INDEPENDENT REVIEW
OF THE SLUDGE SOLIDIFICATION WASTE TREATMENT PROCESS
FOR THE TRU WASTE PROCESSING CENTER
AT THE OAK RIDGE RESERVATION

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CONTENTS

TABLES

FIGURES

APPENDICES

ACRONYMS

ALARA	as low as reasonably achievable
BVEST	Bethel Valley Evaporator Storage Tanks
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act
CFR	Code of Federal Regulations
CH	contact handled
CH-TRU	contact handled transuranic waste
CIP	Capacity Increase Project
DOE	Department of Energy
DOT	Department of Transportation
EM	Office of Environmental Management
FGE	fissile gram equivalent
FWENC	Foster Wheeler Environmental Corporation
FY	fiscal year
GAAT	Gunite and Associated Tanks
HEPA	high efficiency particulate air
IRPC	Indian Red Pottery Clay
LDR	land disposal restrictions
LLC	limited liability corporation
LLLW	liquid low level waste
LLW	low level waste
MVST	Melton Valley Storage Tank
NNSA	National Nuclear Security Administration
NSO	Nevada Test Site Office
NTS	Nevada Test Site
NUVE	NuVision Engineering
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
PE-g	^{239}Pu equivalent grams
RCRA	Resource Conservation and Recovery Act
RH	remote handled
RH-TRU	remote handled transuranic waste
rpm	revolutions per minute
SL	sludge
SN	supernate
SRS	Savannah River Site
TCLP	Toxicity Characteristic Leaching Procedure
TRU	transuranic
TWPC	Transuranic Waste Processing Center
U.S.	United States of America
WAC	waste acceptance criteria
WIPP	Waste Isolation Pilot Plant

EXECUTIVE SUMMARY

The Melton Valley Storage Tanks, Capacity Increase Project Tanks, and the Bethel Valley Evaporator Service Tanks at the Oak Ridge National Laboratory (ORNL) contain over 350,000 gallons of radioactively contaminated sludge. To eliminate the long-term liability associated with continued storage of these materials, these sludges are to be removed from the tanks, mobilized to the Transuranic Waste Processing Facility (TWPC), and processed for permanent off-site disposal. Sludge solidification is one of three alternatives under evaluation by the Department of Energy (DOE or the Department) for treating sludge contaminated with transuranic (TRU) and Resource Conservation and Recovery Act (RCRA) constituents. The sludge solidification process involves mobilizing, stabilizing, and solidifying the sludge by adding a grouting mixture, resulting in a low-level waste monolith suitable for disposal at the Nevada Test Site (NTS).

This report documents the findings of an independent review on the operability of the proposed sludge solidification process. This review was conducted in response to a request from DOE to assist the Department in determining the potential for success of the proposed sludge solidification methodology and to provide information to DOE to assist them in determining if the proposed sludge solidification waste treatment process is superior to the sludge drying and dewatering alternatives.

The evaluation and assessment focuses on the following questions:

1. Can the sludge be mobilized to flow from the storage tanks to the TWPC?
2. Will the equipment operate as required to enable sludge solidification and waste processing?
3. Will the end product meet the NTS waste acceptance criteria (WAC)?

The review concludes that the sludge can be successfully mobilized. The three proposed sludge mobilization techniques include pulse fluidic jet mixing (NuVision Engineering (NUVE) technology), chemical mobilization (acid dissolution), and mechanical agitation (robotic arm). All three mobilization options are potentially viable. The assessment concludes that the NUVE pulse fluidic jet mixing technology appears to have the greatest potential for success based on its proven track record in similar applications. This conclusion may need to be reconsidered if the manufacturer of the proposed robotic arm is able to produce convincing documentation demonstrating the viability of the mechanical agitation option.

The assessment concludes that the sludge solidification process is a conceptually sound, viable method because grouting is a mature technology that has been repeatedly successful in similar applications; however areas of concern remain. The primary concerns associated with the sludge solidification process involve the proposal to convert the existing supernate dryer into a mixer, stabilization of the mercury to meet NTS WAC requirements, and the identification of the point of waste generation which needs formal acceptance by the applicable regulators.

Equipment operability issues of concern involve the converted batch mixer, grout feeding system, process shields for the liners, and the enclosure of the 30-ton crane bay. The greatest equipment operability concern involves the mixer that will combine the mobilized sludge with the grouting agents. It is currently proposed that the existing dryer in the supernate system be converted to a mixer by increasing the maximum speed of the agitator shaft from 10 rpm to 50 rpm via a gearbox change. However, due to the thixotropic nature of grout, mixers capable of producing high quality grout are typically high shear mixers with shaft speeds in the 1,000 – 2,000 rpm range. Striving to minimize further capital outlays by utilizing existing equipment as much as possible is commendable. However, given the concerns that the dryer could possibly not meet mixing and reliability requirements, it is recommended that a high shear batch mixer be considered as an alternative to the conversion of the dryer to a batch mixer.

Another concern is the grout delivery system. Currently, a single silo feeding a single weigh hopper charging system is conceptualized. A dry component delivery system that allows for multiple dry-blend feed hoppers and metering of various quantities of the dry blend components should be considered. Conceptually, the proposed use of process shields to decrease the cycle time and the enclosure of the 30-ton crane bay to decrease the liner lidding and loading cycle times appear reasonable. A cost-benefit analysis may be appropriate to assess the desirability of these proposals.

Additional parameters beyond those mentioned in the draft feasibility study that need to be understood for implementation and operability of this solidification process and should be evaluated prior to implementing the full scale process, are: mix ratio (wt dry solids blend/volume waste), establishing whether there is a need for more than one grout recipe, ability to back blend any weep liquids from the curing of a batch, adequacy of gravity feed of LLW liners and approximate time to empty the batch mixer/fill liners using gravity flow.

Pro2Serve agrees that bench scale testing on actual MVST sludge is necessary for development of a grout recipe (or recipes) that will generate a solidified monolith that meets the NTS WAC. Prior to initiating the bench scale testing, performance criteria for the grout should be established as well as the conceptual treatment approach for handling various sludges from the different tanks. Furthermore, DOE may wish to consider testing beyond typical grout bench scale testing (Hobart mixers and grout in small cups) to evaluate grout viscosity, gravity flow of grout, impacts to the processing area from heat of hydration and determining minimum adequate mixing needs.

The solidified sludge monoliths are likely to satisfy the NTS WAC provided that the ^{241}Am-rich sludge in Tank W-23 does not have to be treated as a separate waste stream. NTS WAC attainment concerns include stabilization of mercury, establishing the point of generation of the waste, and the amount of void space within the low-level waste liners. The primary concern is the mercury content of the solidified products. The determination of point of generation of the waste is a key issue, as that will determine whether the final waste product must merely cease to exhibit the toxicity characteristic (40 CFR 261.24 TCLP limits) or must satisfy the more restrictive limits of the land disposal restrictions (LDRs) found in 40 CFR 268.40. It is recommended that this issue be settled with the applicable regulators as soon as possible.

Tests on sludge samples and sludge surrogates provide evidence indicating that Toxicity Characteristic Leaching Procedure (TCLP) results on the solidified product will be below both the 40 CFR 261.24 and 40 CFR 268.40 limits. However, the number of sludge samples that have been drawn is limited, and the homogeneity of the sludges is questionable. Consequently, there is a possibility that the mercury could be more difficult to immobilize than expected. Therefore, especially if it is determined that the TCLP test results of the product must meet the more restrictive 40 CFR 268.40 LDR limits, it is recommended that the bench-scale testing be conducted early in the development process. This will provide the maximum amount of time to make any necessary adjustments to the grout recipe(s) to improve their abilities to immobilize the mercury. Bench-scale testing of actual sludge samples is essential to ensure a grout recipe(s) that will produce a solidified waste product that satisfies the NTS WAC.

Another issue of lesser, but significant, concern is the amount of void space that will be present in the low-level waste liners. NTS should be consulted at an early stage of the conceptual development to confirm that a 25% void fraction in the liners is acceptable.

The assessment concludes that the sludge solidification approach appears to be a technically sound, likely viable method to prepare the ORNL tank sludges for off-site disposition. Of the three alternatives under consideration, the sludge solidification option appears to have the greatest potential for success based upon the potential for continued operability throughout the project life cycle, the challenges involved in shipping TRU waste for disposal, and the lower projected worker radiation exposures. Unlike the drying and dewatering approaches, the sludge solidification methodology does not involve the creation of dry powders within the processing equipment that are likely to cake up and plug material flow at some point during the course of the project. Such problems were encountered to some degree during the nine month supernate campaign, and would be even more problematic during an extended five to ten year operating run. If a suitable recipe providing a sufficiently low viscosity grout can be developed during the bench-scale testing, then the grout mixture is expected to have greater fluidity and less of a tendency to plug the piping associated with the mixer, provided that the grout mixture is not allowed to set and cure while in the mixer. The capability of flushing the mixer between batches is likely to prevent the setting of the grout within the mixer. By producing a low level waste product rather than a TRU product, the sludge solidification approach bypasses many of the difficulties involved in the disposal of TRU waste. The solidification process is expected to result in lower doses to plant operators because of the lower ^{137}Cs concentrations in the waste form and the self-shielding provided by the grouting materials.

Based on the information reviewed, this independent review concludes that the sludge solidification process appears to be a viable methodology. This conclusion would need to be revisited if bench-scale testing indicates that mercury immobilization is less successful than currently anticipated, or the grout viscosity and set times are less desirable than expected.

1. INTRODUCTION

This report contains the results of an independent review on the operability of a proposed sludge solidification waste treatment process involving transuranic (TRU) waste from the Oak Ridge National Laboratory (ORNL). The review was conducted in response to a request from the Department of Energy (DOE or Department) Oak Ridge Operations (ORO) to assist the Department in determining the potential for success of the proposed sludge solidification methodology and to provide information to DOE to assist them in determining if the proposed sludge solidification waste treatment process is superior to the sludge drying and dewatering alternatives.

1.1 HISTORY AND BACKGROUND

ORNL manages the largest inventory of remote handled (TRU) waste in the DOE complex (Ref. 1). TRU waste is defined in DOE Manual 435.1-1 as radioactive waste containing more than 100 nanoCuries (nCi) of alpha-emitting TRU isotopes per gram of waste, with half-lives greater than 20 years except for (1) high level radioactive waste; (2) waste that the Secretary of Energy has determined, with the concurrence of the Administrator of the Environmental Protection Agency, does not need the degree of isolation required by the 40 CFR Part 191 disposal regulations; or (3) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61 (Ref. 2 and Ref. 3). TRU waste is categorized as contact handled (CH) or remote handled (RH) depending on the surface dose rates. Remote handled transuranic waste (RH-TRU) is defined as TRU waste that has a measured dose rate at the container surface of 200 millirem (mrems) per hour or greater and therefore, must be shielded for safe handling. Whereas, contact handled waste is defined as TRU waste that has a measured radiation dose rate at the container surface of 200 mrems per hour or less and can be safely handled without special equipment when placed in containers (Ref. 4).

Due to the amount of TRU waste at ORNL and the fact that TRU waste is one of the most hazardous forms of radiological waste at the ORNL, In 1998, DOE awarded a privatized, fixed price contract to Foster Wheeler Environmental Corporation (FWENC) to construct, operate and decontaminate and decommission a TRU waste processing facility. Construction of the TRU Waste Processing Center (TWPC) was completed by Foster Wheeler in 2003. The TWPC was designed and built to address treatment and disposal of TRU waste from ORNL to meet the waste acceptance criteria of the WIPP or the NTS (Ref. 1). The TRU Waste Processing Center is a TRU waste handling facility which retrieves, processes, treats, packages, and ships TRU and LLW for off-site disposal.

Since ORNL manages the largest inventory of RH-TRU waste in the DOE complex, and TRU waste is one of the most hazardous forms of radiological waste at ORNL, the regulatory community has emphasized the need for off-site disposal of TRU waste generated at ORNL. For example, two Comprehensive Environmental Regulatory Compensation and Liability Act (CERCLA) documents identify utilization of the TWPC for processing TRU waste for off-site disposal. The Interim Record of Decision for eight of the Gunite and Associated Tanks (GAAT), and the Action Memorandum for the five Old Hydrofracture Facility tanks require the tank waste to be processed in the TWPC and disposed of at the Waste Isolation Pilot Plant (WIPP) or Nevada Test Site (NTS), further emphasizing the regulatory importance of ORNL TRU waste off-site disposal (Ref 2)..

Source: Presentation, Oak Ridge EM Program Overview, U.S. DOE, ORO, August 2, 2005

Figure 1. Transuranic Waste Facility

The TWPC was designed to process four waste streams (1) Supernate (SN), (2) RH-TRU debris, (3) contact handled transuranic waste (CH-TRU) debris, and (4) RH-TRU sludge. Since completion of construction in 2003, the supernate wastestream was treated, packaged, and sent for off-site disposal to NTS in 2004. The TWPC is receiving, processing and packaging CH-LLW, CH-MLLW and CH-TRU waste for off-site disposal. RH-TRU debris is the next waste stream to be processed. This will be followed by RH sludge waste stream processing.

TRU waste sludge was produced as a result of the collection, treatment, and storage of liquid radioactive waste originating from ORNL radiochemical processing and radioisotope production programs. Sludge and most of the associated liquid low level waste (LLLW) from the gunite tanks in ORNL's Tank Farms in Bethel Valley and the sludge and associated LLLW from the Old Hydrofracture Facility tanks in Melton Valley have been successfully consolidated into the Melton Valley Storage Tanks (MVSTs) allowing for mobilization and treatment of the sludge in the TWPF.

During 2006, DOE converted the privatized TRU Project contract to a cost reimbursable plus fee contract and directed the TWPC Operations and Maintenance subcontractor, Energ-X TN LLC, to charter an operability study for the RH debris and sludge processes (Ref. 5). As part of the operability review, the baseline sludge drying alternative was reevaluated in light of the lessons learned from the 2004 Supernate campaign. This evaluation resulted in a dewatering alternative being included for sludge treatment evaluation. A third sludge treatment option, solidification, was added near the end of the operability review, due to changes in WIPP requirements and limitations in the number and availability of 72-B RH-TRU shipping casks (Ref. 5). The operability review team decided that sludge solidification resulting in disposal at NTS as LLW should be added as an alternative for evaluation. Consequently, an evaluation was conducted and documented in the draft *RH Sludge Solidification Feasibility Study*, RH-R-AD-002/Rev. P4.

Source: WM'01 Conference, February 25-March 1, 2001, Tucson, Arizona

Figure 2. TRU Waste Tank Storage

BVESTs	Bethel Valley Evaporator Service Tanks
GAAT	Gunite and Associated Tanks
MVSTs	Melton Valley Storage Tanks
LLLW	Liquid Low Level Waste
CIP	Capacity Increase Project

1.2 METHODOLOGY AND CRITERIA

As part of the review process, Pro2Serve undertook a concerted effort to gather relevant information from a variety of different sources. The evaluation included a review of design documents, drawings, previous technical evaluations and studies, and data. In addition to the aforementioned activities, Pro2Serve participated in a facility tour and conducted an interview with the Sludge Solidification Feasibility Study Lead. The primary focus of the review was the proposed sludge solidification methodology with subsequent, limited comparative analysis of the sludge solidification process to the drying and dewatering alternatives. During the review, Pro2Serve limited its assessment to the conceptual design and operability elements associated with the proposed solidification sludge treatment methodology. Subsequent comparisons of the sludge solidification to the drying and dewatering sludge alternatives were based on existing conclusions and documentation. Because of the limited four week time frame involved, Pro2Serve's conclusions regarding the viability of the alternative methodologies rely heavily on the conclusions from existing documentation. Pro2Serve's review did not include project cost and schedule estimates, nor did it specifically evaluate the environmental issues (i.e., permitting, regulatory permissibility of dilution, etc.) associated with the project.

The underlying criteria for determining the operability and technical feasibility was derived from the Engineering Evaluation/Cost Analysis and the CERCLA Feasibility Study criteria which has been used by the United States (U.S.) Environmental Protection Agency, the Tennessee Department of Environment and Conservation, and the DOE-ORO as part of the *Federal Facility Agreement for the Oak Ridge Reservation* in the review and evaluation of alternatives. Although the criteria are used for evaluation of remediation alternatives, relevant feasibility and implementability criteria was reviewed and adopted to provide an objective means of evaluating the sludge solidification alternative.

As part of a focused subset of the CERCLA criteria, the following criteria were used to determine the operability of the proposed solidification sludge treatment system. Implicit within the evaluation and assessment is the need to answer the following question: Will the proposed solidification sludge treatment process work and, if so, is it superior to the drying and dewatering methods previously proposed. Operability, one of the basic alternative evaluation criteria from CERCLA, is highlighted as the primary focus of the review of the proposed sludge solidification treatment system alternative performed by Pro2Serve. The following criteria were used to determine the operability of the proposed solidification sludge treatment option and to determine the potential for success:

1. Can the sludge be mobilized to flow from the storage tanks to the TWPC?
2. Will the equipment operate as required to enable sludge solidification and waste processing?
3. Will the end product meet the NTS WAC?

Since the sludge solidification process is the newest of the three proposed processes to be introduced for evaluation as an alternative, the team prioritized evaluation of operability of the sludge solidification waste treatment process to ensure the proposed sludge treatment system was a viable and feasible option before conducting a comparative analysis of the three sludge waste treatment alternatives.
The results of the operability and focused comparative analysis are included in the Conclusions Section, Section 6.

1.3 REFERENCES

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2. DOE Manual 435.1-1, *Radioactive Waste Management Manual*, June 19, 2001.
3. DOE Carlsbad Area Office, *Remote-Handled Transuranic Waste Study*, DOE/CAO 95-1095, October 1995.
4. DOE Carlsbad Field Office, *Transurancic Waste Acceptance Criteria for the Waste Isolation Pilot Plant, Rev. 6,* DOE/WIPP-02-3122, November 15, 2006
5. Draft *RH Sludge Solidification Feasibility Study*, RH-R-AD-002/Rev.P4.
6. *Feasibility Report Annotated Outline Contents*, Revised July 29, 2005.
7. *Engineering Evaluation/Cost Analysis Annotated Outline Contents*, Revised July 29, 2005.
8. *Federal Facilities Agreement for the Oak Ridge Reservation*, United States Environmental Protection Agency, the Department of Energy, and the Tennessee Department of Health and Environment, January 1, 1992
9. DOE, Draft *2007 Remediation Effectiveness Report for the United Stated Department of Energy, Oak Ridge Reservation, Oak Ridge, Tennessee, Volume 1 Compendium*, DOE/OR/01-2337&D1/V1, March 2007.

2. SLUDGE PROCESSING ALTERNATIVES

Sludge solidification is one of three alternatives under evaluation by the DOE for treating sludge containing TRU and RCRA characteristic hazardous constituents. The original baseline option, drying, and another alternative, dewatering; are currently under evaluation along with the sludge solidification alternative. This section will briefly describe the three proposed sludge waste treatment options.

The TWPC has been designed and built to perform the sludge drying alternative, the baseline treatment option. Dewatering, via a tube press, has been proposed as an alternative to drying based on operability and reliability issues associated with the dryer during the 2004 Supernate campaign. Reliability issues associated with the dryer are detailed in the *RH Debris and Sludge Operability Report* and identified in Section 4.2 of this report. Solidification, currently in its conceptual design phase, involves sludge mobilization, stabilization, and conversion of the SN process to allow sludge solidification for disposal at NTS as LLW.

All three proposed sludge processing alternatives will result in a solid waste form for disposal at WIPP or NTS. The drying and dewatering treatment options will result in a final TRU solid waste form for disposal at WIPP and the solidification treatment process is anticipated to result in a solid waste monolith for disposal at NTS as LLW.

2.1 SLUDGE DRYING ALTERNATIVE – BASELINE OPTION

Sludge mobilization/transfer via pulse fluidic jet mixing followed by low-temperature evaporation and drying of tank waste is the baseline waste treatment process. The final waste form for the drying alternative is anticipated to be a granular precipitate. As depicted in Figure 3, the sludge drying alternative is similar to the SN process.

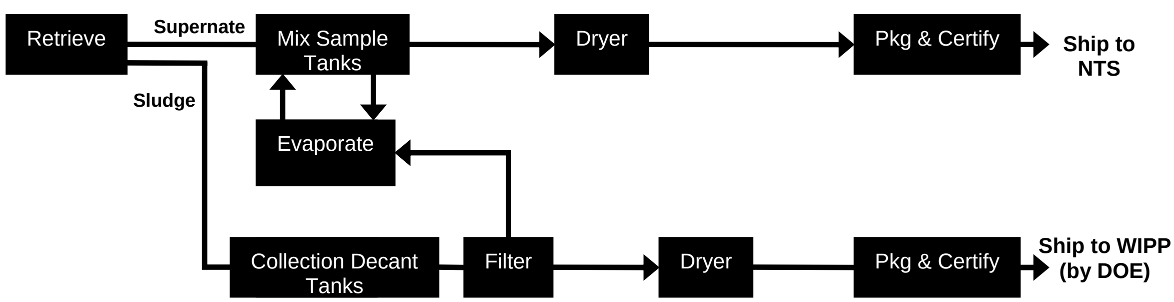

Figure 3. Sludge Drying and Supernate Process

The RH Debris and Sludge Operability Review identified operability issues associated with the dryer during the supernate campaign.

- "Significant build-up on the dryer agitator and dryer wall occurred in both surrogate testing and actual supernate processing."
- "Reliable powder discharge could not be achieved due to frequent plugging of the SN dryer discharge valve during surrogate testing."
- "Numerous entries in to the high radiation areas were required for inspection, testing and repair of single point failures/leaks during the nine month campaign."
- "[Since] crystal formation on sealing surfaces can cause premature component failure/leakage; periodic outages to drain, flush and acid clean the systems were necessary to keep equipment operable."

- Although the overall dose during supernate operations was very low, 69 mRem/liner shipped, 6.7 mRem/liner shipped "The most dose intensive task during the SN campaign was the seal/cut of the SN [Supernate] liner fill sleeve from the SN [Supernate] dryer discharge chute which included dose related to clean-up of any ensuing contamination of the LLW liner of shipping cask. Contamination spread was occurring when only a single discharge sleeve was used. A second sleeve (double confinement) was incorporated into the process. Even without a powder waste form, contamination control around the final SN [Supernate] waste container interface was a challenge."

Additional operational issues are listed in Section 4.2. Based on the lessons learned from the SN [Supernate] campaign, the following processing difficulties are likely to be encountered during the sludge drying campaign according to the draft *RH Debris and Sludge Operability Review*.

- Sludge dryer scaling and reduced dryer performance/throughput,
- Sludge solids entrainment into sludge chemistry with frequent downtime for acid cleaning,
- Sludge dryer agitator wear and premature agitator drive failure,
- Sludge dryer agitator shaft seal excessive leakage and premature failure, and
- Increased risk of chloride stress corrosion cracking in the welds and heat effected zones of the dryer due to the higher chloride levels indicated in ORNL/TM-2001/151.

Due to the operability issues associated primarily with the dryer during the supernate campaign, sludge dewatering was identified as a potential sludge processing alternative in the draft *RH Sludge Solidification Feasibility Study.*

2.2 SLUDGE DEWATERING

Sludge dewatering is similar to the sludge drying alternative except the dryer is replaced with a tube press. The dewatering alternative includes mobilization of the sludge from the MVSTs, transferring the sludge to the T-101 A/B tank where liquid is decanted, sent to T-109 and is evaporated and processed using the Supernate system. The sludge is then transferred to T-102- A/B where water is extracted in the Hydroclone. The sludge is then moved to the Tube press where it is processed as a dried sludge, discharged into a 72-B canister, overpacked in a 72-B cask, and shipped to WIPP, as illustrated in Figure 4.

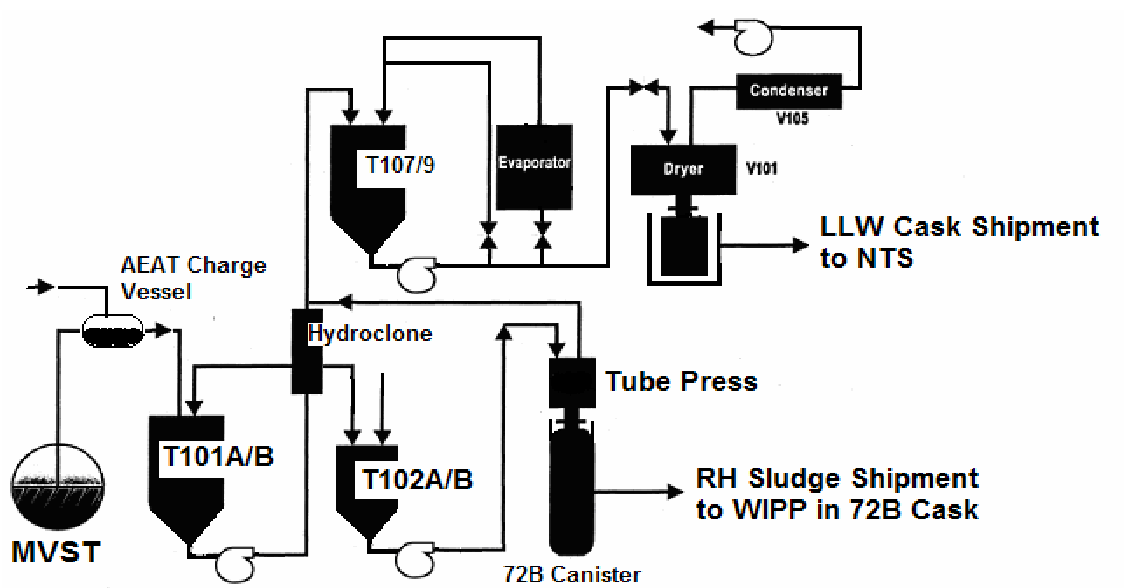

Figure 4. Sludge Dewatering Process System

Due to the logistical issues associated with limited staging/storage capacity, the desire to further minimize personnel exposure related to equipment maintenance, and the limited number of 72-B shipping casks, the sludge solidification alternative was proposed.

2.3 SLUDGE SOLIDIFICATION

The sludge solidification process involves modification to the Supernate process resulting in a LLW monolith for NTS disposal. Changes to the SN process include adding a dry blend grout and Thio-Red mercury stabilization agent to the sludge and converting the SN Dryer to a batch sludge mixer as well as associated changes described in Section 4.2.

A step by step process, defined in the draft *Sludge Solidification Feasibility Study* includes:

- Mobilizing and fluidizing the sludge for transfer.
- Transferring the mobilized sludge to the Capacity Increase Project (CIP) tank with sludge mixing capabilities (W-35) for aggregation in a “big batch.”
- Blending/homogenizing, sampling, analyzing, and characterizing the contents of W-35, and then transferring the mobilized sludge to the TWPC Supernate tanks.
- Pumping the mobilized sludge to a batch mixer, adding metals stabilizing agents and a cement, blast furnace slag, and fly ash based grout dry blend (similar to the SRS Saltstone and ORNL GAAT Tank blends) to stabilize the RCRA metals, forming a solid with no free liquid and preventing stratification or concentration of fissile isotopes. At this point the TRU concentration in the final solidified waste form is anticipated to be below 100 nCi/g.
- Pre-loading the LLW liners with an absorbent material like Nochar Acid-Bond as added insurance to absorb free liquid (e.g., bleed water, chute flush water).
- Discharging a flowable grout into LLW liners contained in a process shield, and allowing the grout to solidify for 24-48 hours.
- Verifying no-free liquids and formation of a solid monolith inside the LLW liner.
- Transferring LLW liners from the process shields into a DOT Type A shipping cask.
- Shipping the LLW Liner (i.e., “monolith”), as fissile exempt LLW, to NTS. A total of 1,500-2,500 LLW liners would be shipped to NTS over a 4-7 year period.

The process is also illustrated in Figure 5 which represents the Best Case Scenario regarding the number of shipments per week.

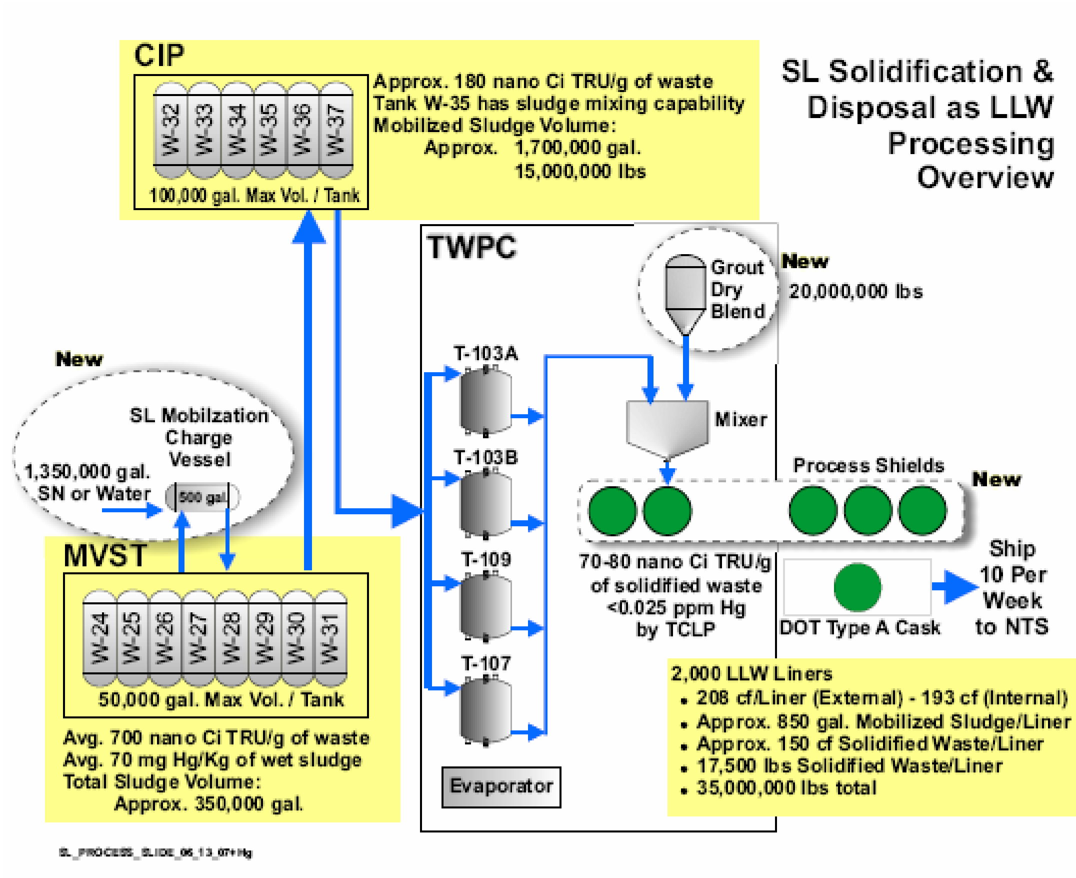

Figure 5. Sludge Solidification Process

It is anticipated that sludge from the MVSTs, Capacity Increase Project (CIP), and Bethel Valley Evaporator Service Tanks (BVEST) will undergo sludge treatment. The sludges in BVEST Tank W-23 contain higher levels of TRU radionuclides, particularly ^{241}Am. If it is determined that the W-23 sludges constitute a separate waste stream that may not be mixed with the MVST and CIP tank sludges, then the solidified monoliths from the W-23 sludges are expected to exceed 100 nCi/g, and will have to be disposed at WIPP as RH-TRU waste. However, because the Tank W-23 sludges constitute only a small fraction of the sludges (less than 6%), most of the waste could still be sent to NTS.

As previously mentioned, determining the operability of the proposed sludge solidification option was prioritized as part of the review followed by subsequent comparative analysis of the three proposed sludge treatment options. As a result, the following sections provide an evaluation of the sludge solidification treatment option to determine the answers to the following questions:

- Can the sludge be mobilized to flow from the storage tanks to the TWPC?
- Will the equipment operate as required to enable sludge solidification and waste processing?
- Will the end product meet the NTS WAC?

Section 3 of this report addresses sludge mobilization, Section 4 addresses equipment operability and Section 5 addresses the ability of the final waste form to achieve the NTS WAC.

2.4 REFERENCES

1. Gentry, Ron, *Sludge Waste Operations Overview*, 1-29-07.
2. Draft *RH Sludge Solidification Feasibility Study*, RH-R-AD-002/Rev.P.4.
3. *RH Debris and Sludge Operability Review*, RH-R-AD-001/Rev. 2.

3. MVST SLUDGE MOBILIZATION

3.1 NUVE PULSE FLUIDIC MOBILIZATION SYSTEM

3.1.1 General Description

The base design for mechanical mobilization is currently pulse fluidic mixing as depicted in Figure 6. This system uses a series of nozzles in the tanks that are coupled to air ejectors through a charge tank. The air ejectors apply suction, filling the charge tank with waste. Next, air is applied to the charge tank, forcing the waste back through the nozzles to mix the tanks' contents. The cycle repeats until the resulting slurry is suitable for pumping (Ref. 1).

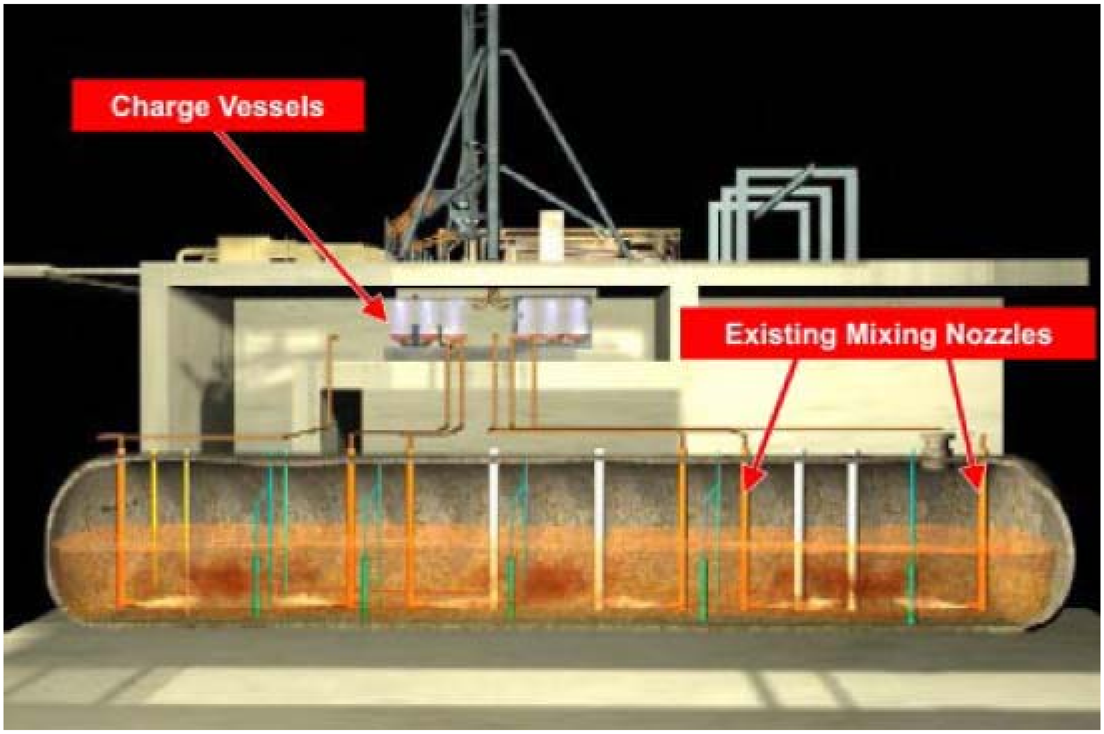

Figure 6. Pulse Fluidic Jet Mixer (Ref. 2)

3.1.2 Historical Data

This system has been successfully used on several DOE projects. During the transuranic sludge removal from the C-1, C-2, and W-23 waste storage tanks at ORNL, two pulse fluidic jet mixing systems were used to successfully mobilize remote-handled TRU sludge for retrieval from three 50,000-gal horizontal waste storage tanks. The report on these projects concluded as part of their recommendations that this system be seriously considered for mixing and other bulk retrieval of sludge in other vertical and horizontal tanks at ORNL and at other DOE sites (Ref. 3).

3.1.3 Conclusions

The advantages of the system are;

- The system has no in-tank moving parts; reducing maintenance and maintaining as low as reasonably achievable (ALARA) principles for worker radiological exposure (Ref. 4);

- The system is suitable for tanks with interior structures; and
- The system has proven to work in similar applications (Ref. 5).

The disadvantages of this system are the;

- Cost of the system is estimated to be about $5 million (Ref. 6) and
- The system is in the critical path and has a lead time of about 12 months (Ref. 6).

Pro2Serve concludes that given the past success of this system in similar applications, it appears to be a viable solution for mobilizing the sludge in the MVSTs.

3.2 CHEMICAL MOBILIZATION

3.2.1 General Description

An alternative for mobilizing the MVST sludge is chemical mobilization. The chemical mobilization of the MVST sludge would be accomplished by slowly adding nitric acid to the tanks. The acid required has been initially estimated at ~50% of the sludge volume. Each tank would be allowed to soak for a couple of weeks allowing time for maximum dissolution of the sludge at which point the sludges in the MVSTs could be pumped to the CIP tanks using the existing transfer pumps. The tanks are constructed of 304 L SS which is highly resistant to nitric acid. The study notes the importance of temperature regulation because of the strong exothermic acid reaction and the need to monitor the dewpoint of the offgas to ensure that the HEPA filters are not damaged (Ref. 6). A more thorough review of process implementation may be necessary once a more detailed design is completed.

3.2.2 Historical Data

The proposed chemical mobilization primarily uses a nitric acid bath to mobilize the sludge. No historical data have been found that show nitric acid used in a similar application to the one being proposed in the draft feasibility study. However, at the Hanford Tank C-106 Project, oxalic acid was used for chemically mobilizing the remaining hard heel of the waste in the tank after standard sluicing techniques did not work. This was done in a two stage procedure, the first being an acid bath and the second being a sluicing operation. While the proposed process is for mobilizing the sludge only and not the associated heel, the lessons learned during the oxalic acid bath phase of the Tank C-106 Project may provide some relevant process knowledge that could be applied to MVST sludge mobilization (Ref. 7).

3.2.3 Conclusion

If successful, the advantages of this system include the following;

- Large cost savings over Pulse Fluidic mixing system (~$5 M) (Ref. 6),
- Accelerates the earliest possible start date for sludge by eliminating the Pulse Fluidic mixing system (Ref. 6), and it
- Eliminates the worker radiation exposure to install the Pulse Fluidic mixing system hoses. This is a significant dose avoidance since this task is expected to incur 5,000-10,000 mrem in collective dose over the campaign. Acid can be added to the MVSTs using the existing chemical addition system (Ref. 6).

The disadvantages of this system are it

- May reduce the service life of the MVST pump stators depending upon the stators resistance to low pH conditions (Ref. 6),
- Additional worker hazards introduced related to handling of a strong acid (Ref. 6), and

- Although extensive lab and full scale work has been done using acid to assist in sludge and heel removal, there appears to be no previous examples of using the proposed method of chemical (nitric acid) mobilization on a similar scale.

3.3 ROBOTIC ARM MOBILIZATION

3.3.1 General Description

The concept for this system of mobilization is to have a large robotic arm reach the length of the tank to mechanically stir the sludge. SA Robotics has provided EnergX with a preliminary cost estimate. Additional engineering information and data is needed to perform an evaluation of this option (Ref. 6).

3.4 CONCLUSIONS

It is Pro2Serve's conclusion that the three options for mobilizing the sludge are still potentially viable with the pulse fluidic system being the favored of the three because of its historical success in similar applications. As mentioned previously, there was not enough information available at the time of this review to give the robotic arm option a thorough assessment. It is also Pro2Serve's opinion that FWENC/EnergX review the methods and technologies developed during the Cleanup of the Hanford Tank Waste project. If not previously evaluated, techniques such as vacuum retrieval and oxalic acid dissolution may be viable solutions to be used in conjunction with the currently proposed methods of mobilization.

3.5 REFERENCES

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4. SLUDGE SOLIDIFICATION SYSTEM

4.1 SOLIDIFICATION OF SLUDGES PROOF OF PRINCIPLE

Solidification is a well proven, robust technology that has been implemented across the DOE complex at full scale. Furthermore, grout has been shown to effectively stabilize a sample of MVST W-25 sludge (Ref. 1). Therefore, solidification appears to be an appropriate treatment choice for the tank sludge predominantly from the MVST, CIP tanks, and some BVEST tank sludge.

Compared to the alternative sludge drying and dewatering processes, the sludge solidification process is more conducive to worker safety. The lower ^{137}Cs concentrations in the final product and the self-shielding provided by the grouting components will reduce direct dose rates in the vicinity of the liners. The potential for inhalation exposure to personnel inside and outside the TWPC are also minimized, as the final product will not contain any loose powders with a propensity to become airborne. The high water content of the material through all stages of the process reduces its releasibility in the event of a fire.

Solidification of MVST sludge has been demonstrated at the bench scale. The proof of principle documented in 1998 by R.D. Spence, et. al., ORNL/TM-13653 (Ref. 1) concluded from grouting of a tank W-25 surrogate and actual W-25 sludge sample that a robust grout formulation was effective in producing a grout that adequately stabilizes the contaminants in the waste form. The untreated W-25 sludge failed the characteristic Toxicity Characteristic Leaching Procedure (TCLP) limit and universal treatment standards TCLP limit for mercury. Grout samples containing surrogate and actual tank sludge passed the TCLP test and were under the Universal Treatment Standards limits for Ag, As, Ba, Cd, Cr, Hg, Pb, and Se.

The evaluation in the FWENC/EnergX draft Feasibility Study (Ref. 2) indicates that solidification and stabilization of sludge using a flowable cement/grout mixture comparable to Savannah River Site Saltstone is feasible. The evaluation considered "a conservative waste loading (high dry blend grout to liquid ratio) along with the use of a highly controllable batch mixing process." Calculations based on information given in the draft Feasibility Study (Ref. 2) indicate an assumed waste loading of 50 weight (wt) % (sludge specific gravity of 1.3). This appears to be a reasonable, conservative assumption for estimating purposes, prior to bench scale testing and grout recipe development, since the 1998 grout and glass report (Ref. 5) recommended a 60 wt % (sludge specific gravity of 1.2) waste loading for development of a strong monolith. The grout recipe documented in the 1998 grout and glass study (Ref. 1) chose usual grout components. They used 33 wt % blast furnace slag to create a reducing environment and help stabilize ^{90}Sr; 20 wt % Type I-II Portland cement for capture of RCRA metals; 19 wt % Class F fly ash as a ^{90}Sr stabilizer; 20 wt % Perlite as a water sorptive agent; and 8 wt % Indian Red Pottery Clay (IRPC) to help stabilize the ^{137}Cs. (Ref. 1). These dry blend components were chosen to address the ^{90}Sr, RCRA metals, water and ^{137}Cs that were all present in the sludge sample. FWENC/EnergX proposes a comparable dry blend that is similar to SRS Saltstone (45% Class F Fly Ash, 45% Blast Furnace Slag, 10% Portland Cement, Stabilization Additives such as Thio-Red for Hg) with addition of a water sorptive agent to the grout liner such as No-Char Acid bond.

4.2 REVIEW OF CONVERSION OF SUPERNATE DRYING PROCESS TO SLUDGE SOLIDIFICATION PROCESS

As depicted in Figure 7, the Supernate campaign processed the Supernate waste stream by the use of evaporation, vacuum drying, and solidification. The Supernate final waste form was a monolithic solid that was disposed at NTS. The Supernate campaign used the process as originally designed with the addition of anhydrous sodium metasilicate within the dryer to produce the final solidified waste form. It lasted 9 months and successfully treated and disposed of >1,600 m^3 of supernate (Ref. 3). The sludge campaign currently estimates treating approximately 1.7M gal of sludge (after mobilization) for 60 to 119 months (5 to 10 years) (Ref. 2). Figure 8 depicts the proposed sludge solidification system, which is the modified Supernate system. The proposed SL campaign uses sludge mobilization, stabilization and grout solidification.

As a result of assessing the needs of the SL solidification against the Supernate system design, changes to the disposal requirements and incorporating lessons learned, the draft Feasibility Study (Ref. 2) has proposed that the SN system should be changed to convert that system to the sludge (SL) solidification process. Furthermore they wish to incorporate lessons learned from SN operations.

The RH Debris and Sludge Operability Review (Ref. 3) SN [Supernate] lessons learned indicated:

1. "Significant build-up on the dryer agitator and dryer wall occurred in both surrogate testing and actual SN processing."
2. "Excessive powder entrainment resulting in rapid dryer demister pressure drop build-up and solids carryover into the distillate system …"
3. "Frequent plugging of the SN [Supernate] dryer discharge valve occurred during surrogate testing."
4. "High torque loadings on the SN dryer agitator during the viscous drying phase, prior to achieving a granular powder placed more strain on the gearbox and more stress on the dryer agitator shaft seals due to the radial shaft movement/deflection. The SN [Supernate] dryer agitator actually locked up in Dryer Surrogate Demo 5 and the test run was aborted."
5. "The most dose intensive task during the SN [Supernate] campaign was the seal/cut of the SN liner fill sleeve from the SN [Supernate] Dryer discharge chute which included dose related clean-up of any ensuing contamination of the LLW liner or shipping cask. Contamination spread was occurring when only a single discharge sleeve was used. A second sleeve…was incorporated into the process. Even without a powder waste form, contamination control around the final SN was container interface was a challenge."
6. "Crystal formation on sealing surfaces … can cause premature component failure/leakage. Periodic outages to drain, flush, and acid clean the systems were necessary to keep equipment operable."
7. "Due to Isolok sampler leaking during the SN [Supernate] campaign, "an alternative design/supplier for the SL samplers should be evaluated."

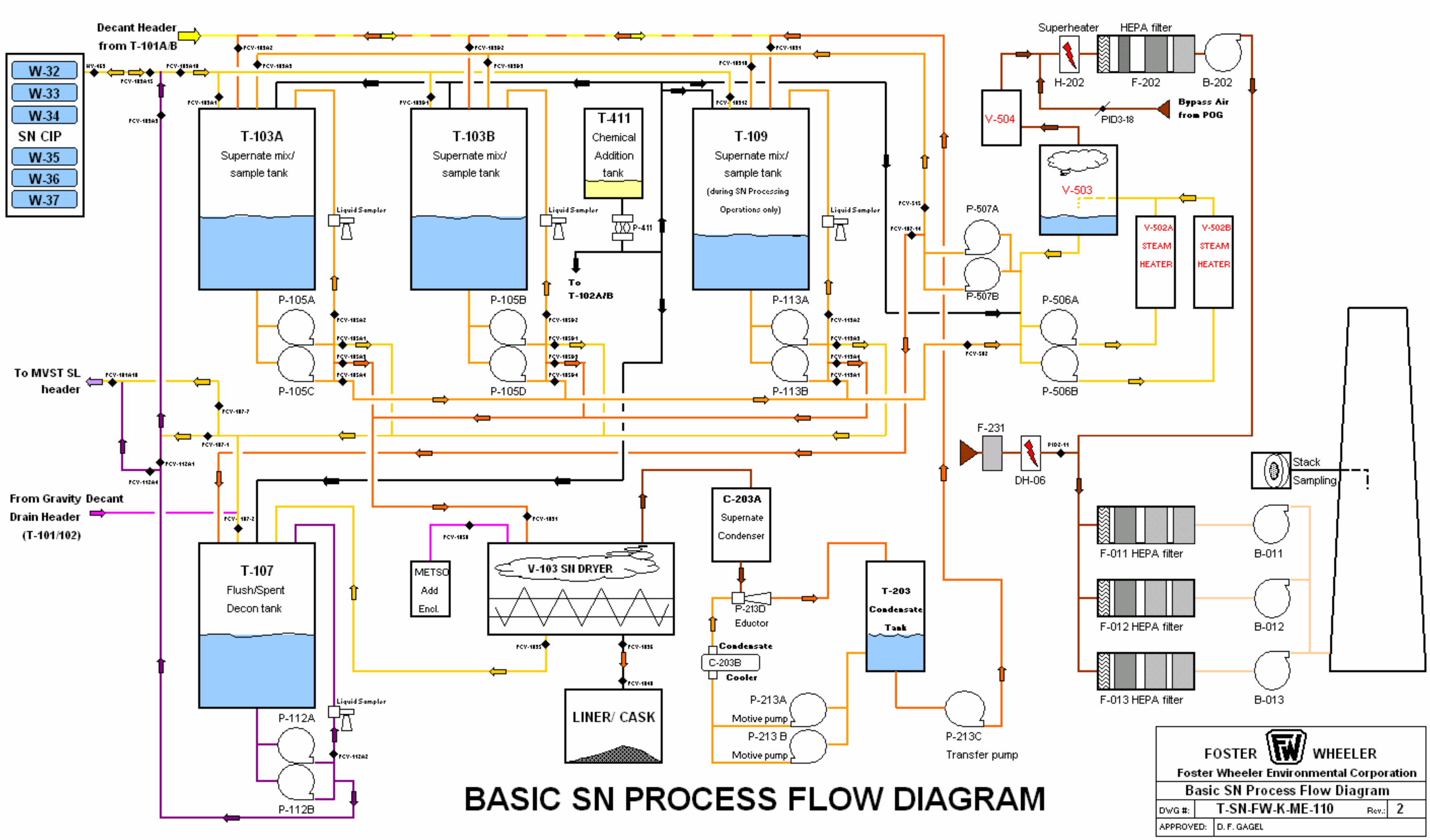

Figure 7. SN Basic Process Flow Diagram (Ref. 4)

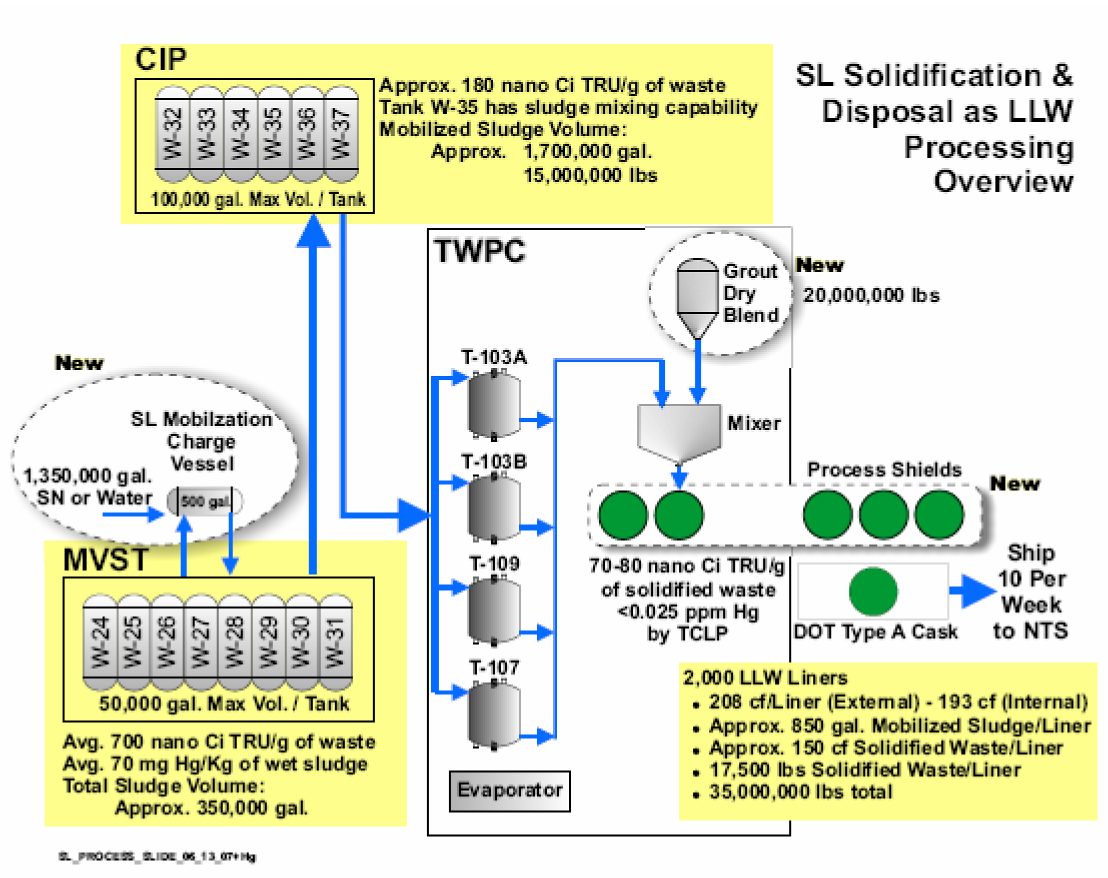

Figure 8. Sludge Solidification Process Overview (Ref. 2)

From the draft Feasibility Study (Ref. 2), proposed changes include modifications to:

- The SN [Supernate] dryer, presumably from lessons learned 2, 3, and 4 (above) in the SN [Supernate] campaign. This is discussed in 4.2.3 below.
- The back-up power system, presumably from lessons learned 1, 2, and 6 (above) in the SN [Supernate] campaign and reasonable operational consideration. This recommendation is based on the need to maintain operations for a grout system such that a power outage would not cause system failure due to the grout setting up in the dryer because the power is out. This is appropriate and not evaluated further in this review.
- The 30-ton crane bay, presumably as a result of new operational needs. This is discussed in Section 4.2.5 below.
- The decontamination/system flush, presumably from lessons learned 6 (above). This is appropriate and not evaluated further in this review.
- The acid cleaning system for Batch Mixer, presumably from lessons learned 1 and 2 (above). This is appropriate and not evaluated further in this review.
- The Isolok samplers, presumably from lessons learned 7 (above). This is appropriate and not evaluated further in this review.

New work and/or equipment required for the system conversion is proposed in the draft Feasibility Study to be:

- A new bench scale testing program, as a result of new system requirements. It is discussed in Section 4.2.1
- Installation of a grout addition system, as a result of new system requirements. It is discussed in Section 4.2.2.
- There are also proposed changes to the LLW liners and liner filling process, presumably from lessons learned 5 (above). These are discussed in Section 4.2.4.

As part of Pro2Serve's technical assessment, a review of the proposed changes to the existing system, recommended new work and operational changes as stated in the draft Feasibility Study (Ref. 2) was performed. The general materials of construction of existing pipes and tanks appear to be compatible with the proposed SL solidification system; however, due to time limitations a detailed review of sludge flow considerations, installed valves, and pumps were not reviewed in detail for this effort.

4.2.1 SL Solidification Bench Scale Testing Program

FWENC/EnergX proposes "bench scale testing to confirm the performance of the solidification of the MVST sludge and produce specific data for scale-up. In particular, the draft Feasibility Study states bench scale testing will determine "dry blend grout recipe, mixing times, grout viscosity and set times, ability to accommodate excess water from chute flushing, cure times, grout density, and TCLP results for RCRA metals." Furthermore, FWENC/EnergX asserts "to be meaningful, the bench scale testing needs to be performed on actual MVST sludge samples."

Pro2Serve is in agreement with these statements. Should DOE wish to pursue solidification as the sludge processing method, bench scale testing is imperative to implementing the full scale processing. Prior to initiating the bench scale testing, performance criteria for the grout should be established as well as the conceptual treatment approach for handling various sludges from the various tanks (i.e., whether tank sludges will be combined or treated separately). Furthermore, DOE may wish to consider testing beyond typical grout bench scale (Hobart mixers and grout in small cups) to evaluate grout viscosity, gravity flow of grout, impacts to the processing area from heat of hydration and determine minimum adequate mixing needs.

Additional parameters beyond those mentioned in the draft Feasibility Study that need to be understood for implementation and operability of this solidification process and should be evaluated prior to implementing the full scale process, are:

- mix ratio (wt dry solids blend/volume waste),
- establishing whether there is a need for more than one grout recipe,
- ability to back blend any weep liquids from the curing of a batch, and
- adequacy of gravity feed of LLW liners and approximate time to empty the batch mixer/fill liners using gravity flow.

4.2.2 Grout Feed System

To address the need to feed dry blend grout to the mixer, FWENC proposes installing a dry blend unloading and storage system and installing a dry blend weigh hopper charging system.

1. Installing Dry Blend Grout/Powder Unloading and Storage System

Basically, the concept is to install a tanker unloading station north of the 30-ton crane bay for conveyance of dry blend grout up to the roof of the facility where it will be put into a new bulk storage silo. The plan to open the existing roof so the new silo can extend into the sludge tank vault can be workable as long as adequate care is taken to address floor loading issues for the new bulk storage silo and the new penthouse is designed and installed sufficiently to prevent water infiltration to the lower levels of the facility. However, FWENC/EnergX also needs to consider a dry blend system that allows for adequate metering of the dry blend components. This is discussed in more detail below.

2. Installing Dry Blend Grout/Powder Transfer Weigh Hopper Charging System

The addition of the conceptualized powder transfer weigh hopper charging system in the hot cell maintenance area appears spatially adequate. That is, if the necessary equipment will fit into the described spaces and no hot cell maintenance activities are impeded by using a portion of the hot cell maintenance area. During design, care must be taken to ensure floor loading capacities are not exceed by the proposed weigh hopper when it is full. Furthermore, these kinds of systems typically operate with supplemental vibrating devices to help keep solids from sticking to the insides of the hoppers. The impacts of the potential noise in the facility and also the force of vibration in addition to static loads should be considered.

Once in the batch weigh hopper charging system, the dry blend will presumably be fed to the mixer. The draft Feasibility Study states "[the] batch weigh hopper charging system located in the Hot Cell maintenance area, which is the third floor elevation directly above the batch mixer on the second floor." The connection of the batch weigh hopper charging system to the batch mixer was not discussed in detail in the draft Feasibility Study, thus is not evaluated in this review of the conceptual process modifications.

Discussions with FWENC/EnergX engineering and operations personnel regarding grout solidification have indicated that multiple grout recipes are anticipated. From the draft Feasibility Study, it is not clear which dry components would be stored in the storage silo (discussed above), versus which dry components would be added at the weigh hopper charging system. Previous bench scale testing indicates 33 wt % blast furnace slag, 20 wt % Type I-II Portland cement, 19 wt % Class F fly ash, 20 wt % Perlite and 8 wt % IRPC ratios are a successful recipe. If multiple grout recipes are needed and multiple components at similar (33 wt%, 20 wt%, 19% wt%) ratios are necessary, then the conceptualized weigh hopper charging system, normally filled from the silo, with provision for bags of material being manually added, is probably not sufficient. Thus a dry component delivery system that allows for metering of various quantities of the dry blend components will be valuable and, depending on batch testing results, potentially necessary.

Instead of having the dry blend components mixed outside of the TWPC, or manually fed at the weigh hopper charging system, better control of the mix will be realized if dry blend quantities that are established in bench scale testing are metered inside the TWPC. This will likely require a multiple hopper-metered feed system. Whether there is adequate space for installation of a multiple hopper feed system will need to be evaluated. If there is not a need for the open floor space in the hot cell maintenance area, and the floor loading requirements are adequate, the hoppers could still potentially be placed in the 42' x 17' hot cell maintenance area as currently conceptualized by FWENC/EnergX for the weigh hopper charging system.

This needs further engineering evaluation as the ability to adequately feed grout mix components is essential to the feasibility of the solidification process.

4.2.3 Batch Mixer Design and Operability

FWENC/EnergX is proposing using a converted supernate dryer(s) as the grout mixer for the mixing of the sludge with the dry grout solid. The current FWENC/EnergX proposal, as described in the draft Feasibility Study, is to convert the dryer to a batch mixer by:

- Increasing the maximum speed of the agitator shaft from 10 rpm to 50 rpm via a gearbox change,
- Converting the manual agitator shaft injectable packing addition system to a continuous, automated, injectable packing system to keep this area flushed with injectable packing and minimize shaft wear from grout,
- Processing smaller batches in the Batch Mixer so that the grout level is below the agitator shaft,
- Qualifying the grout recipe with additional water absorbing ability so that the two discharge chute flushes per mixer batch can be performed if required, and
- Installing an acid injection system on the third floor that can be used to add acid into the Batch Mixer.

Pro2Serve recognizes that ideally, the grout mixer for the sludge process should:

A. give a consistent homogenous grout product,
B. last for the duration of the campaign so that equipment change-out due to component failure is not required,
C. be remotely flushable between batches, and
D. have the ability to run 7 days/week.

Per the Rotary Vacuum Supernate Dryer Equipment Specification, when purchased, the dryer was designed to perform as follows:

1. Dry/crystallize a saturated solution that consists primarily of sodium and potassium nitrates,
2. Process ≈ 45 wt% solids feed (including additive) at 32 gal/hour (hr) (356 lb (pound)/hr),
3. Operate 24 hours/day, 5 days/week, and
4. Produce a dried product (average continuous) at 159 lb/hr (13.2 gal/hr) with 5 wt% water.

While the Supernate dryer is a candidate to perform the grout mixing functions, it appears to be a potentially inappropriate choice as a grout mixer for this process. This is based on evaluating the proposed batch mixer/dryer by its ability to meet four mixer parameters listed above:

A. *Give a consistent homogenous grout product*: To achieve an excellent mix between the dry solids blend and the liquid/slurry feed resulting in a consistent homogenous grout product, high shear mixing is best. This is why many full scale grout plant applications are performed by a high shear grout mixer. Due to the thixotropic nature of grout, mixers capable of producing high quality grout are high shear mixers. High shear mixing involves shaft speeds in the 1000 – 2000 rpm range, with mix times less than 10 minutes. Low shear mixing can be successfully accomplished, though it will yield different grout properties compared with high shear mixed grout.

It is recognized that there are two $650K dryers that have been purchased and are readily available for use; however, the availability of these pieces of equipment need to be evaluated against the required equipment performance and grout performance as a function of adequate mixing.

B. *Last for the duration of the campaign so that equipment change-out due to component failure is not required*. Upon review, it appears that this process requirement will likely not be met. The lessons learned from the 9 month SN campaign listed in section 4.2 applicable to this requirement are:

- "Significant build-up on the dryer agitator and dryer wall occurred in both surrogate testing and actual SN [Supernate] processing."
- "Excessive powder entrainment resulting in rapid demister pressure drop build-up and solids carryover into the distillate system …"
- "Frequent plugging of the SN [Supernate] dryer discharge valve occurred during surrogate testing."
- "High torque loadings on the SN [Supernate]dryer agitator during the viscous drying phase, prior to achieving a granular powder placed more strain on the gearbox and more stress on the dryer agitator shaft seals due to the radial shaft movement/deflection. The SN [Supernate] dryer agitator actually locked up in Dryer Surrogate Demo 5 and the test run was aborted."

Furthermore, the operability review (Ref. 3) concluded "the ability of the (dryer) equipment to operate for the potentially extended (sludge) processing duration (6 -17 years) with limited maintenance as originally planned is also not likely." While the lessons learned and conclusion has resulted in proposed changes to the dryer, the remedy proposed to address the high torque loadings on the SN dryer agitator should be re-evaluated. It is doubtful that the gear box conversion and the addition of an automated injectable packing system will be sufficient to ensure continuous operation of the dryer as a batch mixer for the proposed 5 – 10 year campaign.

It is doubtful that even a mixer specially designed for this purpose with over engineered parts including abrasive-resistant materials and multiple packing systems, could be expected to last for 10 years of continuous operation, though it would be expected to last longer than the dryer converted to mixer. Taking a risk based view of this fundamental piece of equipment, FWENC/EnergX may wish to consider an in-line spare mixer as an option that could potentially eliminate costly delays caused by equipment changeout.

At a minimum, long term testing of the dryer turned mixer system for durability and sufficient mixing with an increase in rotational shaft speed and the injectable packing system should be performed with surrogate grout prior to any implementation of actual sludge grouting.

C. *Remotely flushing between batches*. One of the proposed changes includes acid cleaning for the batch mixer. Though limited detail is given regarding this system, the concept is appropriate based on SN lessons learned thus, is not reviewed in more detail. It is recommended that a plan for handling the dirty flush fluid be developed.

D. *Have the ability to run 7days/week*. Per the original equipment specification, and its performance during the SN campaign, this equipment would have the ability to run 7 days/week, if the other operational parameters are not exceeded such that component failure occurs. However, based on the expected operational duration (5 – 10 years), component failure of the dryer turned batch mixer would be expected.

Given the concerns that the dryer could possibly not meet requirements A and B; it is recommended that a high shear batch mixer be considered as an alternative to the conversion of the dryer to a batch mixer..

4.2.4 LLW Liner Filling/ Handling and Process Shields

The lessons learned indicated "The most dose intensive task during the SN campaign was the seal/cut of the SN liner fill sleeve from the SN Dryer discharge chute which included dose related clean-up of any ensuing contamination of the LLW liner or shipping cask. Contamination spread was occurring when only a single discharge sleeve was used. A second sleeve…was incorporated into the process. Even without a powder waste form, contamination control around the final SN waste container interface was a challenge."

From the draft Feasibility Study (Ref. 2) problem issues associated with liner filling are plugging of ports and chutes, overfilling and excessive flush water added to monolith. A key strategy to address the plugging is formulation of a low viscosity and slow set time recipe. It is also stated that a high dry blend grout to waste ratio is proposed to give a high confidence level of achieving an acceptable monolith. Achieving both a low viscosity and a high grout to waste ratio without adding excessive flush water poses a challenge. Furthermore, due to the gravity feed nature of the liner system, the grout must be flowable to load into the containers. These issues should be addressed by batch testing and appropriate planning and will be pivotal in the choice of dryer conversion versus purchase of high shear mixer. Additionally, the use of a camera inside the LLW liner is proposed for visual confirmation.

From the draft Feasibility Study (Ref. 2), discussion of SL LLW Process Shields, "The proposed concept is a simple reusable shield that resembles a Department of Transportation (DOT) Type A shipping cask, but is thinner walled, lighter, and much less expensive. The shielding objective would be to reduce the LLW liner contact dose rate to less than 100 mrem/hr on contact. The initial driver for the use of the process shields was to avoid the risk of contaminating a shipping cask… However, the process shields also provide another benefit that could reduce the average cycle time per liner and shorten the operating duration."

Conceptually, the use of the process shields to decrease the cycle time appears reasonable and FWENC/EnergX's recommendation to perform time/motion studies on this process step is also reasonable. However, Pro2Serve also recommends that FWENC/EnergX include study of expected decrease in dose rate from this step, as a means of addressing the lesson learned.

4.2.5 Enclosing and Ventilating the 30 Ton Crane Bay

Though longer than expected cycle times for the SN [Supernate] dryer were documented in the SN campaign lessons learned (Ref. 3) there was no mention of LLW liner cycle times. Thus, enclosure of the 30 Ton Crane Bay for the purpose of minimizing LLW liner cycle time warrants a cost benefit analysis.

4.3 SOLIDIFICATION PROCESS DESIGN AND OPERABILITY REVIEW CONCLUSIONS

The following are conclusions of the Pro2Serve design and operability review of the proposed solidification process as documented in the draft Feasibility Study (Ref. 2):

1. If the other implementation and operational process conclusions/concerns (as stated below) can be addressed such that a safe, cost effective solidification process can be implemented, then grout solidification appears to be an appropriate treatment choice for the tank sludge from the MVST, BVEST, and CIP tanks.
2. Pro2Serve agrees that bench scale testing on actual MVST sludge is necessary for development of a grout recipe (or recipes) that will generate a solidified monolith that meets the NTS WAC.

   Additional parameters beyond those mentioned in the draft Feasibility Study that need to be understood for implementation and operability of this solidification process and should be evaluated prior to implementing the full scale process, are: mix ratio (wt dry solids blend/volume waste), establishing whether there is a need for more than one grout recipe, ability to back blend any weep liquids from the curing of a batch, adequacy of gravity feed of LLW liners and approximate time to empty the batch mixer/fill liners using gravity flow.

Prior to initiating the bench scale testing, performance criteria for the grout should be established as well as the conceptual treatment approach for handling various sludges from the different tanks. Furthermore, DOE may wish to consider testing beyond typical grout bench scale testing (Hobart mixers and grout in small cups) to evaluate grout viscosity, gravity flow of grout, impacts to the processing area from heat of hydration and determining minimum adequate mixing needs.

3. Currently a single silo feeding a single weigh hopper charging system is conceptualized in the draft Feasibility Study. Pro2Serve suggests that a dry component delivery system be considered; one that allows for multiple dry blend feed hoppers and metering of various quantities of the dry blend components. This added flexibility will be valuable and, depending on batch testing results, is potentially necessary.

   Furthermore, this needs further engineering evaluation as having the space in the TWPC to adequately feed grout mix components is essential to the feasibility of the solidification process.

4. Given the concerns that the dryer could possibly not meet mixing and reliability requirements, it is recommended that a high shear batch mixer be considered as an alternative to the conversion of the dryer to a batch mixer.

5. Conceptually, the use of the process shields to decrease the cycle time appears reasonable and FWENC's recommendation to perform time/motion studies on this process step is also reasonable. However, Pro2Serve also recommends that FWENC/EngergX include study of expected decrease in dose rate from this step, as a means of addressing the lesson learned.

6. From the draft Feasibility Study, a key strategy to address the grout discharge plugging is formulation of a low viscosity and slow set time recipe. It is also stated in the draft Feasibility Study that a high dry blend grout to waste ratio is proposed to give high confidence level of achieving and acceptable monolith. The low viscosity grout parameter, coupled with the high dry blend grout to waste ratio, are somewhat mutually exclusive or would imply that extra liquid will potentially be added to the mixture, thus further increasing the disposal volume. These issues should be addressed by batch testing and will be pivotal in the choice of dryer conversion versus purchase of high shear mixer.

7. Though longer than expected cycle times for the SN dryer were documented in the SN campaign lessons learned (Ref. 3) there was no mention of LLW liner lidding and loading cycle times. Thus, enclosure of the 30-ton crane bay for the purpose of minimizing LLW liner lidding and loading cycle time warrants a cost benefit analysis.

4.4 SECTION REFERENCES

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5. FINAL WASTE FORM

5.1 NTS WAC ATTAINMENT

The dried supernate from the MVSTs was successfully shipped from the TWPC to the NTS in 2004. Consequently, the programmatic elements that must be developed to ship wastes to the NTS (e.g., quality assurance, self-assessment, vendor evaluation, verification actions, etc.) are in place. Hence, the remaining concern is whether the waste form itself will comply with the NTS waste acceptance criteria (WAC). The WAC for NTS are delineated in DOE/NV-325, *Nevada Test Site Waste Acceptance Criteria* (Ref. 1). The waste acceptance criteria address aspects of the waste including radiological content, chemical content, physical form, packaging, etc. WAC issues that could potentially affect the suitability of the solidified sludge at NTS are discussed in the following subsections.

5.1.1 TRU Content

Section 3.1.1 of the NTS WAC (Ref. 1) requires that the concentration of alpha-emitting TRU nuclides with half-lives greater than 20 years must not exceed 100 nCi/g. TRU isotopes in the MVST sludge identified in the Keller report (Ref. 2) include ^{237}Np, ^{241}Am, ^{238}Pu, and $^{239/240}$Pu. In addition to these isotopes, the sludges in Tank W-23 are believed to contain ^{243}Cm and ^{242}Pu as well. In addition to these TRU isotopes, the MVST and W-23 sludge also contains the non-TRU isotopes ^{241}Pu and ^{244}Cm, which decay into the TRU isotopes ^{241}Am and ^{240}Pu, respectively.

5.1.1.1 Projected TRU Content of Sludge Product from MVST and W-23

The projected average isotopic concentrations in the solidified sludge monoliths created from MVST sludges, W-23 sludge, and a mixture of the MVST sludges and W-23 sludge are estimated using the methodology described in Appendix A and listed in Tables A.6, A.7, and A.8 in Appendix A. The TRU isotopes in the monoliths are summarized in Table 1. Radionuclide concentrations in individual monoliths are not expected to diverge greatly from these average values. The variability of the monoliths produced from a single “big batch” is expected to be quite low, as the mobilized sludge will be homogenized in the W-35 CIP Tank and continually mixed prior to treatment to prevent re-stratification of the sludge. Variability between big batches could be more significant. However, operators can control the uniformity of the big batches to the degree necessary by ensuring that big batches containing high activity sludges (e.g., from W-23) also contain sludges from tanks with below average activities.

Table 1. Projected TRU Content of Solidified Sludge Monoliths

Isotope	MVST Monolith (nCi/g)	W-23 Monolith (nCi/g)	Monolith from Mixed MVST and W-23 Sludges
^{241}Am	2.55E+01	8.01E+01	2.86E+01
^{243}Cm	0.00E+00	2.95E+01	1.71E+00
^{237}Np	3.30E-02	1.26E-02	3.18E-02
^{238}Pu	2.69E+01	5.34E+01	2.85E+01
$^{239/240}$Pu	1.76E+01	3.29E+01	1.85E+01
^{242}Pu	0.00E+00	7.39E-02	4.28E-03
Total TRU	**7.00E+01**	**1.96E+02**	**7.73E+01**

As illustrated in Table 1, if the W-23 sludge is considered to be a separate waste stream and is not mixed with the MVST sludge prior to solidification, the solidified sludge monoliths created from the W-23 sludges will be TRU wastes and cannot be accepted by NTS. However, if the W-23 and MVST sludges are mixed prior to solidification, the resulting solidified sludge monoliths will have TRU content below 100 nCi/g and can be classified as low-level waste acceptable at NTS.

5.1.1.2 Decay Effects

The total TRU activity in the sludges increases over time by the decay of non-TRU isotopes into TRU daughters. This increase is offset by the decay of TRU isotopes into non-TRU daughters. Ref. 3 raises a concern that the TRU activity in the sludges could substantially increase by the time the sludges are eventually processed, thereby potentially jeopardizing the conclusions reached in Section 5.1.1.1. To address this concern, the effects of the two primary decay modes are evaluated.

The important decay modes are the decay of non-TRU ^{241}Pu into TRU ^{241}Am and the decay of TRU ^{238}Pu into non-TRU ^{234}U. The decay of non-TRU ^{244}Cm into TRU ^{240}Pu is less significant than the decay of ^{241}Pu because of the low specific activity of ^{240}Pu. Conversely, the decays of TRU isotopes other than ^{238}Pu have limited significance because their half lives are so much longer than that of ^{238}Pu.

The rate of ^{238}Pu decay is given by:

$$d[^{238}\text{Pu activity}]/dt = [^{238}\text{Pu activity}]\ \ln(0.5) / T_{1/2,\ Pu\text{-}238} \quad (1)$$

The rate of ^{241}Am generation from ^{241}Pu decay is given by:

$$d[^{241}\text{Am activity}]/dt = -[^{241}\text{Pu activity}]\ \ln(0.5)\ (SA_{Am\text{-}241}/SA_{Pu\text{-}241}) / T_{1/2,Pu\text{-}241} \quad (2)$$

The projected isotopic concentrations of ^{238}Pu and ^{241}Pu in solidified W-23 sludge are 5.34E+01 nCi/g and 5.98E+02 nCi/g, respectively (Table A.7). Inserting these values into equations (1) and (2) yields:

$$d[^{238}\text{Pu activity}]/dt = [5.34{+}01\ \text{nCi/g}]\ \ln(0.5) / 87.7\ \text{yrs}$$
$$= -0.42\ \text{nCi/g/year (yr)}$$

$$d[^{241}\text{Am activity}]/dt = -[5.98\text{E}{+}02\ \text{nCi/g}]\ \ln(0.5)\ ((3.43\ \text{Ci/g})/(103\ \text{Ci/g})) / 14.29\ \text{yrs}$$
$$= +0.97\ \text{nCi/g/yr}$$

The rate of ^{241}Am generation exceeds the rate of ^{238}Pu decay. Consequently, the TRU content of the Tank W-23 sludge is increasing with time. However, this has only marginal significance, because the solidified W-23 sludge will be TRU regardless unless it can be mixed with the MVST sludges. Therefore, a more important question is the effect of time on the total TRU content of the combined MVST and W-23 sludges.

The projected isotopic concentrations of ^{238}Pu and ^{241}Pu in solidified mixed MVST/W-23 sludges are 2.85E+01 nCi/g and 7.49E+01 nCi/g, respectively (Table A.8). Inserting these values into equations (1) and (2) yields:

$$d[^{238}\text{Pu activity}]/dt = [2.85{+}01\ \text{nCi/g}]\ \ln(0.5) / 87.7\ \text{yrs} = -0.23\ \text{nCi/g/yr}$$

$$d[^{241}\text{Am activity}]/dt = -[7.49\text{E}{+}01\ \text{nCi/g}]\ \ln(0.5)\ ((3.43\ \text{Ci/g})/(103\ \text{Ci/g})) / 14.29\ \text{yrs}$$
$$= +0.12\ \text{nCi/g/yr}$$

The rate of ^{238}Pu decay exceeds the rate of ^{241}Am generation. Consequently, the total TRU content of the combined MVST and W-23 sludges is decreasing with time.

5.1.2 Fissile Content

Section 3.2.1 of the NTS WAC (Ref. 1) requires that the fissile material in waste containers be limited so that an infinite array of such packages will be subcritical under "as packaged" conditions even if the array were flooded with water to any credible degree. The MVST and W-23 sludges contain no graphite and only trivial quantities (much less than 1%) of beryllium (as discussed in Section 5.1.5). Consequently, one of the criteria listed in Section E.7 of Ref. 1 that can be used to demonstrate that the waste satisfies the criticality requirements is that the ^{235}U fissile gram equivalent (FGE) of the waste does not exceed 350 grams per package or 2 grams per kilogram (kg) of waste.

Projected average radionuclide concentrations in solidified sludge monoliths created from MVST sludges, W-23 sludge, and a mixture of MVST and W-23 sludge are estimated using the methodology described in Appendix A and listed in Tables A.6, A.7, and A.8 of Appendix A. As discussed in Section 5.1.1.1, the radionuclide concentrations in individual monoliths are not expected to diverge greatly from these average concentrations. The projected concentrations of fissile isotopes are summarized in Tables 2, 3, and 4. It is conservatively assumed that all of the activity in the MVST ascribed to "$^{239/240}$Pu" consists of ^{239}Pu.

Table 2. Projected Fissile Content of Solidified Monoliths of MVST Sludge

Isotope	Concentration (nCi/g)	Specific Activity (Bq/g)	Mass Concentration (Isotope g/g)	^{235}U FGE Conversion Factor	^{235}U FGE (g FGE/kg)
^{233}U	1.55E+01	3.6E+08	1.6E-06	1.4	2.2E-03
^{235}U	3.78E-02	8.1E+04	1.7E-05	1.0	1.7E-02
^{239}Pu	1.76E+01	2.3E+09	2.8E-07	1.6	4.5E-04
^{241}Pu	4.27E+01	3.8E+12	4.2E-10	3.5	1.5E-06
Total					**2.0E-02**

Table 3. Projected Fissile Content of Solidified Monoliths of W-23 Sludge

Isotope	Concentration (nCi/g)	Specific Activity (Bq/g)	Mass Concentration (Isotope g/g)	^{235}U FGE Conversion Factor	^{235}U FGE (g FGE/kg)
^{233}U	1.50E+01	3.6E+08	1.5E-06	1.4	2.2E-03
^{235}U	7.21E-03	8.1E+04	3.3E-06	1.0	3.3E-03
^{239}Pu	1.75E+01	2.3E+09	2.8E-07	1.6	4.5E-04
^{241}Pu	5.98E+02	3.8E+12	5.8E-09	3.5	2.0E-05
^{243}Cm	2.95E+01	1.9E+12	5.7E-10	7.8	4.5E-06
Total					**6.0E-03**

Table 4. Projected Fissile Content of Solidified Monoliths of MVST/W-23 Sludge Mixtures

Isotope	Concentration (nCi/g)	Specific Activity (Bq/g)	Mass Concentration (Isotope g/g)	^{235}U FGE Conversion Factor	^{235}U FGE (g FGE/kg)
^{233}U	1.55E+01	3.6E+08	1.6E-06	1.4	2.2E-03
^{235}U	3.60E-02	8.1E+04	1.6E-05	1.0	1.6E-02
^{239}Pu	1.85E+01	2.3E+09	3.0E-07	1.6	4.8E-04
^{241}Pu	7.49E+01	3.8E+12	7.3E-10	3.5	2.6E-06
^{243}Cm	1.71E+00	1.9E+12	3.3E-11	7.8	2.6E-07
Total					**1.9E-02**

As illustrated in Tables 2, 3, and 4, the FGE concentrations in the solidified sludge monoliths will be orders of magnitude below 2 FGE/kg of waste. Ref.erence 3 indicates that approximately 17,500 lbs of solidified sludge will be placed in each liner. Therefore, the total FGE quantities per liner for MVST, W-23, and MVST/W-23 mixtures are projected to be approximately 160 FGE, 48 FGE, and 150 FGE, respectively. All of these values are well below the 350 FGE/package limit. Consequently, the fissile content of the waste is expected to satisfy the NTS WAC requirements.

5.1.3 Other Radiological Characteristics

Section 3.2.2 of the NTS WAC limits the radiological contents of shipments to less than 2,000 ^{239}Pu inhalation equivalent grams (PE-g). Projected radionuclide concentrations in solidified sludge monoliths created from MVST sludges, W-23 sludge, and a mixture of MVST and W-23 sludge are estimated using the methodology described in Appendix A and listed in Tables A.6, A.7, and A.8 of Appendix A. These activities are converted to PE-g by multiplying them by the conversion factors listed in Appendix B of Ref. 1 and making the appropriate unit conversions, as illustrated in Tables 5, 6, and 7.

Table 5. PE-g in Solidified MVST Sludge

Isotope	Concentration (nCi/g)	PE-g Conversion Factor (PE-g/Bq)	PE-g/g
^{63}Ni	8.95E+00	5.35E-15	1.77E-12
^{60}Co	7.95E+01	1.86E-13	5.47E-10
^{90}Sr	9.15E+03	1.11E-12	3.76E-07
^{99}Tc	1.96E+00	7.08E-15	5.13E-13
^{129}I	1.16E-04	1.48E-13	6.35E-16
^{134}Cs	1.86E+01	4.00E-14	2.75E-11
^{137}Cs	2.13E+03	2.72E-14	2.14E-09
^{152}Eu	1.03E+03	1.88E-13	7.16E-09
^{154}Eu	3.36E+02	2.43E-13	3.02E-09
^{155}Eu	9.00E+01	3.53E-14	1.18E-10
^{241}Pu	4.27E+01	8.50E-12	1.34E-08
^{232}Th	1.07E-01	1.39E-09	5.50E-09
^{233}U	1.55E+01	1.15E-10	6.60E-08
^{234}U	1.14E+00	1.13E-10	4.77E-09
^{235}U	3.78E-02	1.05E-10	1.47E-10
^{238}U	1.16E+00	1.02E-10	4.38E-09
^{237}Np	3.30E-02	4.60E-10	5.62E-10
^{241}Am	2.55E+01	4.44E-10	4.19E-07
^{244}Cm	1.91E+02	2.11E-10	1.49E-06
^{238}Pu	2.69E+01	3.90E-10	3.88E-07
$^{239/240}$Pu	1.76E+01	4.35E-10	2.83E-07
Total			**3.06E-06**

Table 6. PE-g in Solidified W-23 Sludge

Isotope	Concentration (nCi/g)	PE-g Conversion Factor (PE-g/Bq)	PE-g/g
^{227}Ac	1.59E+01	5.70E-09	3.35E-06
^{241}Am	8.01E+01	4.44E-10	1.32E-06
^{14}C	4.14E-01	1.79E-15	2.74E-14
^{144}Ce	3.85E+01	3.18E-13	4.53E-10
^{250}Cf	1.14E-01	2.23E-10	9.41E-10
^{252}Cf	7.96E-01	1.17E-10	3.45E-09
^{243}Cm	2.95E+01	2.61E-10	2.85E-07
^{244}Cm	4.41E+02	2.11E-10	3.44E-06
^{60}Co	1.88E+02	1.86E-13	1.29E-09
^{134}Cs	1.48E+01	4.00E-14	2.19E-11
^{137}Cs	3.54E+03	2.72E-14	3.56E-09
^{152}Eu	7.77E+02	1.88E-13	5.40E-09
^{154}Eu	4.83E+02	2.43E-13	4.34E-09
^{155}Eu	1.15E+02	3.53E-14	1.50E-10
^{95}Nb	8.22E+00	4.94E-15	1.50E-12
^{59}Ni	7.57E-02	2.30E-15	6.44E-15
^{63}Ni	9.74E+00	5.35E-15	1.93E-12
^{237}Np	1.26E-02	4.60E-10	2.14E-10
^{238}Pu	5.34E+01	3.90E-10	7.71E-07
^{239}Pu	1.75E+01	4.35E-10	2.82E-07
^{240}Pu	1.54E+01	4.35E-10	2.48E-07
^{241}Pu	5.98E+02	8.50E-12	1.88E-07
^{242}Pu	7.39E-02	4.09E-10	1.12E-09
^{106}Ru	7.36E+01	4.06E-13	1.11E-09
^{90}Sr	3.92E+03	1.11E-12	1.61E-07
^{99}Tc	8.16E+00	7.08E-15	2.14E-12
^{232}Th	7.75E-02	1.39E-09	3.99E-09
^{233}U	1.50E+01	1.15E-10	6.38E-08
^{234}U	5.91E-01	1.13E-10	2.47E-09
^{235}U	7.21E-03	1.05E-10	2.80E-11
^{236}U	9.01E-03	1.07E-10	3.57E-11
^{238}U	4.38E-01	1.02E-10	1.65E-09
^{95}Zr	5.10E+01	2.01E-14	3.79E-11
Total			**1.01E-05**

Table 7. PE-g in Solidified MVST/W-23 Sludge Mixture

Isotope	Concentration (nCi/g)	PE-g Conversion Factor (PE-g/Bq)	PE-g/g
^{227}Ac	9.19E-01	5.70E-09	1.94E-07
^{241}Am	2.85E+01	4.44E-10	4.70E-07
^{14}C	2.40E-02	1.79E-15	1.59E-15
^{144}Ce	2.23E+00	3.18E-13	2.62E-11
^{250}Cf	6.58E-03	2.23E-10	5.43E-11
^{252}Cf	4.61E-02	1.17E-10	2.00E-10
^{243}Cm	1.71E+00	2.61E-10	1.65E-08
^{244}Cm	2.05E+02	2.11E-10	1.60E-06
^{60}Co	8.57E+01	1.86E-13	5.90E-10
^{134}Cs	1.83E+01	4.00E-14	2.71E-11
^{137}Cs	2.21E+03	2.72E-14	2.22E-09
^{152}Eu	1.02E+03	1.88E-13	7.10E-09
^{154}Eu	3.45E+02	2.43E-13	3.10E-09
^{155}Eu	9.15E+01	3.53E-14	1.20E-10
^{129}I	1.09E-04	1.48E-13	5.97E-16
^{95}Nb	4.76E-01	4.94E-15	8.70E-14
^{59}Ni	4.38E-03	2.30E-15	3.73E-16
^{63}Ni	9.00E+00	5.35E-15	1.78E-12
^{237}Np	3.18E-02	4.60E-10	5.41E-10
^{238}Pu	2.85E+01	3.90E-10	4.11E-07
$^{239/240}$Pu	1.85E+01	4.35E-10	2.98E-07
^{241}Pu	7.49E+01	8.50E-12	2.36E-08
^{242}Pu	4.28E-03	4.09E-10	6.48E-11
^{106}Ru	4.27E+00	4.06E-13	6.41E-11
^{90}Sr	8.85E+03	1.11E-12	3.63E-07
^{99}Tc	2.32E+00	7.08E-15	6.08E-13
^{232}Th	1.05E-01	1.39E-09	5.40E-09
^{233}U	1.55E+01	1.15E-10	6.60E-08
^{234}U	1.10E+00	1.13E-10	4.60E-09
^{235}U	3.60E-02	1.05E-10	1.40E-10
^{236}U	5.22E-04	1.07E-10	2.07E-12
^{238}U	1.12E+00	1.02E-10	4.23E-09
^{95}Zr	2.95E+00	2.01E-14	2.19E-12
Total			**3.47E-06**

Reference 3 indicates that approximately 17,500 lbs of solidified sludge will be placed in each liner. Multiplying this mass by the total PE-g concentrations from Tables 5 through 7 indicate that the total PE-g/shipment for solidified MVST sludge, W-23 sludge, and MVST/W-23 sludge mixtures would be approximately 24 PE-g, 80 PE-g, and 27 PE-g, respectively. Therefore, no difficulties in satisfying the 2,000 PE-g limit per shipment are foreseen.

In addition to the overall PE-g limit, radionuclide limits for disposal for individual isotopes are listed in Table E-1 of the NTS WAC (Ref. 1). Exceedance of these limits does not necessarily mean that the waste cannot be accepted at NTS, but requires review by NNSA/NSO. The nCi/g concentrations from Tables A.4, A.5, and A.6 of Appendix A are converted to Bq/m^3 assuming a solidified sludge specific gravity of 1.87. These concentrations are compared to their respective disposal limits from Table E-1 of Ref. 1 in Table 8.

Table 8. Projected Radionuclide Concentration in Solidified Sludge Monoliths

Isotope	Solidified W-23 Sludge (Bq/meter (m)^3)	Solidified MVST Sludge (Bq/m^3)	Solidified MVST/W-23 Sludge Mixture (Bq/m^3)	NTS WAC Table E-1 Action Level (Bq/m^3)
^{227}Ac	1.10E+09	0.00E+00	6.36E+07	1.0E+12
^{241}Am	5.54E+09	1.76E+09	1.98E+09	1.8E+10
^{14}C	2.87E+07	0.00E+00	1.66E+06	2.3E+08
^{144}Ce	2.66E+09	0.00E+00	1.54E+08	No Limit
^{250}Cf	7.89E+06	0.00E+00	4.55E+05	Not Listed
^{252}Cf	5.51E+07	0.00E+00	3.19E+06	No Limit
^{243}Cm	2.04E+09	0.00E+00	1.18E+08	Not Listed
^{244}Cm	3.05E+10	1.32E+10	1.42E+10	8.1E+12
^{60}Co	1.30E+10	5.50E+09	5.93E+09	No Limit
^{134}Cs	1.02E+09	1.29E+09	1.27E+09	No Limit
^{137}Cs	2.45E+11	1.47E+11	1.53E+11	3.4E+11
^{152}Eu	5.38E+10	7.13E+10	7.06E+10	4.8E+13
^{154}Eu	3.34E+10	2.33E+10	2.39E+10	1.2E+16
^{155}Eu	7.96E+09	6.23E+09	6.33E+09	No Limit
^{129}I	0.00E+00	8.03E+03	7.54E+03	2.9E+09
^{95}Nb	5.69E+08	0.00E+00	3.29E+07	No Limit
^{59}Ni	5.24E+06	0.00E+00	3.03E+05	8.1E+12
^{63}Ni	6.74E+08	6.19E+08	6.23E+08	2.5E+13
^{237}Np	8.72E+05	2.28E+06	2.20E+06	7.0E+08
^{238}Pu	3.70E+09	1.86E+09	1.97E+09	1.2E+11
$^{239/240}$Pu	2.28E+09	1.22E+09	1.28E+09	2.3E+10
^{241}Pu	4.14E+10	2.96E+09	5.18E+09	5.2E+11
^{242}Pu	5.11E+06	0.00E+00	2.96E+05	2.4E+10
^{106}Ru	5.09E+09	0.00E+00	2.96E+08	No Limit
^{90}Sr	2.71E+11	6.33E+11	6.12E+11	1.5E+12
^{99}Tc	5.65E+08	1.36E+08	1.61E+08	1.1E+11
^{232}Th	5.36E+06	7.41E+06	7.27E+06	8.1E+08
^{233}U	1.04E+09	1.07E+09	1.07E+09	3.1E+10
^{234}U	4.09E+07	7.89E+07	7.61E+07	1.9E+10
^{235}U	4.99E+05	2.62E+06	2.49E+06	1.2E+10
^{236}U	6.24E+05	0.00E+00	3.61E+04	1.2E+11
^{238}U	3.03E+07	8.03E+07	7.75E+07	5.9E+10
^{95}Zr	3.53E+09	0.00E+00	2.04E+08	No Limit

As illustrated in Table 8, none of the individual isotope concentrations in the waste products would exceed their respective action levels. The ^{137}Cs concentration in solidified unmixed W-23 sludge would approach its limit. However, as discussed in Section 5.1.1, if W-23 sludge is not combined with the MVST sludges, it will be unable to go to NTS because of its high TRU content. Therefore, the potential for ^{137}Cs to exceed its NTS disposal action level would be a moot issue.

5.1.4 RCRA Issues

Low concentrations of the RCRA-regulated metals silver, arsenic, barium, cadmium, chromium, mercury, lead, and selenium have been detected in the MVST sludges and reported in the Keller report (Ref. 2). For each of these metals, the weighted average of the maximum concentration found in each tank is listed in the third column of Table 9. Section 3.3.1 of the NTS WAC allows mixed waste exhibiting the toxicity characteristic (RCRA codes D004 through D043) to be accepted. However, Section 3.3.4 of the

NTS WAC requires that mixed waste accepted at NTS meet the land disposal restrictions (LDR) treatment standards.

Table 9. RCRA Constituents in the MVSTs

Metal	RCRA Code	Raw Sludge C (milligram (mg)/kg)*	Raw Sludge C/200 (mg/kg)	40 CFR 261.24 TCLP Regulatory Limit (mg/l)	40 CFR 268.40 TCLP Regulatory Limit (mg/l)
Silver	D011	5.04E+00	2.52E-02	5	0.14
Arsenic	D004	2.95E+00	1.48E-02	5	5
Barium	D005	1.05E+02	5.27E-01	100	21
Cadmium	D006	4.60E+01	2.30E-01	1	0.11
Chromium	D007	2.37E+02	1.19E+00	5	0.6
Mercury	D009	9.33E+01	4.66E-01	0.2	0.025
Lead	D008	7.99E+02	3.99E+00	5	0.75
Selenium	D010	2.57E+00	1.29E-02	1	5.7

* Weighted Average of the Maximum Sample in Each Tank

The point at which the sludge must be considered a waste is a critical issue. If the point of generation is defined as the point at which the solidified sludge monoliths are created, then the solidified sludge monoliths must simply satisfy the 40 CFR 261.24 TCLP limits. If they do so, then the solidified sludge monoliths will not exhibit the toxicity characteristic and thus would not be mixed waste.

However, if the point of generation is defined as the point at which the material was originally discharged into liquid low-level waste drains, regulatory requirements are more problematic. 40 CFR 261.3 (d)(1) states: *"…wastes that exhibit a characteristic at the point of generation may still be subject to the requirements of part 268, event if they no longer exhibit a characteristic at the point of land disposal."* It does not seem plausible that the concentrations of RCRA metals in the MVSTs could be as high as they are without at least some of the material discharged into the liquid low-level waste system over the past 50 years exhibiting the toxicity characteristic. Consequently, if the point of generation is defined as the point at which the material entered the liquid low-level waste system, the solidified sludge monoliths must satisfy the 40 CFR 268.40 TCLP limits, which are substantially more restrictive than the 40 CFR 261.24 limits for most contaminants.

The addition of the mobilization water and the dry grouting mixture to the sludge will reduce the concentration of hazardous constituents by approximately an order of magnitude. To mobilize the sludge, five parts water by volume will be added to each part of raw sludge. The specific gravity of the raw MVST sludge is approximately 1.33, while the specific gravity of water is 1. Consequently, the mass of mobilization water is approximately 3.8 times the mass of the raw sludge. The mass ratio of the dry grouting mixture to the mobilized sludge is estimated to be 1.2:1. Hence, for each kg of raw sludge, 3.8 × 1 kg = 3.8 kg of mobilization water and (1 kg + 3.8 kg) × 1.2 = 5.7 kg of dry grout mixture will be added. Consequently, each kg of raw sludge will result in 1 kg + 3.8 kg + 5.7 kg = 10 kg of solidified sludge monolith. Therefore, even if the treatment fails to reduce the solubility of the metals, the TCLP results from the monolith will be $1/10^{th}$ of the TCLP results obtained from the raw sludge.

During the TCLP test, the mass of leachate added is 20 times the mass of the waste sample. Consequently, even if the solidified sludge monolith were completely ineffective at retaining the hazardous constituent and 100% of the constituent dissolved into the leachate, the concentration of the hazardous constituent in the leachate would still be no more than $1/20^{th}$ of the concentration in the solidified sludge monolith.

With the metal concentrations in the solidified sludge monoliths approximately $1/10^{th}$ the concentrations in the original raw sludge, and the metal concentrations in the TCLP leachate no more than

1/20th the metal concentrations in the solidified sludge monoliths, the metal concentrations in the monolith leachate can be no more than 1/200th the metal concentrations in the original raw sludge. These maximum potential leachate concentrations are listed in the fourth column of Table 9. A comparison of these values to the TCLP regulatory limits from 40 CFR 261.24 and 40 CFR 268.40 indicates that silver, arsenic, barium, and selenium will pass both sets of regulatory limits. Lead, chromium, and cadmium will pass the 40 CFR 261.24 limits, but could theoretically fail the 40 CFR 268.40 standards. However, because of the low solubility of these metals in high pH conditions, the potential for lead, chromium, and cadmium to exceed the 40 CFR 268.40 limits is considered minimal.

Mercury could potentially fail both the 40 CFR 261.24 and 40CFR 268.40 limits. Furthermore, mercury compounds are typically much more soluble in alkaline environments than other heavy metals. Consequently, mercury is the RCRA-regulated metal that is a major concern.

As discussed previously, the theoretical maximum TCLP leachate mercury concentration from the solidified sludge monolith would be no more than 1/200th of the mercury concentration in the raw sludge if it is conservatively assumed that all of the mercury in the sample would migrate into the leachate. In reality, most of the mercury will be retained in the waste matrix. TCLP tests have been performed on the raw MVST sludges, with the results documented in ORNL/TM-2003/30 (Ref. 4). Reference 4 reports that these tests indicate that only 10% of the mercury in the raw, untreated sludge would extract during a wet TCLP test. Consequently, unless the Thio-Red additive and the sulfide content in the blast furnace slag actually increased the solubility of the mercury, the mercury concentration in the TCLP leachate from the solidified sludge monoliths would be no more than 1/2,000th the mercury concentration in the original sludge. (One order of magnitude from the dilution of the sludge from the addition of the mobilization water and grouting mixture, another order of magnitude because only 10% of the mercury in the sample will migrate into the leachate, and then a factor of 20 because the mass of leachate is 20 times greater than the mass of the sample). Hence, the mercury concentration in the leachate would not be expected to exceed 0.0466 mg/l, which is below the 40 CFR 261.24 limits, and only marginally (less than a factor of two) above the 40 CFR 268.40 limits.

Previous testing to demonstrate the ability of Thio-Red and sulfide precipitation to immobilize mercury in MVST sludge samples and sludge surrogates has yielded mixed results (e.g., Ref. 4 and Ref. 5). However, because the leachate from the solidified sludge monoliths is only expected to marginally exceed the 40 CFR 268.40 limits without any stabilizing agents, the stabilizing agents do not need to be dramatically effective to ensure that the solidified sludge monoliths satisfy the LDRs. Consequently, it is likely that the TCLP results from the solidified sludge monoliths will satisfy both the 40 CFR 261.24 and 40 CFR 268.40 limits and thereby satisfy the LDRs. Further evidence supporting this projection is found in ORNL/TM-13653 (Ref. 6), which reports that grouting a sample of actual Tank W-25 sludge caused the product to satisfy both the 40 CFR 261.24 and 268.40 TCLP limits, even through the ungrouted sludge failed both.

5.1.5 Beryllium

Section 3.1.17 of the NTS WAC identifies additional packaging requirements for wastes containing 0.1% or more of beryllium that could be released as an airborne particulate. The MVST sample with the highest beryllium concentration reported in the Keller report (Ref. 2) was 21 mg/kg (0.0021%) found in the 1996 W-31S sample. This is nearly two orders of magnitude below the 0.1% action level in the NTS WAC. Furthermore, the sludge mobilization and treatment processes will reduce the beryllium concentrations by another order of magnitude, as well as putting it in a form that is not readily subject to potential particulate airborne releases. There is no reason to expect the beryllium content in Tank W-23 to be appreciably different from that in the MVST. Therefore, beryllium content in the solidified sludge monoliths is not projected to be an issue of concern.

5.1.6 Void Space

Section 3.2.9 of the NTS WAC requires that waste packages be loaded so that the interior volume is as efficiently and compactly loaded as practical to minimize void space. Per Section 4.1 of Ref. 3, the liners will be filled up to their weight limit, which will occupy approximately 75% of the volume, leaving a 25% void space. Section 3.3.6.2 of the NTS WAC limits the void space in mixed waste containers to less than 10%, but there is no analogous hard limit for LLW. It is likely that NTS will consider a 25% void fraction acceptable for LLW. During the 2004 supernate campaign, the LLW liners accepted by NTS had similar void fractions. Nevertheless, this should be verified through discussions with NTS.

5.1.7 Free Liquids

Section 3.1.5 of the NTS WAC requires that the waste must contain as little free-standing water as is reasonably achievable, and that the free liquid must not exceed 1% of the volume of waste when in a disposal container or 0.5% of the volume of the waste processed to a solidified form. This seems to be a readily achievable objective for the sludge solidification process, as the amount of dry grouting mixture used can be selected to minimize the generation of bleed water, while the amount of absorbents (e.g., Nochar Acid-Bond) pre-loaded in the LLW canisters can be adjusted to accommodate chute flush water.

5.2 COORDINATION WITH NTS

Reference 2 projects that the sludge solidification campaign is expected to ship up to ten low-level waste liners to NTS per week. Each liner has a volume of 208 ft^3, so the volume of low-level waste sent to NTS will be up to 2,080 ft^3/week or up to 27,000 ft^3/quarter. Such quantities are not expected to overwhelm NTS' capacity to receive waste.

The volumes of waste recently received at NTS are available in References 7 through 12 and summarized in Table 10. As illustrated in Table 10, the 27,000 ft^3 of solidified sludge monolith shipped to NTS per quarter will be less than 12% of the typical waste volume received at NTS. Furthermore, the increase of 27,000 ft^3/quarter is much less than a standard deviation, so it will not increase the rate of waste receipt beyond the normal operating range.

Table 10. Recent LLW Shipments to NTS

Quarter	Volume of Waste Received (ft^3)
1st Quarter FY 2006	243,952
2nd Quarter FY 2006	259,227
3rd Quarter FY 2006	443,377
4th Quarter FY 2006	163,883
1st Quarter FY 2007	89,912
2nd Quarter FY 2007	204,518
Mean	**234,144**
Standard Deviation	**119,265**

Much more serious difficulties would occur if the solidified sludge monoliths had to be considered treated mixed waste. NTS is only allowed to accept out-of-state mixed waste through December 2010. Even if the processing could be dramatically accelerated so that all the material could reach NTS by the December 2010 deadline, the volume of waste would be problematic. The solidified sludge monoliths are expected to fill approximately 2,000 LLW liners (Ref. 3). Each liner has a volume of 208 ft^3. Consequently, the total volume of the waste is expected to be nearly 12,000 m^3. The total volume of mixed waste that NTS is allowed to accept is only 20,000 m^3. Consuming such a large fraction of NTS' capacity would adversely affect other sites such as the Idaho National Laboratory that also have large quantities of mixed waste requiring disposal. As discussed in Section 5.1.6, the limitations on void space in the waste containers would also be much more restrictive if the material were classified as mixed waste.

Fortunately, it does not appear that the solidified sludge monoliths will be considered mixed waste, even if the point of generation is determined to be prior to the completion of the treatment. If the point of generation is prior to treatment, the sludges will have originally been hazardous wastes, and hazardous wastes normally remain hazardous wastes. However, 40 CFR 261.3(c) offers an exception to solid wastes that meet the criteria of 40 CFR 261.3(d). 40 CFR 261.3(d)(1) requires that the waste no longer exhibits any of the characteristics of hazardous waste. As discussed in Section 5.1.4, after solidification the monoliths are not expected to exhibit any toxicity characteristics. 40 CFR 261.3(d)(2) is not applicable, as the sludges contain no listed wastes.

5.3 TRANSPORTATION

One of the advantages of the proposed sludge solidification process cited in Ref. 3 is that the product could be shipped in a Type A package. This is potentially quite significant because there are only a small number of RH-72B casks available, and this limited number must be shared with all of the other DOE sites across the country. Low specific activity (LSA) material may be shipped in a Type A package even if the total package activity exceeds the A_1 and A_2 limits established in 49 CFR 173.435. Per Table 5 of 49 CFR 173.427, there are no activity limits for non-combustible LSA-II solids. Per 49 CFR 173.403, solids with uniformly distributed activity qualify as LSA-II material if the average activity per gram does not exceed 10^{-4} A_2. To demonstrate that the solidified sludge monoliths are expected to qualify as LSA-II material, the projected concentrations of solidified W-23 sludge from Table A.7 are compared to $10^{-4} \times A_2$ per gram concentration limits in Table 11. As illustrated in Table 11, the sum of the ratios of the isotopic concentrations to $10^{-4} \times A_2$ is less than unity. Therefore, the solidified W-23 sludge would qualify as LSA-II material. Solidified MVST sludge and solidified mixtures of MVST and W-23 sludge would also qualify as LSA-II material because they would have lower radionuclide concentrations than monoliths created from pure W-23 sludge.

Table 11. Comparison of W-23 Solidified Sludge Monolith Concentrations to LSA-II Limits

Isotope	W-23 Concentration (nCi/g)	A_2 (Ci)	$10^{-4} \times A_2$ (nCi/g)	$C/(10^{-4} \times A_2)$
^{227}Ac	1.59E+01	1.60E-01	1.60E+04	9.91E-04
^{241}Am	8.01E+01	2.70E-02	2.70E+03	2.97E-02
^{14}C	4.14E-01	8.10E+01	8.10E+06	5.12E-08
^{144}Ce	3.85E+01	5.40E+00	5.40E+05	7.12E-05
^{250}Cf	1.14E-01	5.40E-02	5.40E+03	2.10E-05
^{252}Cf	7.96E-01	8.10E-02	8.10E+03	9.83E-05
^{243}Cm	2.95E+01	2.70E-02	2.70E+03	1.09E-02
^{244}Cm	4.41E+02	5.40E-02	5.40E+03	8.17E-02
^{60}Co	1.88E+02	1.10E+01	1.10E+06	1.71E-04
^{134}Cs	1.48E+01	1.90E+01	1.90E+06	7.78E-06
^{137}Cs	3.54E+03	1.60E+01	1.60E+06	2.22E-03
^{152}Eu	7.77E+02	2.70E+01	2.70E+06	2.88E-04
^{154}Eu	4.83E+02	1.60E+01	1.60E+06	3.02E-04
^{155}Eu	1.15E+02	8.10E+01	8.10E+06	1.43E-05
^{95}Nb	8.22E+00	2.70E+01	2.70E+06	3.04E-06
^{59}Ni	7.57E-02	Unlimited	Unlimited	0.00E+00
^{63}Ni	9.74E+00	8.10E+02	8.10E+07	1.20E-07
^{237}Np	1.26E-02	5.40E-02	5.40E+03	2.34E-06
^{238}Pu	5.34E+01	2.70E-02	2.70E+03	1.98E-02
^{239}Pu	1.75E+01	2.70E-02	2.70E+03	6.47E-03
^{240}Pu	1.54E+01	2.70E-02	2.70E+03	5.70E-03
^{241}Pu	5.98E+02	1.60E+00	1.60E+05	3.74E-03
^{242}Pu	7.39E-02	2.70E-02	2.70E+03	2.74E-05
^{106}Ru	7.36E+01	5.40E+00	5.40E+05	1.36E-04
^{90}Sr	3.92E+03	8.10E+00	8.10E+05	4.84E-03
^{99}Tc	8.16E+00	2.40E+01	2.40E+06	3.40E-06
^{232}Th	7.75E-02	Unlimited	Unlimited	0.00E+00
^{233}U	1.50E+01	5.40E-01	5.40E+04	2.78E-04
^{234}U	5.91E-01	5.40E-01	5.40E+04	1.09E-05
^{235}U	7.21E-03	Unlimited	Unlimited	0.00E+00
^{236}U	9.01E-03	5.40E-01	5.40E+04	1.67E-07
^{238}U	4.38E-01	Unlimited	Unlimited	0.00E+00
^{95}Zr	5.10E+01	2.20E+01	2.20E+06	2.32E-05
Total				**1.67E-01**

5.4 REFERENCES

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3. RH-R-AD-002, Draft *RH Sludge Solidification Feasibility Study*, Revision 4, Foster Wheeler Environmental Corporation, 2007.

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5. Spence, R.D. and Barton, J.W., *Stabilization of Mercury in High pH Tank Sludges*, presented at the Waste Management 2003 Conference, February 2003.

6. Spence, R.D., Mattus, C.H., and Mattus, A.J., *Grout and Glass Performance in Support of Stabilization/Solidification of ORNL Tank Sludges*, ORNL/TM-13653, Oak Ridge National Laboratory, September 1998.

7. *Low-Level Radioactive Waste Shipments to the Nevada Test Site First Quarter Report, FY 2006*, http://www.nv.doe.gov/library/publications/emtwg/LLWShipments_NTS_1QFY2006.pdf.

8. *Low-Level Radioactive Waste Shipments to the Nevada Test Site (Inbound) Second Quarter Report, FY 2006*, http://www.nv.doe.gov/library/publications/emtwg/LLWShipments_NTS_2QFY2006.pdf

9. *Low-Level Radioactive and Mixed Waste Shipments to the Nevada Test Site, Third Quarter Report FY 2006*, http://www.nv.doe.gov/library/publications/emtwg/LLWShipments_NTS_3QFY2006.pdf.

10. *Low-Level Radioactive and Mixed Waste Shipments to the Nevada Test Site Fourth Quarter Report, FY 2006*, http://www.nv.doe.gov/library/publications/emtwg/LLWShipments_NTS_4QFY2006.pdf.

11. *Low-Level Radioactive and Mixed Waste Shipments to the Nevada Test Site First Quarter Report, FY 2007*, http://www.nv.doe.gov/library/publications/emtwg/FY2007_1STQTR.pdf.

12. *Low-Level Radioactive and Mixed Waste Shipments to the Nevada Test Site, Second Quarter Report FY 2007*, http://www.nv.doe.gov/library/publications/emtwg/FY2007_2ndQTR.pdf.

6. CONCLUSIONS

As previously stated, the following criteria were used to determine the operability of the proposed solidification sludge treatment option and to determine the potential for success:

1. Can the sludge be mobilized to flow from the storage tanks to the TWPC?
2. Will the equipment operate as required to enable sludge solidification and waste processing?
3. Will the end product meet the NTS WAC?

The overall conclusion of this review is that the sludge solidification process conceptually presents a technically sound viable method to convert the MVST, CIP, and BVEST sludges into forms suitable for off-site disposition. However, areas of potential concern were identified and recommendations to address these concerns are delineated in Sections 6.1 through 6.3.

The following sections summarize the conclusions developed in Chapters 3-5 regarding each of the aforementioned questions.

6.1 MOBILIZATION

The three mobilization methodologies considered (NUVE technology, chemical mobilization, and the use of a robotic arm) all appear to be potentially viable means to mobilize the sludge for transfer from the MVST to Tank W-35 and subsequently into the TWPC, although the limited information available on the robotic arm methodology leaves numerous unanswered questions.

Question: Can the sludge be mobilized to flow from the storage tanks to the TWPC?

Conclusion: Yes.

Recommendation: Based on the information available at the time of this report, the NUVE pulse fluidic jet mixing technology appears to have the greatest potential for success based on its track record in mobilizing sludge in similar tanks. This conclusion may need to be reconsidered if the manufacturer of the proposed robotic arm is able to produce convincing documentation demonstrating the viability of that option.

6.2 OPERABILITY

Conceptually, the sludge solidification process is expected to succeed, as grouting is a mature technology that has been repeatedly successful in similar applications. However, as discussed in Chapter 4, there are specific aspects of the proposed process delineated in the draft feasibility study that merit further examination. If the implementation and operational process concerns can be addressed such that a safe, cost effective solidification process can be implemented, then grout solidification appears to be an appropriate treatment choice for the tank sludge from the MVST, BVEST, and CIP tanks.

Question: Will the equipment operate as required to enable sludge solidification and waste processing?

Conclusion: Yes, if the following recommendations are implemented.

Recommendations:

1. Pro2Serve agrees that bench scale testing on actual MVST sludge is necessary for development of a grout recipe (or recipes) that will generate a solidified monolith that meets the NTS WAC.

   Additional parameters beyond those mentioned in the draft feasibility study that need to be understood for implementation and operability of this solidification process and should be evaluated prior to implementing the full scale process are: mix ratio (weight dry solids blend/volume waste), establishing whether there is a need for more than one grout recipe, ability to back blend any weep liquids from the curing of a batch, adequacy of gravity feed of LLW liners, and approximate time to empty the batch mixer/fill liners using gravity flow.

Prior to initiating the bench scale testing, performance criteria for the grout should be established as well as the conceptual treatment approach for handling various sludges from the different tanks. Furthermore, DOE may wish to consider testing beyond typical grout bench scale testing (Hobart mixers and grout in small cups) to evaluate grout viscosity, gravity flow of grout, impacts to the processing area from heat of hydration and determining minimum adequate mixing needs.

2. Currently a single silo feeding a single weigh hopper charging system is conceptualized in the draft feasibility study. Pro2Serve suggests that a dry component delivery system be considered. One that allows for multiple dry blend feed hoppers and metering of various quantities of the dry blend components. This added flexibility will be valuable and, depending on batch testing results, is potentially necessary.

   Furthermore, this will require an engineering evaluation as having the space in the TWPC to adequately feed the grout mix components is essential to the feasibility of the solidification process.

3. Given the concerns that the dryer could possibly not meet mixing and reliability requirements, it is recommended that a high shear batch mixer be considered as an alternative to the conversion of the dryer to a batch mixer

4. Conceptually the use of the process shields to decrease the cycle time appears reasonable and FWENC's recommendation to perform time/motion studies on this process step is also reasonable. However, Pro2Serve also recommends that FWENC include a study of the expected decrease in dose rate from this step, as a means of addressing the lesson learned.

5. From the draft feasibility study, a key strategy to address the grout discharge plugging is the formulation of a low viscosity and slow set time recipe for the grout. It is also stated that a high dry blend grout to waste ratio is proposed to give a high confidence level of achieving an acceptable monolith. Achieving both a low viscosity and a high grout to waste ratio without adding excessive flush water poses a challenge. These issues should be addressed by batch testing and will be pivotal in the choice of a dryer conversion versus purchase of a high shear mixer.

6. Though longer than expected cycle times for the SN dryer were documented in the SN campaign lessons learned (Ref. 6) there was no mention of LLW liner lidding and loading cycle times. Thus, enclosure of the 30 Ton Crane Bay for the purpose of minimizing LLW liner lidding and loading cycle time warrants a cost benefit analysis.

6.3 WAC ATTAINMENT

Based on the available information, it is expected that the solidified sludge monoliths, with the exception of any solidified sludge exclusively from the W-23 tank, will satisfy the NTS WAC requirements. The issue that poses the greatest concern regarding WAC attainment is the ability to adequately stabilize the mercury. A crucial issue regarding the ability to immobilize the mercury is to receive concurrence with the applicable regulators regarding the set of standards that must be met. Is it sufficient to demonstrate that the solidified sludge monoliths no longer exhibit the toxicity characteristic (i.e., TCLP is below the 40 CFR 261.24 limits), as FWENC/EnergX contends, or must it meet the more rigorous requirements of the LDRs (40 CFR 268.40)?

Question: Will the end product meet the NTS WAC?

Conclusion: High Probability.

Recommendations: Concurrence of the applicable regulatory authorities should also be quickly obtained to conclusively determine the appropriate set of treatment standards (40 CFR 261.24 or 40 CFR 268.40). If it is concluded that the more rigorous 40 CFR 268.40 standards apply, then the bench scale testing using real sludge samples should be accelerated as much as possible so that any difficulties in meeting the standard can be identified as early in the process as possible. NTS should be consulted at an early stage of the conceptual development to confirm that the 25% void fraction in the liners is adequate to satisfy the requirements of Section 3.2.9 of the NTS WAC.

6.4 COMPARISON TO ALTERNATIVE SLUDGE TREATMENT METHODOLOGIES

The Pro2Serve review focused on providing an independent review on the viability of the sludge solidification option, as this methodology was most recently identified and had received less extensive review and study. Because of the limited time frames involved, Pro2Serve's conclusions regarding the viability of the alternative methodologies rely heavily on the conclusions from existing documentation.

The sludge solidification approach appears to be a technically sound, likely viable method to prepare the MVST, CIP, and BVEST sludges for off-site disposition. Of the three alternatives under consideration, the sludge solidification option appears to have the greatest potential for success based upon the potential for continued operability throughout the project life cycle, the challenges involved in shipping TRU waste for disposal, and the lower projected worker radiation exposures. Unlike the drying and dewatering approaches, the sludge solidification methodology does not involve the creation of dry powders within the processing equipment that are likely to cake up and plug material flow at some point during the course of the project. Such problems were encountered to some degree during the 9 month supernate campaign, and would be even more problematic during an extended 5-10 year operating run. If a suitable recipe providing a sufficiently low viscosity grout can be developed during the bench-scale testing, then the grout mixture is expected to have greater fluidity and less of a tendency to plug the piping associated with the mixer, provided that the grout mixture is not allowed to set and cure while in the mixer. The capability of flushing the mixer between batches is likely to prevent the setting of the grout within the mixer. Furthermore, by producing an LLW product, rather than a TRU product, the sludge solidification approach bypasses many of the obstacles encountered in shipping waste to WIPP. The solidification process is also expected to result in lower doses to plant operators because of the lower ^{137}Cs concentrations in the waste product and the self-shielding provided by the grouting materials.

Based on the information reviewed, this review concludes that the sludge solidification appears to be a viable methodology. This conclusion would need to be revisited if bench scale testing indicates that mercury immobilization is less successful than currently anticipated, or the grout viscosity and set times are less desirable than expected.

APPENDIX A

RADIOLOGICAL CONTENT OF THE MVST AND TANK W-23 SLUDGES AND SOLIDIFIED SLUDGE MONOLITHS

A.1. RADIOLOGICAL CHARACTERIZATION OF MVST SLUDGES

The radiological content of sludge samples withdrawn from the MVST Tanks W-24 through W-31 in 1996, 2000, and 2001 are documented in ORNL/TM-2001/151 (Ref. 1). The isotopic activities in each tank varied appreciably between the three different years in which samples were collected. For the purposes of this assessment, it is conservatively assumed that the isotopic inventories in each tank are the maximum sample result recorded in Ref. 1 for that tank. These maximum sample results are summarized in Table A.1.

Table A.1. Maximum Sample Activities in MVST Tanks

Isotope	W-24 (nCi/g)	W-25 (nCi/g)	W-26 (nCi/g)	W-27 (nCi/g)	W-28 (nCi/g)	W-29 (nCi/g)	W-30 (nCi/g)	W-31 (nCi/g)
^{63}Ni	8.92E+01	9.19E+01	1.08E+02	4.59E+01	8.92E+01	N/A	N/A	1.19E+02
^{60}Co	8.11E+02	9.46E+02	1.57E+03	3.24E+02	1.14E+03	6.76E+02	4.32E+02	5.95E+02
^{90}Sr	3.78E+04	8.65E+04	3.51E+04	1.08E+05	4.86E+04	3.78E+04	5.14E+04	2.97E+05
^{99}Tc	2.14E+01	2.46E+01	3.24E+01	1.16E+01	9.73E+00	2.51E+01	1.57E+01	1.97E+01
^{129}I	N/A	N/A	N/A	N/A	1.11E-03	N/A	N/A	1.22E-03
^{134}Cs	3.51E+02	1.62E+02	3.24E+02	3.78E+01	3.24E+01	8.92E+01	5.14E+02	6.76E+01
^{137}Cs	1.70E+04	1.27E+04	2.41E+04	1.78E+04	1.30E+04	1.57E+04	5.14E+04	1.73E+04
^{152}Eu	1.86E+04	1.62E+04	1.73E+04	5.95E+03	2.16E+04	4.05E+03	2.00E+03	1.32E+03
^{154}Eu	6.76E+03	2.70E+03	7.84E+03	1.14E+03	7.30E+03	1.30E+03	6.76E+02	5.41E+02
^{155}Eu	1.78E+03	7.57E+02	1.70E+03	4.86E+02	1.89E+03	4.86E+02	1.03E+02	2.97E+02
^{241}Pu	3.78E+02	7.03E+02	4.05E+02	1.76E+02	3.24E+02	N/A	N/A	6.49E+02
^{232}Th	8.11E-01	1.11E+00	4.86E-01	1.92E+00	5.41E-01	5.41E-01	6.22E-01	2.27E+00
^{233}U	2.41E+02	1.95E+02	2.84E+02	1.68E+02	1.41E+02	6.24E+01	5.24E+01	1.41E+02
^{234}U	1.92E+01	2.70E+00	1.73E+01	1.03E+01	9.73E+00	8.78E-01	8.14E+00	2.32E+01
^{235}U	4.05E-01	2.14E-01	3.24E-01	4.65E-01	5.49E-01	2.62E-01	2.95E-01	4.59E-01
^{238}U	1.57E+01	1.03E+01	1.24E+01	1.15E+01	1.40E+01	8.05E+00	8.78E+00	1.30E+01
^{237}Np	2.70E-01	2.70E-01	5.41E-02	3.24E-01	4.32E-01	N/A	N/A	5.68E-01
^{241}Am	4.05E+02	2.78E+02	1.35E+02	3.14E+02	2.05E+02	2.03E+02	1.49E+02	3.78E+02
^{244}Cm	4.19E+03	2.45E+03	1.08E+03	2.08E+03	1.16E+03	1.14E+03	9.19E+02	2.97E+03
^{238}Pu	4.59E+02	3.78E+02	2.24E+02	2.70E+02	2.00E+02	1.78E+02	1.68E+02	3.51E+02
$^{239/240}$Pu	2.97E+02	2.57E+02	1.38E+02	1.57E+02	1.65E+02	1.22E+02	1.65E+02	1.68E+02

The mass of sludge in each tank is estimated in Ref. 2, and summarized in Table A.2.

Table A.2. Sludge Masses in the MVSTs

Tank	Sludge Mass (kg)
W-24	1.42E+05
W-25	1.60E+05
W-26	1.93E+05
W-27	2.31E+05
W-28	2.12E+05
W-29	2.07E+05
W-30	1.98E+05
W-31	2.12E+05
Total MVST	1.55E+06

The overall average of the sludge activities in the MVSTs are obtained by taking a weighted average of the activities in each tank listed in Table A.1 using the sludge masses from Table A.2 as the weighting factors. The results are summarized in Table A.3.

Table A.3. Weighted Average Activities in the MVSTs

Isotope	Weighted Average (nCi/g)
^{63}Ni	8.95E+01
^{60}Co	7.95E+02
^{90}Sr	9.15E+04
^{99}Tc	1.96E+01
^{129}I	1.16E-03
^{134}Cs	1.86E+02
^{137}Cs	2.13E+04
^{152}Eu	1.03E+04
^{154}Eu	3.36E+03
^{155}Eu	9.00E+02
^{241}Pu	4.27E+02
^{232}Th	1.07E+00
^{233}U	1.55E+02
^{234}U	1.14E+01
^{235}U	3.78E-01
^{238}U	1.16E+01
^{237}Np	3.30E-01
^{241}Am	2.55E+02
^{244}Cm	1.91E+03
^{238}Pu	2.69E+02
$^{239/240}$Pu	1.76E+02

A.2. RADIOLOGICAL CHARACTERIZATION OF TANK W-23 SLUDGE

The sludge in the BVEST Tank W-23 is more recently generated than the sludges in the MVSTs. The activities of many key radionuclides in the Tank W-23 sludge are substantially higher than the activities encountered in the MVST sludge. The best available estimates of the radionuclide content in the W-23 sludge were prepared by Brian Oakley to support the safety basis for the ORNL liquid low-level waste evaporator facility. The estimated isotopic concentrations in the W-23 sludge are summarized in Table A.4. The concentrations were originally reported in Bq/ml, which is converted to nCi/g assuming a sludge specific gravity of 1.5.

Table A.4. Estimated Isotopic Concentrations in Tank W-23 Sludge

Isotope	Concentration (Bq/ml)	Concentration (nCi/g)
^{227}Ac	8.80E+03	1.59E+02
^{241}Am	4.45E+04	8.01E+02
^{14}C	2.30E+02	4.14E+00
^{144}Ce	2.13E+04	3.85E+02
^{250}Cf	6.30E+01	1.14E+00
^{252}Cf	4.42E+02	7.96E+00
^{243}Cm	1.63E+04	2.95E+02
^{244}Cm	2.45E+05	4.41E+03
^{60}Co	1.04E+05	1.88E+03
^{134}Cs	8.20E+03	1.48E+02
^{137}Cs	1.97E+06	3.54E+04
^{152}Eu	4.31E+05	7.77E+03
^{154}Eu	2.68E+05	4.83E+03
^{155}Eu	6.41E+04	1.15E+03
^{95}Nb	4.56E+03	8.22E+01
^{59}Ni	4.20E+01	7.57E-01
^{63}Ni	5.41E+03	9.74E+01
^{237}Np	7.00E+00	1.26E-01
^{238}Pu	2.97E+04	5.34E+02
^{239}Pu	9.70E+03	1.75E+02
^{240}Pu	8.54E+03	1.54E+02
^{241}Pu	3.32E+05	5.98E+03
^{242}Pu	4.10E+01	7.39E-01
^{106}Ru	4.09E+04	7.36E+02
^{90}Sr	2.18E+06	3.92E+04
^{99}Tc	4.53E+03	8.16E+01
^{232}Th	4.30E+01	7.75E-01
^{233}U	8.34E+03	1.50E+02
^{234}U	3.28E+02	5.91E+00
^{235}U	4.00E+00	7.21E-02
^{236}U	5.00E+00	9.01E-02
^{238}U	2.43E+02	4.38E+00
^{95}Zr	2.83E+04	5.10E+02

A.3. COMBINED CONTENT OF MVST AND TANK W-23 SLUDGES

If it is determined that the MVST and W-23 sludges will be considered a single waste stream, then the W-23 sludges will be combined with the MVST sludges prior to treatment. Consequently, the overall combined average activities of the MVST and W-23 sludges are of interest. As indicated in Table A.2, the total mass of the MVST sludges is approximately 1.55E+06 kg. Per Ref. 2, the mass of the W-23 sludges is estimated to be approximately 9.53E+04 kg. The overall average activities in the W-23 and MVST sludges are obtained by taking the weighted averages of the MVST concentrations from Table A.3 and the W-23 concentrations in Table A.4, using the sludge masses as the weighting factors. The results are summarized in Table A.5.

Table A.5. Combined Isotopic Activities of MVST and W-23 Sludges

Isotope	MVST Sludge (nCi/g)	W-23 Sludge (nCi/g)	Weighted Average of MVST and W-23 Sludges (nCi/g)
^{227}Ac	0.00E+00	1.59E+02	9.19E+00
^{241}Am	2.55E+02	8.01E+02	2.86E+02
^{14}C	0.00E+00	4.14E+00	2.40E-01
^{144}Ce	0.00E+00	3.85E+02	2.23E+01
^{250}Cf	0.00E+00	1.14E+00	6.58E-02
^{252}Cf	0.00E+00	7.96E+00	4.61E-01
^{243}Cm	0.00E+00	2.95E+02	1.71E+01
^{244}Cm	1.91E+03	4.41E+03	2.05E+03
^{60}Co	7.95E+02	1.88E+03	8.57E+02
^{134}Cs	1.86E+02	1.48E+02	1.83E+02
^{137}Cs	2.13E+04	3.54E+04	2.21E+04
^{152}Eu	1.03E+04	7.77E+03	1.02E+04
^{154}Eu	3.36E+03	4.83E+03	3.45E+03
^{155}Eu	9.00E+02	1.15E+03	9.15E+02
^{129}I	1.16E-03	0.00E+00	1.09E-03
^{95}Nb	0.00E+00	8.22E+01	4.76E+00
^{59}Ni	0.00E+00	7.57E-01	4.38E-02
^{63}Ni	8.95E+01	9.74E+01	9.00E+01
^{237}Np	3.30E-01	1.26E-01	3.18E-01
^{238}Pu	2.69E+02	5.34E+02	2.85E+02
$^{239/240}$Pu	1.76E+02	3.29E+02	1.85E+02
^{241}Pu	4.27E+02	5.98E+03	7.49E+02
^{242}Pu	0.00E+00	7.39E-01	4.28E-02
^{106}Ru	0.00E+00	7.36E+02	4.27E+01
^{90}Sr	9.15E+04	3.92E+04	8.85E+04
^{99}Tc	1.96E+01	8.16E+01	2.32E+01
^{232}Th	1.07E+00	7.75E-01	1.05E+00
^{233}U	1.55E+02	1.50E+02	1.55E+02
^{234}U	1.14E+01	5.91E+00	1.10E+01
^{235}U	3.78E-01	7.21E-02	3.60E-01
^{236}U	0.00E+00	9.01E-02	5.22E-03
^{238}U	1.16E+01	4.38E+00	1.12E+01
^{95}Zr	0.00E+00	5.10E+02	2.95E+01

A.4. RADIOLOGICAL CHARACTERIZATION OF SOLIDIFIED MONOLITHS

The addition of the mobilization water and the dry grouting mixture to the tank sludges will dilute the radionuclide concentrations in the waste, causing the concentrations in the solidified sludge monoliths to be approximately an order of magnitude below the concentrations in the original raw sludge. The volume of mobilization water added will be approximately 5 times the volume of raw sludge. Assuming a sludge specific gravity of 1.33 per Ref. 2, the mass of mobilization water added to each gram of sludge would be approximately:

$$(1\text{ g sludge}) \times (\text{centimeter}^3\text{ sludge}/1.33\text{ g sludge}) \times (5\text{ centimeter}^3\ H_2O/\text{centimeter}^3\text{ sludge})\ (1\text{ g }H_2O/\text{cm}^3\ H_2O) = 3.8\text{ g }H_2O$$

The mass ratio of grouting mixture to mobilized sludge will be approximately 1.2. Consequently, the mass of dry grouting mixture for each gram of raw sludge will be:

(1 g sludge + 3.8 g mobilization water) × (1.2 g grout/g mobilized sludge) = 5.8 g grout mixture

Consequently, the total mass of the solidified sludge monolith produced from a gram of raw sludge is 1 gram + 3.8 grams + 5.8 grams, which is approximately an order of magnitude greater than the mass of the original sludge, causing the radionuclide concentrations to be approximately an order of magnitude below those in the original sludge. The projected isotopic concentrations in monoliths created from MVST sludges, W-23 sludge, and mixed MVST and W-23 sludges are listed in Tables A.6, A.7, and A.8, respectively.

Table A.6. Projected Concentrations in Solidified Monoliths of MVST Sludge

Isotope	Concentration (nCi/g)
^{63}Ni	8.95E+00
^{60}Co	7.95E+01
^{90}Sr	9.15E+03
^{99}Tc	1.96E+00
^{129}I	1.16E-04
^{134}Cs	1.86E+01
^{137}Cs	2.13E+03
^{152}Eu	1.03E+03
^{154}Eu	3.36E+02
^{155}Eu	9.00E+01
^{241}Pu	4.27E+01
^{232}Th	1.07E-01
^{233}U	1.55E+01
^{234}U	1.14E+00
^{235}U	3.78E-02
^{238}U	1.16E+00
^{237}Np	3.30E-02
^{241}Am	2.55E+01
^{244}Cm	1.91E+02
^{238}Pu	2.69E+01
$^{239/240}$Pu	1.76E+01

Table A.7. Projected Isotopic Concentrations in Solidified Monoliths of W-23 Sludge

Isotope	Concentration (nCi/g)
^{227}Ac	1.59E+01
^{241}Am	8.01E+01
^{14}C	4.14E-01
^{144}Ce	3.85E+01
^{250}Cf	1.14E-01
^{252}Cf	7.96E-01
^{243}Cm	2.95E+01
^{244}Cm	4.41E+02
^{60}Co	1.88E+02
^{134}Cs	1.48E+01
^{137}Cs	3.54E+03
^{152}Eu	7.77E+02
^{154}Eu	4.83E+02
^{155}Eu	1.15E+02
^{95}Nb	8.22E+00
^{59}Ni	7.57E-02
^{63}Ni	9.74E+00
^{237}Np	1.26E-02
^{238}Pu	5.34E+01
^{239}Pu	1.75E+01
^{240}Pu	1.54E+01
^{241}Pu	5.98E+02
^{242}Pu	7.39E-02
^{106}Ru	7.36E+01
^{90}Sr	3.92E+03
^{99}Tc	8.16E+00
^{232}Th	7.75E-02
^{233}U	1.50E+01
^{234}U	5.91E-01
^{235}U	7.21E-03
^{236}U	9.01E-03
^{238}U	4.38E-01
^{95}Zr	5.10E+01

Table A.8. Projected Concentrations in Solidified Sludge Monoliths from Mixed MVST and W-23 Sludges

Isotope	Concentration (nCi/g)
^{227}Ac	9.19E-01
^{241}Am	2.86E+01
^{14}C	2.40E-02
^{144}Ce	2.23E+00
^{250}Cf	6.58E-03
^{252}Cf	4.61E-02
^{243}Cm	1.71E+00
^{244}Cm	2.05E+02
^{60}Co	8.57E+01
^{134}Cs	1.83E+01
^{137}Cs	2.21E+03
^{152}Eu	1.02E+03
^{154}Eu	3.45E+02
^{155}Eu	9.15E+01
^{129}I	1.09E-04
^{95}Nb	4.76E-01
^{59}Ni	4.38E-03
^{63}Ni	9.00E+00
^{237}Np	3.18E-02
^{238}Pu	2.85E+01
$^{239/240}$Pu	1.85E+01
^{241}Pu	7.49E+01
^{242}Pu	4.28E-03
^{106}Ru	4.27E+00
^{90}Sr	8.85E+03
^{99}Tc	2.32E+00
^{232}Th	1.05E-01
^{233}U	1.55E+01
^{234}U	1.10E+00
^{235}U	3.60E-02
^{236}U	5.22E-04
^{238}U	1.12E+00
^{95}Zr	2.95E+00

A.5 REFERENCES

1. Keller, J. M. and Giaquinto, J. M., *Characterization of the Radioactive Sludge from the ORNL MVST Waste Tanks*, ORNL/TM-2001/151, Oak Ridge National Laboratory, Oak Ridge, Tennessee, September 2001.
2. RH-R-AD-002, *RH Sludge Solidification Feasibility Study*, Revision 4, Foster Wheeler Environmental Corporation, 2007.