmus, Baker, 1996)
- Transporter for NuHOMS = $3000K (Calmus, Baker, 1996)
- CWC disposal cost = $171/ft3 (McDonald 1999)

Vehicles/Cask s = (11 DSC x $375K) + (2 Casks x $180K) + $3000K = $7485K (1995 $'s)

Mods at Storage Facility (i.e., 11 concrete pads) = 11 x $19K = $209K (1995 $'s)

Secondary Waste Disposal/Storage (based on volume of pads) = 11 x (3m x 12m x .305m) x 35.314 ft3/m3 x $171/ft3 = $729K

OP's (based on # of transports) = 8 hours/shipment x 9 BU x $55/hr x 13 shipments = $51.5K

I5.4.2 Long-Term Costs

Geologic Repository Transportation/Handling/Disposal

- $422K disposal fee per canister (Schaus 1998)

Transportation/Disp/Handling = 46 canisters x $422K = $19,412K

I5.5 ALTERNATIVE 5 - CALCINATION

I5.5.1 Near-Term

ERDF Disposal Costs

- Total number of shielded RH drums disposed at ERDF = 189 (Appendix G)

(189 drums x 2150 lbs/drum)/2000 lb/ton = 203 tons

Secondary Waste Disposal/Storage = (203tons x $50/ton) = $10.2K

OP's (based on # of transports) = 4 hrs x 4 BU x $55/hr x 63 = $55.4K

CWC Waste Acceptance (McDonald 1999)

- Acceptance criteria = $30K
- NEPA documentation = $40K
- Part B modification = $30K
- ISB modification = $100K
- Waste acceptance modification = $10K
- Evaluate floor loading = $1K
- Evaluate DE-Ci limits = $5K
- Criticality safety analysis = $40K

Mods At Storage Facility = $256K

CWC Handling/Disposal for CH-Overpacks

- Cost based on high-activity package volume of 0.464 m3 (16.4 ft3)
- CH-TRU rate = $85.57/ft3
- Total number of overpacks disposed at CWC = 192 (Appendix G)
- 4039 cans total; 21 cans per overpack (192 overpacks)
- 3 overpacks per truck (or 64 shipments)

Secondary Waste Disposal/Storage = 192 overpacks x 16.4ft3/overpack x $85.57/ft3 = $ 269K

OP's (based on # of transports) = 6 hours/shipment x 5 BU x $55/hr x 64 shipments = $105.6K

Vehicles/Casks = $300,000 (development) + $3M (NRC approval) = $3300K

I5.5.2 Long-Term Costs

WIPP Transportation/Handling/Disposal

- Cost per CH-TRU drum is $750 for transportation
- Cost per CH-TRU drum is $190 for disposal
- Cost for overpack is assumed same as CH-TRU drum costs

Transportation/Disp/Handling = 192 overpacks x $940 = $181K

I5.6 ALTERNATIVE 6 – GROUTING

I5.6.1 Near-Term Costs

CWC Waste Acceptance

Mods at Storage Facility = $210K (McDonald 1999)

CWC Handling/Disposal (waste receipt)

- $85.57/ft3 = $3025/m3 for CH-TRU drum
- volume of RH-TRU canister with shielding to get CH-TRU ≃ 1.5 m3
- ENSR Inc. estimates an overpack for a 55-gal drum to reduce dose from 10 R/h to 200 mR/h will cost about $4,000. Increase cost by factor of 3 for height/diameter differences. Shielding = $12,000/RH-canister
- Total number of shielded RH-Canisters disposed at CWC = 364
- 1 canister per shipment

Secondary Waste Disposal/Storage = 364 shielded canisters x 1.5 m3/canister x $3025/m3 = $1,652K

Ops (based on # of transports) = 6 hours x 5 BU x $55/hr x 364 shipments = $601K

I5.6.2 Long-Term Costs

WIPP Transportation/Handling/Disposal

- RH-TRU transportation cost is $14,200 per shipment
- RH-TRU disposal cost is $ 2500 per shipment
- Each RH-TRU shipment consists of one RH-72B cask containing one canister

Transport/Disp/Handling = $16,700/shipment x 364 shipments = $6079K

I5.7 SUMMARY OF COSTS

Description	ALT 1 Baseline	ALT 2 Mod. Chem	ALT 3 Grind/Mill	ALT 4 Vitrification	ALT 5 Calcination	ALT 6 Grouting
NEAR-TERM COSTS						
Mods at Storage Facility	$3310K	$3100K	$3100K	$419K	$256K	$210K
Vehicles/Casks	$4700K	$4700K	$4640K	$7485K	$3300K	
OPS (based on # transports)	$3920K	$4154K	$3331K	$107K	$161K	$610K
Secondary Waste Disposal/Storage	$32K	$38K	$2.3K	$740K	$280K	$1652K
LONG-TERM COSTS						
Transportation/Disp/Handling	$2200K	$2000K	$300K	$19412K	$181K	$6080K
Additional Costs Treat./Int. Storage	$42300K	$35000K	$5100K	-	-	-
Secondary Waste to WIPP	$3K	-	-	-	-	-

I6.0 REFERENCES

Calmus, R. B., and J. R. Baker, 1996, *Solidified High-Level Waste Interim Storage Alternative Analysis and Path Forward Recommendation*, WHC-SD-WM-SP-011, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Dials, G. E., 1997, *Differential Cost for Transportation and Disposal of TRU Waste at WIPP*, [Memo to Distribution], CAO:NTP:ADC 96-2254, dated February 3, DOE Carlsbad Area Office, Carlsbad New Mexico.

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APPENDIX J

SENSITIVITY ANALYSIS OF THE EVALUATION PROCESS

APPENDIX J

SENSITIVITY ANALYSIS OF THE EVALUATION PROCESS

J1.0 INTRODUCTION

Sensitivity analysis was used in the sludge treatment alternatives evaluation to identify the variables that most strongly influence the net scores for each of the alternatives, and the extent to which changes in these variables affect assessment decisions, i.e., relative rankings. A number of techniques were used to assess the sensitivity of various aspects of the sludge treatment alternatives evaluation process. The analysis included evaluations of the following: 1) the relative contribution of the six decision criteria to the nominal net score for each alternatives; 2) identification of the parameters having the greatest influence on rankings; and 3) the manner and extent to which variations in the parameters influence rankings, i.e., the sensitivity of the rankings to variations in the weighting factors and attribute scores.

The sensitivity analysis was based on evaluating the effect of variations in the nominal values assigned to weighting factors and decision criteria scores listed in Table 9-1 of the main report. Variations of up to ± 20% from the nominal values were used to evaluate the relative sensitivity of the various parameters using rank correlation tests. Variations up to ± 100% of the nominal values were considered in quantitatively evaluating the sensitivity of rankings on parameter values (e.g., the effects of ranking on changing a nominal weighting value of 20% to values from 0 to 40%). Parametric methods were used for this aspect of the analysis which involved evaluating the effects of varying one parameter at a time (one-way analysis), and in some cases, two parameters together (two-way analysis). The categories and magnitude of score changes required for the various treatment methods to be ranked as the #1, #2, or #3 alternative were also calculated to determine the relative sensitivity of the ranking order on the assigned scores.

J1.1 SENSITIVITY ANALYSIS RESULTS

The rankings and net scores calculated for the sludge treatment alternatives are based on the nominal weightings and attribute scores listed in Table 9-1. The nominal rankings (highest to lowest) based on these values are: 1-Modified Chemical, 2-Calcination, 3-Baseline chemical, 4-Grouting, 5-Vitrification, 6-Grinding/Milling. The relative contributions of the weighted decision criteria scores are illustrated in Figure J-1. It is seen from this diagram that Near-Term Implementability is the dominant component in net score for all of the alternatives. Near-Term Cost is the second most important component for the four highest scoring alternatives. The relative importance of the decision criteria in the scoring of the other alternatives is shown in Figure J-1.

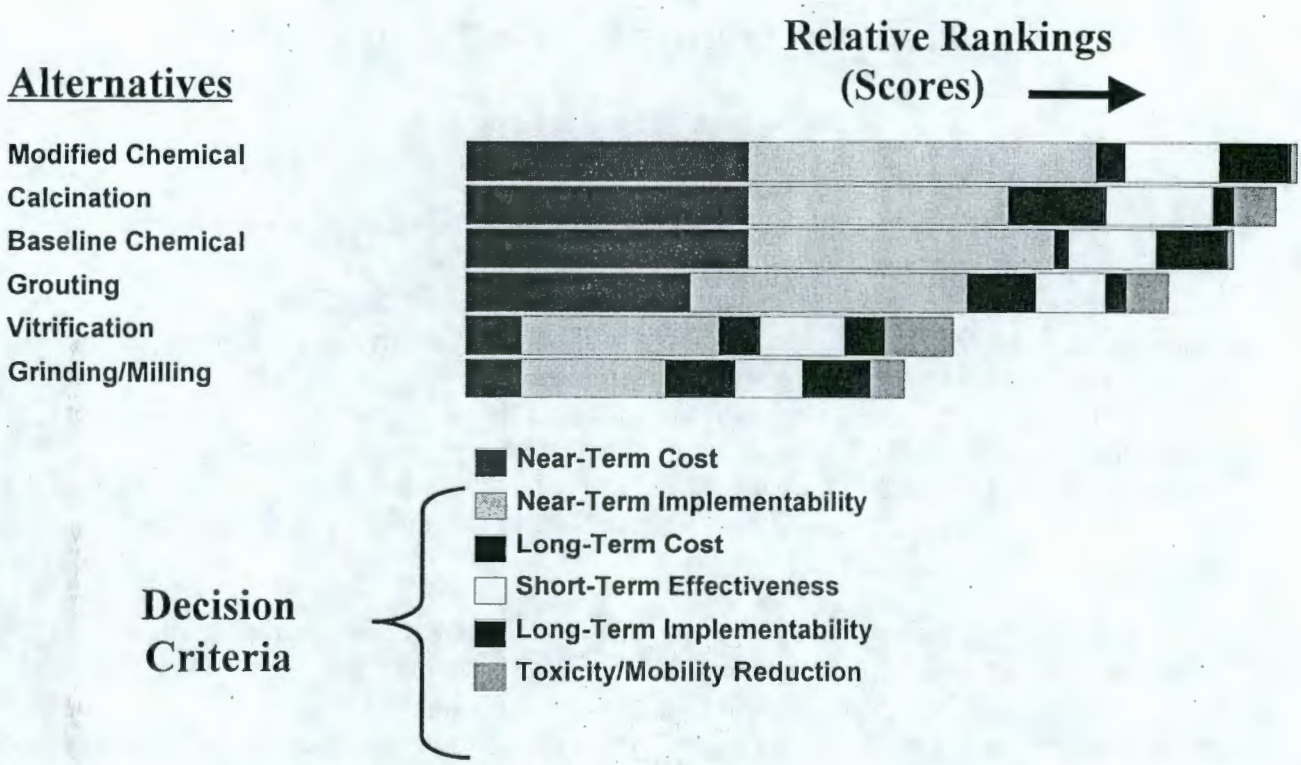

Figure J-1. Relative Strengths of Alternatives. Relative strengths of the various alternatives in terms of the factors contributing to the nominal net scores.

It is indicated from the analysis of parameter sensitivity that the net scores and rankings are most sensitive to variations in two parameters: 1) the weighting factor for Near-Term Implementability, and 2) the weighting factor for Near-Term Cost. The rank correlation values for these two parameters were 0.71 and 0.50, with all other values <0.18, indicating that the analysis is sensitive to variations in these two parameters, but relatively insensitive to variations in other parameters. The rank correlation values are numbers ranging from 0 to 1.0, representing coefficients of relative sensitivity, with the higher numbers corresponding to greater sensitivity. However, when correlations among the parameters were considered, 34 of the 42 parameters combinations were found to have rank correlation values from 0.47 to 0.25, indicating that the evaluations process is moderately sensitive to variations in most of the parameters used in the analysis when correlations are considered.

The sensitivity of the rankings to variations in the weighting factors assigned to the decision criteria is shown in Figure J-2. It is indicated from this analysis that the ranking of the alternatives is highly sensitive to changes in the weighting factors for Near-Term Implementability, Long-Term Implementability, Long-Term Cost, and Reduction of

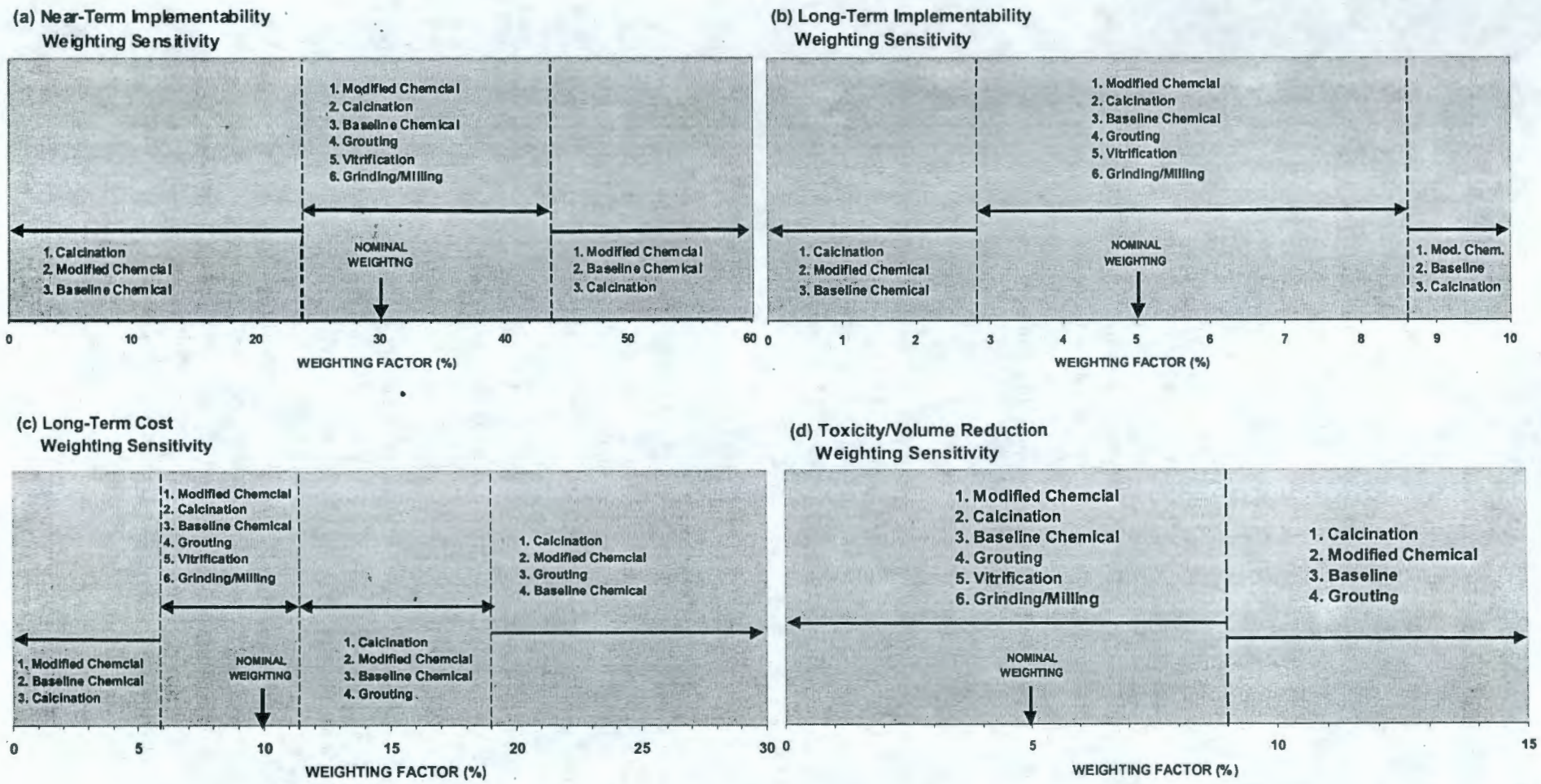

Figure J.2 a,b,c,d. Weighting Sensitivity. Sensitivity of the alternative rankings (net scores) to variations in attribute weighting factors. The changes to the relative rankings resulting from changes in weighting factors are shown in each of the four attributes depicted. The nominal weighting factors in each category are highlighted. This analysis reflects one-at-a-time changes in individual weighting factors. Changes of up to ±100% in weighting factors for Toxicity Reduction , Short-Term Effectiveness, and Near-Term Cost (not shown) were found to have no effect on the relative rankings.

Toxicity/Volume/Mobility, but unaffected by changes for the other decision criteria. The top ranked alternative, for example, changes from Modified Chemical to Calcination by changing the weighting factor for Long-Term Cost from 10% to 11%. However, the relative rankings are unaffected any variation in the attribute weightings for Short-Term Effectiveness and Near-Term Cost.

The changes in the ranking of the top four alternatives that would result from variations in decision criteria weightings are shown in Figure J-2. The most notable results of this analysis are that: 1) Calcination is the only alternative that can replace the Modified Chemical process as the top ranked alternative from changes in the decision criteria weighting factors, and 2) the four highest ranking alternatives in all modification scenarios to weighting factors involve the same four alternatives (i.e., Modified Chemical, Calcination, Baseline Chemical, and Grouting) in various sequences. It is also indicated that changes in the weighting factors in any of the four decision criteria depicted in Figure J-2 potentially results in Calcination becoming the top ranked alternative.

The only other significant changes that would result from modifying the decision criteria weighting factors are that the second and third highest ranked alternatives are sensitive to variations in weighting values for each of the alternatives shown in Figure J-2, i.e., Near-Term Implementability, Long-Term Implementability, Long-Term Cost, and Reduction of Toxicity/Volume/Mobility.

J1.2 PAIRED CHANGES IN WEIGHTING FACTORS:

The one-at-a-time sensitivity results reflect the effects of changing only one variable by a specified amount, with the ratios of the other weighting factors remaining constant. However, variation in weighting factors may be coupled to changes in another weighting factor, e.g., an increase in Near-Term Implementability coupled with a decrease in Long-Term Implementabilty, or vice versa. The sensitivity of coupled changes in three pairs of weighting factors was also evaluated: Toxicity Reduction with Short-Term Effectiveness; Near-Term Implementability with Long-Term Implementability; and Near-Term Cost with Long-Term Cost (Figure J-3 a,b,c).

The results of this analysis indicate that changes in the ranking order of the top four alternatives result in each of the three sets of paired changes in weighting factors. The same general results seen in the one-at-a-time sensitivity analysis were observed in the analysis of paired changes in weighting factors. The ranking of alternatives can change with only small shifts (<10%) in the weighting of Short-Term/Long-Term Implementability, and Short-Term/Long-Term Cost (Figure J-3a, b). Paired changes of about 80% in the weightings of Toxicity Reduction/Short-Term Effectiveness are required to affect the ranking. Again, Calcination is the only alternative that would displace Modified Chemical as the top ranked alternative. This scenario also occurs in each of the paired sets of decision criteria evaluated. The same four alternatives identified in the one-way analysis occur in all scenarios for paired changes in weighting factors.

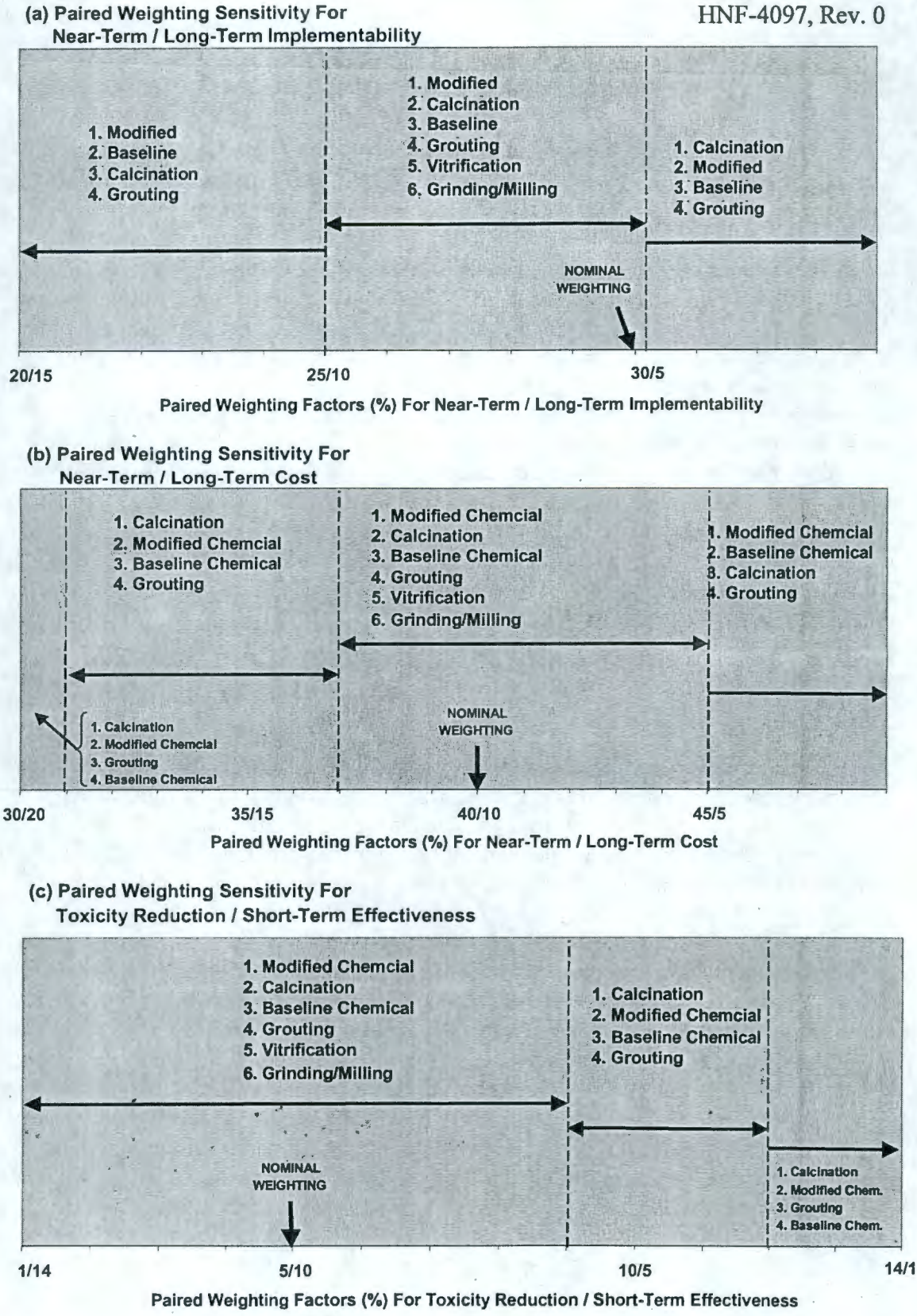

Figure J.3 a,b,c . Paired Weighting Sensitivity. Sensitivity of the alternative rankings to variations in paired weighting factors (2-way sensitivity). The relative rankings that would result from paired changes in the weighting factors are shown for three pairs of attributes. This analysis assumes a constant total weight for the pair, with changes in the ratio of the two components. Weighting factor pairs are denoted as values separated by slashes, e.g., the nominal values for Toxicity Reduction (5) and Short-Term Effectiveness (10) are represented as 5/10 in J.3c. Nominal values for the attribute pairs are indicated in each Figure.

J1.3 SENSITIVITY OF RANKINGS TO SCORING PARAMETERS

The sensitivity of the rankings to variations in the scores assigned in the six decision criteria are summarized in Tables J-3 a,b,c. The extent to which the relative rankings can be changed by variations in decision criteria scores is shown in these Tables. The categories (alternatives and decision criteria) in which score changes are capable of impacting rankings are shown together with the magnitude of the score change necessary to effect the change. It is indicated from this analysis that the #1 and #2 rankings are sensitive to only modest score changes in some categories and are insensitive to changes in others categories. Score changes of < 1.5 points for four of the six categories of decision criteria. are capable of promoting Calcination to the highest ranked alternative. The scores in the category of Near-Term Cost and Near-Term Implementability, have the greatest potential for changing the rankings, especially for Calcination, Baseline Chemical, and Grouting. An increase of only about 1 point in the Near-Term Cost scores would promote any of these three alternatives to the #1 ranked alternative. Score changes in other categories are also capable of significantly altering the rankings, particularly those assigned for Baseline Chemical and in the categories of Near-Term Cost and Near-Term Implementabilty, however, most require unreasonably large score changes (see Table J-3).

J1.4 SUMMARY

It is indicated from the results of these sensitivity analyses, that the net score (and ranking) for each treatment alternative is most sensitive to the values of the weighting factors assigned to the decision criteria, and the scores assigned to the most heavily weighted criteria. The most sensitive parameters are the criteria with the largest weightings , i.e., Near-Term Implementability and Near-Term Cost, and to the scores assigned in these categories. The top four alternatives for the nominal values of weightings and scores are: 1-Modified Chemical, 2-Calcination, 3-Baseline Chemical, and 4-Grouting. The net scores for these alternatives differ by <15%. However, the net scores for Vitrification and Grinding/Milling are over 40% lower than the top-ranked score. The relative rankings are sensitive to variations in the weightings of for Short-Term Implementabilty, Long-Term Implementability, Long-Term Cost and Toxicity/Volume/Mobility Reduction. One-at-a-time and paired changes in weighting criteria result in variable ranking sequences for the top four options, and involve the same four alternatives for all scenarios; Modified Chemical, Calcination, Baseline Chemical, and Grouting. The most significant consequence of weighting changes on ranking is that Calcination is the only alternative with the potential to displace Modified Chemical as the preferred alternative. The ranking order for the top three alternatives are also sensitive to scoring variations in some categories, particularly for the scores assigned to Calcination, and Baseline Chemical treatment, and for the scores assigned in the categories of Near-Term Cost and Near-Term Implementability. Although the rankings are insensitive to score changes in most categories, a score increase of <1.5 points would result in Calcination replacing Modified Chemical as the highest scored alternative. Thus, there appears to be little distinction between Modified Chemical and Calcination as the highest ranked alternative based on the scoring process alone.

Table J-3 a,b,c Scoring Sensitivity

(a) Score Changes Required for Alternative to Advance to #1 Ranking

	Modified Chemical	Calcination	Baseline Chemical	Grouting	Vitrification	Grinding / Milling
Reduction:Toxicity, Volume, Mobility		-	1.0 to 9.8	-	-	-
Short-Term Effectiveness		7.4 to 8.9	-	-	-	-
Near-Term Implementability		6.3 to 6.8	7.4 to 8.9	6.7 to 9.6	-	-
Long-Term Implementability		3.0 to 6.0	-	-	-	-
Near-Term Cost		5.0 to 5.4	5.0 to 5.7	4.0 to 5.1	1.0 to 7.0	1.0 to 8.0
Long-Term Cost		7.0 to 8.6	1.0 to 5.4	-	-	-

(b) Score Changes Required for Alternative to Advance to #2 Ranking

	Modified Chemical	Calcination	Baseline Chemical	Grouting	Vitrification	Grinding / Milling
Reduction:Toxicity, Volume, Mobility			1.0 to 6.8	-	-	-
Short-Term Effectiveness			6.2 to 9.1	-	-	-
Near-Term Implementability			7.4 to 8.4	6.7 to 9.1	-	-
Long-Term Implementability			-	-	-	-
Near-Term Cost			5.0 to 5.8	4.0 to 6.2	1.0 to 6.7	1.0 to 7.6
Long-Term Cost			1.0 to 3.9	-	-	-

(c) Score Changes Required for Alternative to Advance to #3 Ranking

	Modified Chemical	Calcination	Baseline Chemical	Grouting	Vitrification	Grinding / Milling
Reduction:Toxicity, Volume, Mobility				-	-	-
Short-Term Effectiveness				5.0 to 9.3	-	-
Near-Term Implementability				6.7 to 8.2	-	-
Long-Term Implementability				-	-	-
Near-Term Cost				4.0 to 5.1	1.0 to 6.0	1.0 to 7.9
Long-Term Cost				5.0 to 9.3	-	-

Table J-3: Score changes required to increase the net score and relative ranking of the specified treatment option to: (a) the #1 (top ranked) alternative; (b) the 2nd ranked alternative; and (c) the 3rd ranked alternative. Each score change shown is individually capable of modifying the relative ranking. The first number shown in each category of the matrix is the nominal score; the second number is the score required to increase the relative ranking of the alternative. Dashes (-) indicate that no score change is capable of increasing the ranking. Scoring sensitivity is based on one-way parametric analysis.

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