Sta 4 (2)

**FEB 28 2000** **ENGINEERING DATA TRANSMITTAL**

Page 1 of 1

1. EDT 628093

| | | |
|---|---|---|
| 2. To: (Receiving Organization) Retrieval Project Definition | 3. From: (Originating Organization) TO & E Plant Engineering | 4. Related EDT No.: N/A |
| 5. Proj./Prog./Dept./Div.: Retrieval | 6. Design Authority/Design Agent/Cog. Engr.: A. R. Tedeschi | 7. Purchase Order No.: N/A |
| 8. Originator Remarks: Issued for final approval and release. Annotated with supernatant chemistry properties, and supernatant level data per QA comments. Minor editing and added expanded tank temperature data per Cog. Mgr. [initials] 2/23/00 | | 9. Equip./Component No.: N/A |
| | | 10. System/Bldg./Facility: Tank Farms |
| | | 12. Major Assm. Dwg. No.: N/A |
| 11. Receiver Remarks: | 11A. Design Baseline Document? ○ Yes ◉ No | 13. Permit/Permit Application No.: N/A |
| | | 14. Required Response Date: 02-07-00 |

15. DATA TRANSMITTED

| (A) Item No. | (B) Document/Drawing No. | (C) Sheet No. | (D) Rev. No. | (E) Title or Description of Data Transmitted | (F) Approval Designator | (G) Reason for Transmittal | (H) Originator Disposition | (I) Receiver Disposition |
|---|---|---|---|---|---|---|---|---|
| 1 | RPP-5664 | -- | 0 | Derived Requirements For Double-Shell Tank High-Level Waste Auxiliary Solids Mobilization | Q | 1 | 1 | 1 |

16. KEY

| Approval Designator (F) | Reason for Transmittal (G) | Disposition (H) & (I) |
|---|---|---|
| E, S, Q, D OR N/A (See WHC-CM-3-5, Sec. 12.7) | 1. Approval 2. Release 3. Information 4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required) | 1. Approved 2. Approved w/comment 3. Disapproved w/comment 4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged |

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)

| (G) Reason | (H) Disp. | (J) Name | (K) Signature | (L) Date | (M) MSIN | (G) Reason | (H) Disp. | (J) Name | (K) Signature | (L) Date | (M) MSIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Design Authority N/A | | | | 1 | 1 | SH Rifaey (R2-58) | [signature] | 2/10/00 | R2-58 |
| | | Design Agent N/A | | | | 1 | 1 | RR Thompson (R2-12) | [signature] | 2/10/00 | R2-12 |
| 1 | 1 | Cog. Eng. EA Pacquet (R3-47) | [signature] | 2/14/00 | R3-47 | 2 | – | RL Schlosser (R1-56) | | | |
| 1 | 1 | Cog. Mgr. PJ Certa (R3-73) | PJ Certa | 2/24/00 | | 2 | – | TC Oten (R1-56) | | | |
| 1 | 2 | QA JF Bores (R2-89) | J.F. Bores | 02/14/00 | | 2 | – | HR Hopkins (R2-58) | | | |
| | | Safety N/A | | | | 2 | – | AH Friberg (R1-56) | | | |
| | | Env. N/A | | | | 2 | – | AR Tedeschi (R1-56) | | | |

| 18. | 19. | 20. | 21. DOE APPROVAL (if required) |
|---|---|---|---|
| [signature] AR Tedeschi 2-8-00 | [signature] GC Deweese 2-25-00 | Paul J Certa PJ Certa 2/24/00 | Ctrl No. ______ |
| Signature of EDT Originator / Date | Authorized Representative for Receiving Organization / Date | Design Authority/ Cognizant Manager / Date | ○ Approved ○ Approved w/comments ○ Disapproved w/comments |

BD-7400-172-2 (10/97)

BD-7400-172-1

# Derived Requirements For Double-Shell Tank High-Level Waste Auxiliary Solids Mobilization

**A. R. Tedeschi**
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-99RL14047

EDT/ECN: 628093 UC: 2000
Cost Center: 74E00 Charge Code: 111850
B&R Code: EW3130000 Total Pages: 38

Key Words: Mixer, Retrieval, Sludge, Mobilization

Abstract: The potential need for auxiliary double-shell tank waste mixing and solids mobilization requires an evaluation of optional technologies. This document formalizes those operating and design requirements needed for further engineering evaluations.



2/28/00
Release Approval Date

DATE: HANFORD RELEASE
STA: 4 ID: 2
FEB 28 2000
Release Stamp

**Approved For Public Release**

*River Protection Project*

CH2MHILL
Hanford Group, Inc.

# DERIVED REQUIREMENTS FOR DOUBLE-SHELL TANK HIGH-LEVEL WASTE AUXILIARY SOLIDS MOBILIZATION

**RPP-5664**
**Revision 0**

# FOREWORD

This document was created by Plant Engineering and Retrieval Engineering, River Protection Project, Hanford, to support the retrieval of High-Level tank wastes within the tank farm complex. This document defines process, design, installation, and operational requirements for the assessment of auxiliary equipment to mobilize tank bottom solids.

The material within is in large part based upon an earlier evaluation by Craig Shaw of COGEMA Engineering in his selection guidance letter report (Shaw 1999), and is greatly acknowledged.

Appendices B and C were copied from Characterization Project files/diagrams, and are in color. For colorized versions of these pages or questions regarding the enclosed document please contact either Eric Pacquet, telephone 509 373-2684, email eric_a_pacquet@rl.gov, or Rick Tedeschi, telephone 509-373-6018, email: allan_r_rick_tedeschi@rl.gov.

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# 1.0 Purpose

This document defines initial functions and requirements for the development of an auxiliary, waste solids mobilization equipment system. *The Tank Waste Remediation System Operation and Utilization Plan* (Kirkbride et al 1999a) recommended the evaluation of supplemental retrieval systems with the planned mixer pumps in tanks 241-AW-103, and 241-SY-102. This supplemental retrieval system would be used to increase the retrieval efficiency of the baseline mixer pumps, specifically in these tanks where the bottom sludge layer may lower the baseline mixer pump effective cleaning radius (ECR). Further discussion on ECR is noted in the "Background."

This document is the next phase in investigation and development of auxiliary solids mobilization equipment, as outlined in the Work Plan *Evaluation of Flygt Mixers for Double-Shell Tank High Level Waste Auxiliary Solids Mobilization* (Pacquet 1999). The requirements in this document will be used to initiate further evaluation and vendor consultations then produce a final engineering case study. This document is not planned to encompass the complete functions and requirements for final equipment modification, design, construction, or procurement. It will identify sufficient criteria for a preliminary engineering examination of auxiliary mobilization technologies.

# 2.0 Background

The Hanford reservation River Protection Project (RPP), in southeastern Washington state, is retrieving radioactive waste for permanent disposal. This 50-year waste legacy is stored in underground storage tanks, and is the form of aqueous solutions, crystallized salt cakes, and viscous sludges. Underground storage tanks built in the 1940's through the 50's ranged normally from 500,000 gallons to 1 M gallons capacity and were comprised of a single steel wall. Tanks built after this time period were all comprised of a double side steel wall, termed "double-shell" tanks, and had a capacity of 1 M gallons. These double-shell tanks are approximately 75 feet in diameter, and were built with multiple openings in the top dome extending through steel piping (risers) above the soil cover. See Appendices C and D for typical tank structures.

Waste in these tanks was placed over periods of years from fuel processing operations resulting in multiple layers. In addition, processing liquid streams through an Evaporator facility minimized waste storage space needs, and produced more concentrated slurries. Chemical interaction and normal tank evaporative processes produced heavier sludge-like material. Sludge waste is generally found in bottom layers. Waste is normally categorized as supernatant liquids (supernate), saltcake, and sludge. Respective definitions (Hanlon 1999 page C-8) are as follows:

*Supernate* - "The estimated or measured liquid floating on the surface of the waste or under a floating solid crust"

*Saltcake* - "The waste resulting from crystallization and precipitation after concentration of liquid waste, usually in an evaporator; if saltcake is layered over sludge, it is possible only to measure total solids volume"

*Sludge* - "Solids formed during sodium hydroxide additions to waste; sludge usually was in the form of suspended solids when the waste was originally received from the waste generator"

The primary source of waste characterization data is currently obtained from core sampling. Core sampling trucks at ground level, insert either a rotary or open-core push mode drill string into the waste via a tank riser. The sample is then extruded in a laboratory and is then subjected to further chemical analysis and categorized as a waste type. The waste type categorization does not accurately depict the total gradation and layering of waste in the tank, but it does allow for generalized characterization of tank contents. This categorization terminology is different from the three types mentioned above to allow a more complete picture of the physical description of the retrieved material. It includes such descriptive terms as "wet sludge," "dry sludge," and "salt slurry." This terminology is noted on the core profile sheets for two key tanks in Appendix B, which classifies material within each layered core segment. A pictorial representation of all of the waste type categories is shown in APPENDIX C.

Waste within the storage tanks needs to be retrieved for delivery to vitrification facilities for converting it into a more stable solid glass form. This glass form will then be stored in an approved permanent storage facility. Programmatic and technical bases for the retrieval effort are summarized in the Operations and Utilization Plan (Kirkbride 1999a) and Waste Feed Delivery Technical Basis (Papp 1998), and its ensuing Addendums, e.g., *Waste Feed Delivery Technical Basis, Volume II, Waste Feed Delivery Flowsheet for Tank 241-AZ-101* (Orme 1999). Hierarchy and subsystem functions of tank farm equipment systems for the first stage of retrieval are detailed in the Double-Shell Tank Functional Analysis document (Smith 2000). Section 2.3 of the Functional Analysis document details that the suspension of settled tank solids/sludge is necessary to ensure that the desired high-level waste solids are transported to the vitrification vendor.

Baseline waste retrieval strategy involves mobilizing tank contents with long shaft mixer pumps, then pumping out the waste with sluicing or submerged centrifugal pumps. Mixer pumps have a bottom or elevated inlet and then force a high-pressure stream of the mixed waste out dual jet discharge tubes in the waste, 180° apart. The entire mixer pump assembly can be rotated to allow a full sweeping of the tank circumference. This discharge sweeping performs a dual function. It both mobilizes solid material into solution for pumping retrieval and maintains a more homogeneous mixture of the tank contents.

The actual sweeping capability of the mixer pump, and its efficiency in mobilizing material in the discharge path is termed "Effective Cleaning Radius" (ECR), and represents the effective radial distance for solids mobilization. In mixer pump performance evaluations ECR is defined as "the distance between the mixer pump nozzle exit and the base of the distant sludge bank…Thus a mixer pump mobilizes the sludge within a circular area with a radius equal to the ECR plus the distance between the nozzle tip and the pump column centerline." (Powell 1997 page 2.3). An empirical equation for ECR, based upon simulant tests, was developed as a function of waste parameters and mixer performance (Crawford 1999). Multiple mixer pumps are planned in a single tank to maximize the discharge coverage. Their locations are restricted to the available larger tank risers.

The primary waste characteristic involved in modeling the ECR is sludge shear strength. This value is defined as the shearing stress required to induce mechanical failure in the sludge. This value of the waste sludge is usually measured using a mechanical shear vane, which is inserted in the waste, and slowly twisted until failure is observed. The measured torque on the vane is directly proportional to the shear strength (Powell 1997). The accuracy of shear strength measurements is not known. A Pacific Northwest National Laboratories report summarized that "sample disruption, variations in waste composition within each tank, and changes in sample properties with temperature all can significantly affect shear strength" (Powell 1997).

This tank location restriction and mixer pump performance, coupled with viscous and/or immobile waste characteristics, may not allow adequate mobilization of tank sludges. Currently some predicted tank retrieval efficiencies from the empirical ECR equation vary from 12 feet (3.7 m) to 42 feet (12.8 m) (Crawford 1999). Studies (Grams 1995) indicate that material may not be adequately mobilized into the liquid layers leaving pockets of unretrievable viscous sludge. For example in the reference Grams, 1995, an ECR of only 12-13 feet was calculated for tank AW-103 (other studies list values to approximately 30 feet – Akins 1999) with only 20% solids mobilized. This ECR performance may thus leave a large potential of open area needing solids mobilization in this 75-foot (22.9 m) diameter double-shell tank. A typical pictorial representation is noted in Figure 1 of dual mixer pump coverage in a storage tank, and the potential material not mobilized.

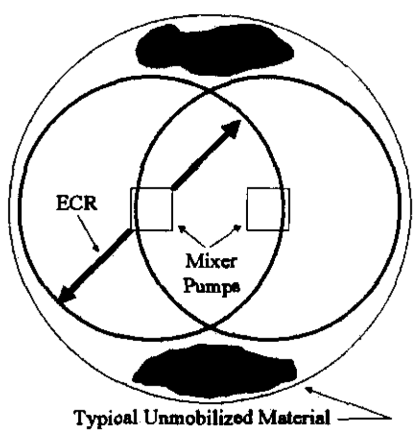


**Figure 1 Tank Plan of Mixer Coverage**

Auxiliary mixing systems may be needed to either mobilize this dead-zone material into the liquid layers or translocate the waste to the ECR area swept by the mixer pumps. This material build-up or layer will be confirmed during actual mixing with sampling. If dead zones remain after initial retrieval activities, in-tank cameras may also be used to view them. In addition, because mixer pumps are costly and require significant lead-time for construction it is prudent to evaluate other mobilization technologies for supplementing failed mixer pump equipment.

Another challenge in mobilizing material within the tanks is the number of instrument systems (e.g., thermocouple trees), pumping equipment, and piping risers extending through waste layers, and an unknown amount of minor debris deposited in the tank from sampling and equipment installation activities.

Summarizing, mixer pumps may potentially require auxiliary solids mobilization because of

- High sludge shear strengths reducing mixer pump effective cleaning radius
- Inadequate coverage of the full tank bottom with optimal mixer pump operation, i.e., to cover "dead spots"
- Mixer pump failure or pluggage
- Installation of mixer pump is unfeasible or extremely costly, and
- Inability to lower mixer pump through all sludge layers.

## 3.0 Introduction

The evaluation of auxiliary solids mobilization technology requires the establishment of a set of minimum performance criteria and specifications. This document completes that effort which was first begun with the development of selection guidance for devices to enhance sludge removal (Shaw 1999). This evaluation analyzes potential waste and tank parameters to establish a conservative but optimal set of criteria that will allow application of new technology to the maximum number of waste/tank scenarios.

The performance criteria and specifications are derived from an examination of waste, tank vessel, and operational data. First, the most recent published information for the applicable double-shell tanks sequencing, for the first phase of retrieval, was examined. This included the baseline document, *Tank Waste Remediation System Operation and Utilization Plan* (Kirkbride et al 1999a) and published case documentation for Retrieval Case 3S5 (Kirkbride 1999b). This produced a listing of eight double-shell tanks and two single-shell tanks:

AN-104, AW-103, AW-104, AY-101, AY-102, AZ-101, AZ-102, C-104, C-107, & SY-102.

The Operation and Utilization Plan identifies two waste storage tanks potentially requiring auxiliary solids mobilization, as defined from modeling ECR results with two mixer pumps (Kirkbride et al 1999a). The two tanks are AW-103 and SY-102. These two tanks are the primary source of requirements to ensure additional mobilization technology would be applicable to their conditions. Requirements applicable to these two tanks are identified as the minimum set to address the greatest potential need. While criteria in this document focuses on these two tanks, the other eight double-shell tanks and two single-shell tanks were examined for applicable requirements, which helped establish requirement ranges. A compilation of tank and related data were tabulated and noted in Appendix A. Evaluation of these parameters and other criteria were completed to identify conservative ranges of requirements documented in Table 5.1 "Functions and Requirements Summary." Specific performance criteria are discussed in section 4.0.

This document may be revised after completion of the final case engineering study and vendor investigation. Additional criteria consistent with examples identified in HNF-IP-0842 Volume IV, Section 3.2 *Functions and Requirements Analysis Allocation and Development of Level 1 and 2 Specifications*, and Volume IV, Section 4.20 *Engineering Specification Requirements* may be added, based upon further architect-engineer and vendor investigation.

Several related investigations are currently in progress for radioactive waste mobilization. Pacific Northwest National Laboratories, in conjunction with Savannah River Site and Oak Ridge National Laboratory are evaluating various size Flygt mixers in vendor, pilot scale, and full scale testing for solids mobilization and suspension. Results are mixed but provide a wide range of test data for further vendor investigation (Powell et al 1999). Pacific Northwest National Laboratories are in progress of issuing an assessment of alternate sludge removal technologies. Draft documentation reviewed (*An Assessment of Technologies to Provide Extended Sludge Retrieval from Underground Storage Tanks at the Hanford Site*, PNNL-13048-DRAFT, J.A. Bamberger, September 1999) indicate great potential for the application of jet technologies. This draft assessment provides data useful for further investigation of auxiliary systems.

## 4.0 Performance Criteria Summary

This section identifies the criteria needed for minimal accepted performance of an auxiliary mobilization system. Along with the minimal performance criteria is direction for maximizing this applied performance. Performance may be summarized as follows. An auxiliary solids mobilization equipment system shall enhance retrieval of high-level tank waste by maximizing "Tank Applicability" and "Effective Cleaning Radius," while minimizing effects on existing property and personnel. Equipment systems shall be evaluated, tested, designed, constructed, and deployed after meeting appropriate quality assurance criteria.

Specific constraints are noted which were used in developing the criteria. These should be used when maximizing performance. For example in section 4.3 "Effective Cleaning Radius," current plans for mixer pump and sluicing pump placement in tank risers limits the availability of riser access and must be considered. In addition, this installed equipment within the tank may impact the ECR.

## 4.1 Auxiliary Mixing

The system shall assist waste mobilization in mixer pump dead zones by either mobilizing solids into the liquid layers, or moving solids material into the mixer jet stream pattern. The goal of solids mobilization is to ensure the maximum retrieval of waste products from the tank by either a sluicing or centrifugal pump.

Minimum Equipment shall mobilize areas outside of ECRs of a dual installed mixer system (See Figure 1).
Maximized Equipment shall be capable of mobilizing solids at various tank locations, including the center of the tank or even under installed mixer pumps.

## 4.2 Tank Applicability

The system shall be used for mobilization of solids in specified double-shell storage tanks. The minimum set of applied storage tanks was derived from a summary of computer simulation modeling results (Kirkbride et al 1999a) which listed two specific tanks as potentially needing auxiliary solids mobilization. Since the certainty of computer simulation has not been verified with full scale mixing at this time, there is some degree of risk in only planning for auxiliary mobilization in two vessels. Maximized performance is defined for the entire set of tanks listed in the current retrieval sequence.

Minimum Equipment shall be installed and operated for auxiliary solids mobilization in double-shell tanks 241-AW-103 and 241-SY-102. (See Appendix B for Latest core sampling profiles)
Maximized Application shall be extended to maximize usage in double-shell tanks 241-AN-104, 241-AW-104, 241-AY-101, 241-AY-102, 241-AZ-101, 241-AZ-102, and single-shell tanks 241-C-104 and 241-C-107. Consideration shall be given to extension of usage to remaining double-shell tanks.

Constraints involved with tank applicability are driven by tank physical conditions and include riser size and availability.

## 4.3 Solids Mobilization

As noted above in "Background" the ECR is used to define the effectiveness of solids mobilization in mixer pumps. It is essentially a distance value where solids are effectively mobilized into the liquid layer. A performance criterion of solids mobilization, that qualifies an applied distance for pump thrust, is defined because it is consistent with the ECR concept for mixer pumps. While this mobilization performance criteria may be empirically calculated similarly as an ECR value (Grams 1995, and Akins 1999) it is expected to be determined and/or validated through scale testing.

Minimum Equipment shall mobilize solids in sludge with shear strength 3.38 kPa (71 $lb/ft^2$) at a distance of 3.0 m (9.8 ft). Equipment shall also be able to operate at varied internal tank heights and controlled to variable discharge directions.
Maximized Equipment shall mobilize solids in a sludge with shear strength of 3.38 kPa (71 $lb/ft^2$) at a distance of 6.0 m (19.6 ft). Consideration shall be given to mobilization of sludges with shear strengths of 4.8 kPa (100 $lb/ft^2$). Consideration shall be given to operation of equipment with varied tank heights and discharge directions without need for riser disconnection/removal or breaking of tank confinement.

Consideration shall also be given to maximize the following additional capabilities: waste dissolution enhancement, viscous liquid mixing, slurry mixing, and dislodgment of solid heels. While some of this activity will occur naturally dependent upon the technology, it is desirable to maximize these parameters to aid in pumping retrieval.

Tank waste physical properties and internal tank systems drive constraints involved with solids mobilization. These include tank waste levels and types, final mixer pump and sluicing pump placements, and location of other tank systems which extend vertically through the tank, e.g., air-lift circulators, level probes, and thermocouple temperature monitoring trees.

## 4.3 Property and Personnel Protection

Maintaining tank and component integrity and protection of workers and site personnel is paramount. Safety considerations are not phrased in "minimum" and "maximum" performance criteria because noted criteria are applicable across all scenarios.

Criteria Equipment shall not erode tank internal surfaces. Equipment shall not displace/damage other installed and operational tank systems. Equipment shall meet all safety-derived requirements (See Table 5.1).

Constraints are driven by environmental and safety requirements.

## 4.4 Quality Assurance

Activities shall be accomplished per quality assurance criteria and strategy documented in the River Protection Program *Quality Assurance Plan* (LMHC 1999b) as applicable. This plan identifies protocols and graded approach strategy applications for all phases of development and operational effort. The technical representative for continuing phases of this development effort may direct the implementation of specific quality assurance plans. At that time additional quality assurance criteria will be implemented.

# 5.0 Derived Requirements

Table 5.1 summarizes all derived requirements. They are grouped in five categories consistent with original work plan direction. The primary units identified are consistent with the units in the original reference

**Table 5.1 Auxiliary High-Level Waste Solids Mobilization Equipment Requirement Summary**

| Function or Requirement | Value/Specification Range | Basis | Reference |
|---|---|---|---|
| *Process Specifications – Waste Properties* | | | |
| Effective cleaning radius | 3m to 6m (9.8ft – 19.8ft)<br><br>Minimum performance criteria = 3m | The lower value represents a typical distance from 4"/6" risers to the interior tank sidewall. Available 42" risers are approximately 6m from the sidewall. | H-14-010507 Sht 1 |
| Total waste volume (includes saltcake and supernate) | 579 Kl (153 Kgal) to 4,232 Kl (1118 Kgal) | The range of reported total waste volume for the included tanks. | (Hanlon 1999) |
| Sludge shear strength | 1.96 kPa (19,631 dynes/cm$^2$, 41 lb/ft$^2$) to 4.8 kPa (47,900 dynes/cm$^2$, 100 lb/ft$^2$)<br><br>Minimum performance criteria = 3.38 kPa | The lower value is commonly reported data from past AZ-102 analyses. The higher value represents the highest limit reported in the Tank Waste Remediation System Operation and Utilization Plan. | (Kirkbride 1999a), (Shaw, 1999) |
| Sludge volume | 269 Kl (71Kgal) to 1196 Kl (316 Kgal) | The lower value is the reported volume in 214-SY-102. The higher value is the reported volume for AW-103. The highest value also represents the largest reported sludge volume for the included tanks. While several of the noted tanks have no sludge, SY-102 data was used for lower data because it was a highlighted tank for auxiliary mixing. (Obviously 0 sludge would be a the maximum low end, but not practical for this scope.) | (Hanlon 1999) |
| Sludge bulk density | 1-2 gm/ml | Core sample results of bottom sludge layers for AW-103 (#194) and SY-102 (#213) (TWINS database) | See Basis |
| Sludge viscosity | 6.0 E-01 to 1.0 E+05 poise | Solids viscosity for AZ-101 and other reported slurry viscosities range from 5.0 E-01 to 1.0 poise; Other reported data for solids are noted at 10,000 cp. The referenced PNNL report is an internal letter report that references other reporting data; characterization data on sludge viscosities is limited. | (Antoniak 1996), and (Kirkbride 1999a) |

| Function or Requirement | Value/Specification Range | Basis | Reference |
|---|---|---|---|
| Weight percent solids of in-tank settled sludge | 30-60% | From AW-103 core sampling data extrapolated from reported percent water values (TWINS database core 194) | See Basis |
| Solids Particle Size | 0.2-50 microns | Commonly reported data for sludges – typical smaller sizes causing which tend to be highly cohesive; translates to high yield stresses in both shear and compressive modes | (Kirkbride 1999a) (Powell 1997) |
| Supernatant Volume/Levels | 0 to 87 Kgals<br>0 to 293 inches<br>(See Appendix A for tank specific) | (Assuming a nominal ratio of 2750 gallons per inch) | (Hanlon 1999) |
| Supernatant specific gravity | 1.0 to 1.2 | Supernatant grab sample results obtained from TWINS database | See Basis |
| Supernatant Viscosity | 0.3 to 3.0 cp | Reported values from tank data and simulation runs | (Akins 1999) (Kirkbride et al 1999a) |
| Waste pH | Caustic, 12 to +14 | Commonly reported data; waste streams are a variety of sodium and other metallic salts | See Basis |
| Radioactive dose | Peak dose rate 10 to 1100 R/hr<br>Total Integrated Dose 3.6 E05 to 9.5 E07 R | Reported ranges | (Claghorn 1998) |
| Waste temperature | 60-95 °F for AW-103 & SY-102<br>60-190 °F for remaining tanks | Reported ranges | Surveillance Monitoring (TMACs) for AW-103 and SY-102 and Temperature profile data from Characterization database (Twins) |
| *Operational Configuration Boundaries* | | | |
| Discharge angle | Adjustable angles in both the vertical and horizontal plane. Best operation would allow adjustment remotely without breaking of confinement. | Mixing may be adequate with a fixed angle position directed at a single dead zone or buildup area. Waste performance and shear strengths may require a variable angle to enhance mixing and impacting of thicker sludges. | Operation/design team request |
| Mixer height | Variable (ability to mobilize waste on bottom and at increments 15-20 feet above bottom tank elevation) | Mixing may be adequate with a fixed position unit set on tank floor directed at a single dead zone or buildup area. Waste properties, specifically shear strengths, may require a phased lowering of the mixer to start movement of lower density material before impacting on thicker sludges. Also, mixer may need to be elevated to mobilize suspended solids in waste layers. | Operation/design team request |

| Function or Requirement | Value/Specification Range | Basis | Reference |
|---|---|---|---|
| *Installation Constraints* | | | |
| Riser installation width for pump and related assembly/mast | Available nominal riser sizes: 4", 6", 12", & 42" | Varied spare risers, and risers used for operations which could be accessed (e.g., construction ports, defunct installed equipment, camera ports etc.) | H-2-64447 Rv 7<br>H-14-010501 Sht 4 Rv 2<br>H-14-010502 Sht 2 Rv 1<br>H-14-010502 Sht 4 Rv 1<br>H-14-010507 Sht 1 Rv 0<br>H-14-010507 Sht 2 Rv 0<br>H-14-010531 Sht 2 Rv 2 |
| Utilities availability | • 240/480 VAC<br>• Flush water through tanker or existing piping<br>• No instrument or compressed air | Current tank farm configurations; systems requiring compressed air or continual flushing will need to install auxiliary provisions | N/A |
| Natural Phenomena Design | None | Final Safety Analysis Report/Technical Safety Requirements, however dependent upon final design | (LMHC 1999a) |
| Ventilation system impacts | <50 scfm additional load | Conservative design estimate with existing ventilation systems | Estimate |
| Delivered horizontal displacement on vertical protuberances (e.g., thermocouple probes) in cleaning radius | Maximum 1 inch at tank bottom elevation | Calculations for specific tanks and waste protuberances will need to be made on a case-by-case basis. The reported range value is derived from calculation in AZ-101 but represents a conservative target for further evaluation | (Julyk 1997) |
| Material of construction | Wetted materials shall maintain 5-year life expectancy within waste conditions; minimum 304 stainless steel on all wetted parts | 5 years estimated maximum life for staging tank application | Estimate |
| Pit confinement | Installation on potential risers within pits shall not intrude upon piping, and shall allow for reinstallation of all existing pit covers. | Minimization of operational and project impact | Operation cost effectiveness |
| *Safety Requirements* | | | |
| Lift criteria | Installation/removal will be per critical lift requirements of Hanford Hoisting & Rigging Manual | Final Safety Analysis Report/Technical Safety Requirement dome loading controls | (LMHC 1999a)<br>AC 5.16 |
| Electrical systems within tank vapor space, and pits | Meets NFPA Class 1, Div 1, Group B; design criteria shall be reviewed by independent buyer expert group | Final Safety Analysis Report/Technical Safety Requirement ignition controls | (LMHC 1999a)<br>AC 5.10 |

| Function or Requirement | Value/Specification Range | Basis | Reference |
|---|---|---|---|
| Electrical systems within submerged waste streams | Meets NFPA Class 1, Div 1, Group B or be demonstrated by process that submerged system provides no spark to tank vapor space | Final Safety Analysis Report/Technical Safety Requirement ignition controls | (LMHC 1999a) AC 5.10 |
| Weight | Free supporting mast and pump assembly must meet allowable limits in addition to mixer pumps and retrieval pumps OR may be designed to rest on tank bottom, fully supported by floor | Final Safety Analysis Report/Technical Safety Requirement Dome Loading Controls; value will need specific calculation however generic rule is that riser may support 50 ton load limit | (LMHC 1999a) AC 5.16 |
| Control system | Capable of being interlocked or remotely shut down upon indication of high waste temperature or tank ventilation shutdown | Final Safety Analysis Report/Technical Safety Requirement waste temperature and ventilation controls | (LMHC 1999a) LCOs 3.2.1, 3.2.2, 3.2.3, 3.3.1, and 3.3.2 |
| Heat input | Maximum sludge/waste temperature rise of 10 °F during continuous equipment operation and following 12 hours | Final Safety Analysis Report/Technical Safety Requirement waste temperature controls, estimated conservative value based upon safety requirements; target motor energy output should be in the range of 50 – 100 hp | (LMHC 1999a) and engineering estimation |
| *Operation, Maintenance, & Radiological Control Constraints* | | | |
| Location of control mechanisms | Localized control at tank farm within tank farm control room (greater than 100 meters away from tank) | ALARA, and Conduct of operations | None |
| Location of electrical components requiring calibration | Not located within pits or shielded areas | ALARA, and Conduct of operations allowing routine access for calibration without removing shielding | None |
| Riser seal | Shall maintain existing confinement; riser seal shall be gasketed. Rotating seals shall be liquid sealed with drain back to the tank | ALARA | None |
| Decontamination | Free draining, internal flushable, with internal void areas for material trapping filled with compatible solids (e.g., foam) | Conduct of operations; current planning does not involve reuse of mixer | None |
| Shielding | System shall be provide with shielding for protection of workers during installation and removal for disposal | ALARA; current planning does not involve reuse of mixer | None |

## 6.0 References

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Kirkbride, R. A., G. K. Allen, P. J. Certa, A. F. Manuel, R. M. Orme, L. W. Shelton, e. J. Slaathaug, R. S. Wittman, and G. T. MacLean and D. L. Penwell (SESC), 1999a, *Tank Waste Remediation System Operation and Utilization Plan*, HNF-SD-WM-SP-012, Rev. 1, Vol. I and II, Numatec Hanford Corporation, Richland, Washington.

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Pacquet, E. A., 1999, *Evaluation of Flygt Mixers for Double-Shell Tank High Level Waste Auxiliary Solids Mobilization – Work Plan,* Rev. 0, Numatec Hanford Corporation, Richland, Washington.

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Powell, M. R., J. R. Farmer, H. Gladki, B. K. Hatchell, M. A. Johnson, M. R. Poirier, and P.O. Rodwell, 1999, *Evaluation of Flygt Mixers for Application in Savannah River Site Tank, Summary Test Results for Phase A, B, and C, Testing,* PNNL-12168, Pacific Northwest National Laboratory, Richland, Washington.

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# 7.0 Unit Measurement Abbreviations/Terms

Note: some of the abbreviations used within this document and highlighted below are not consistent with standard CGS or MKS system designations. They were used because they are the native measurement scales used within the referenced document.

| Abbreviation | Measurement Definition/Term |
|---|---|
| ALARA | as low as reasonably achievable |
| cm | centimeter |
| cp | centipoise |
| ft | foot/feet |
| kPa | kilo(1000) Pascal |
| lbs | pounds |
| M | million |
| m | meter |
| Kgal | kilo (one thousand) gallon [more common: kgal] |
| Kg | kilogram [more common: kg] |
| Kl | kiloliter [more common: kl or $m^3$] |
| L | liter [more common: l] |
| R/hr | Rads/hour |
| R | Rads |
| °F | degrees Fahrenheit |

## APPENDICES



| APPENDIX | TITLE |
|---|---|
| A | Tank Tabulation Data |
| B | Core Sample Profiles AW-103, SY-102 |
| C | Pictorial Core Sample Template |
| D | Tank Profiles AW-103, SY-102 |
| E | Typical Double-Shell Tank Cut-away |
| F | Interoffice Memo Attachment (Crawford 1999) |
| G | Interoffice Memo Attachment (Akins 1999) |

# APPENDIX A

## Tank Tabulation Data

| Tank # (Kirkbride 1999b) | Tank Type (Kirkbride 1999b) | Retrieval Sequence (Kirkbride 1999b) | Waste Physical Properties | | | Maximum # of Mixer Pumps (Kirkbride1999a) | Available Risers (without mixer pumps, i.e. 42" risers may be used for mixer pumps) | Flammable Gas Group (LMHC 1999a) |
|---|---|---|---|---|---|---|---|---|
| | | | Shear Strength (kdynes/cm²) (Note 1) | Level [Total: Supernate, Saltcake, Sludge] (Hanlon 1999) (Kgal) (Note 2) | Tank Waste Temp. Range-°F (TWINS) | | | |
| AN-104 | Intermediate – Minimum order | 6 | None reported | 1053-<br>604, 449, 0 | 105-123 | 2-3 | 1-4"<br>2-8"<br>1-12"<br>1-42"<br>(H-14-010501) | 1 |
| AW-103 | Source – Extended order | 8 | 47.9 (Grams 1995) | 510-<br>147, 47, 316 | 60-75 | 2-3 | 1-4"<br>1-12"<br>2-42"<br>(H-14-010502 sht 3) | 2 |
| AW-104 | Source and Staging – Extended order | 9 | None reported | 1118-<br>887, 231, 0 | 76-104 | 2-3 | 1-4"<br>2-42"<br>(H-14-010502 sht 4) | 2 |
| AY-101 | Source and Staging – Minimum order | 4 | None reported | 152-<br>58, 0, 94 | 98-125 | 2-3 | 1-4"<br>1-16"<br>1-42"<br>(H-2-64447) | 2 |
| AY-102 | Source and Staging | 3 | Top 53.6<br>Mid 16.7<br>Bot 21.7<br>(Kirkbride1999a)<br>30.6<br>(Grams 1995) | 615-<br>399, 0, 216<br>(includes transferred material from C-106) | 72-126 | 4 | 1-4"<br>1-16"<br>1-42"<br>(H-2-64447) | 2 |
| AZ-101 | Source and Staging – Minimum order | 1 | 1st 2.1 & 2.6<br>2nd 15<br>(Kirkbride 1999a)<br>8.6k (Grams 1995) | 846-<br>800, 0, 46 | 144-186 | 2 | 2-3"<br>7-4"<br>6-6"<br>3-42"<br>(H-14-010507 sht 1) | 2 |
| AZ-102 | Source and Staging – Minimum order | 2 | Seg 1: 15.4 & 13.1<br>Seg 2: 26.5<br>(Kirkbride 1999a)<br>19.6 (Grams 1995) | 941-<br>853, 0, 88 | 160-188 | 2 | 2-3"<br>11-6"<br>3-42"<br>(H-14-010507 sht 2) | 2 |
| C-104 | Source – Minimum order | 5 | None reported | 295-<br>0, 0, 295 | 80-101 | 2-3 | N/A | 2 |
| C-107 | Source – Extended order | 7 | None reported | 257-<br>0, 0, 257 | 115-129 | 2-3 | N/A | 3 |
| SY-102 | Source – Minimum order | 6 | 38.8 (Grams 1995) | 756-<br>685, 0, 71 | 64-110 | 2-3 | 4-4"<br>2-42"<br>(H-14-010531 sht 2) | 2 |

Notes

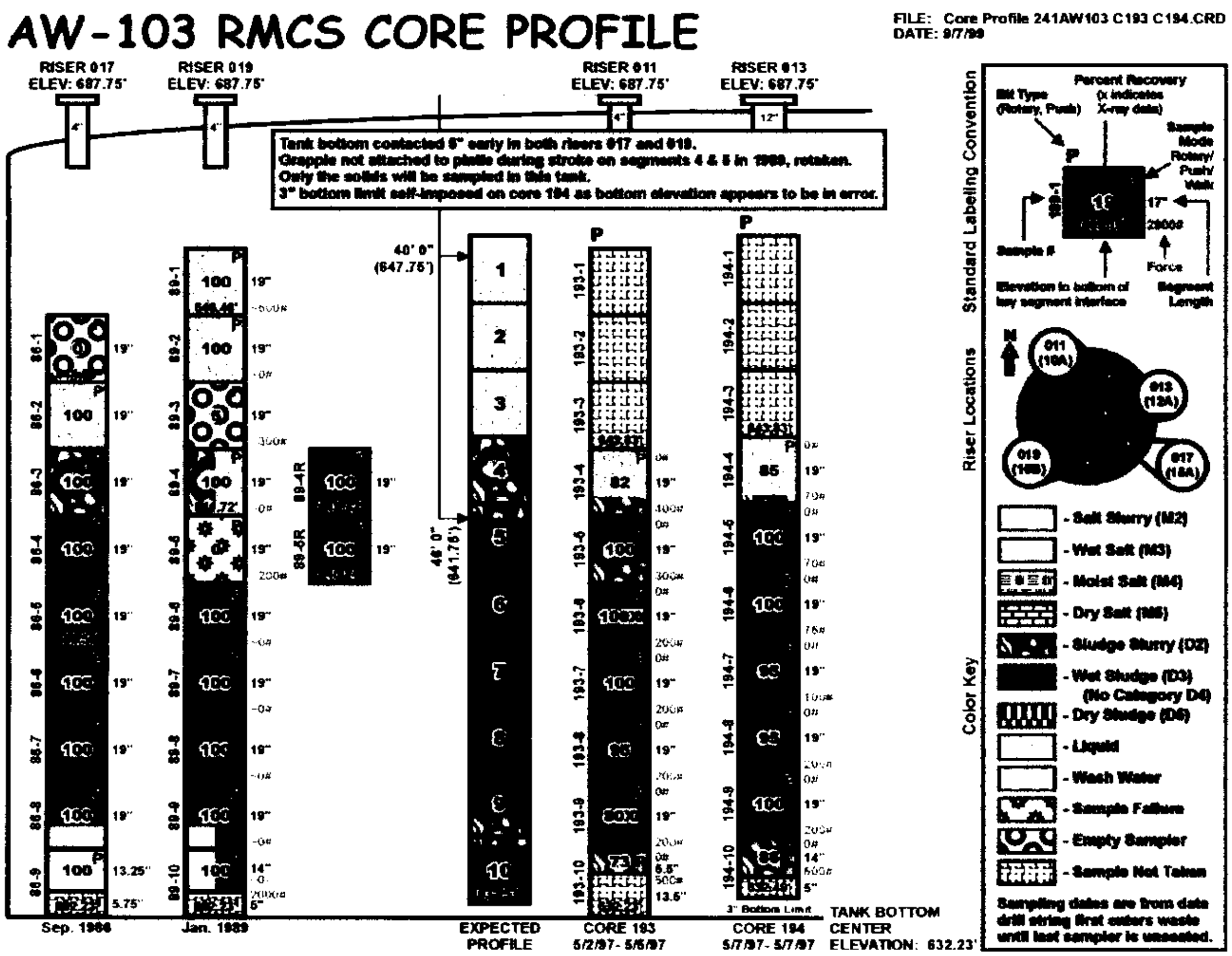
1 For comparison, simulant shear strengths per (Powell et 1997): 50% kaolin 13% plaster water simulant had a shear strength of 2.5 kPa (25 k-dynes/cm²); a 22.5% kaolin, 40% plaster, 37.5% water simulant had a shear strength of 150 kPa (1500 k-dynes/cm²)

2 Height of supernatant liquids can be approximated by the correlation of 1 in/2750 gallons

# APPENDIX B

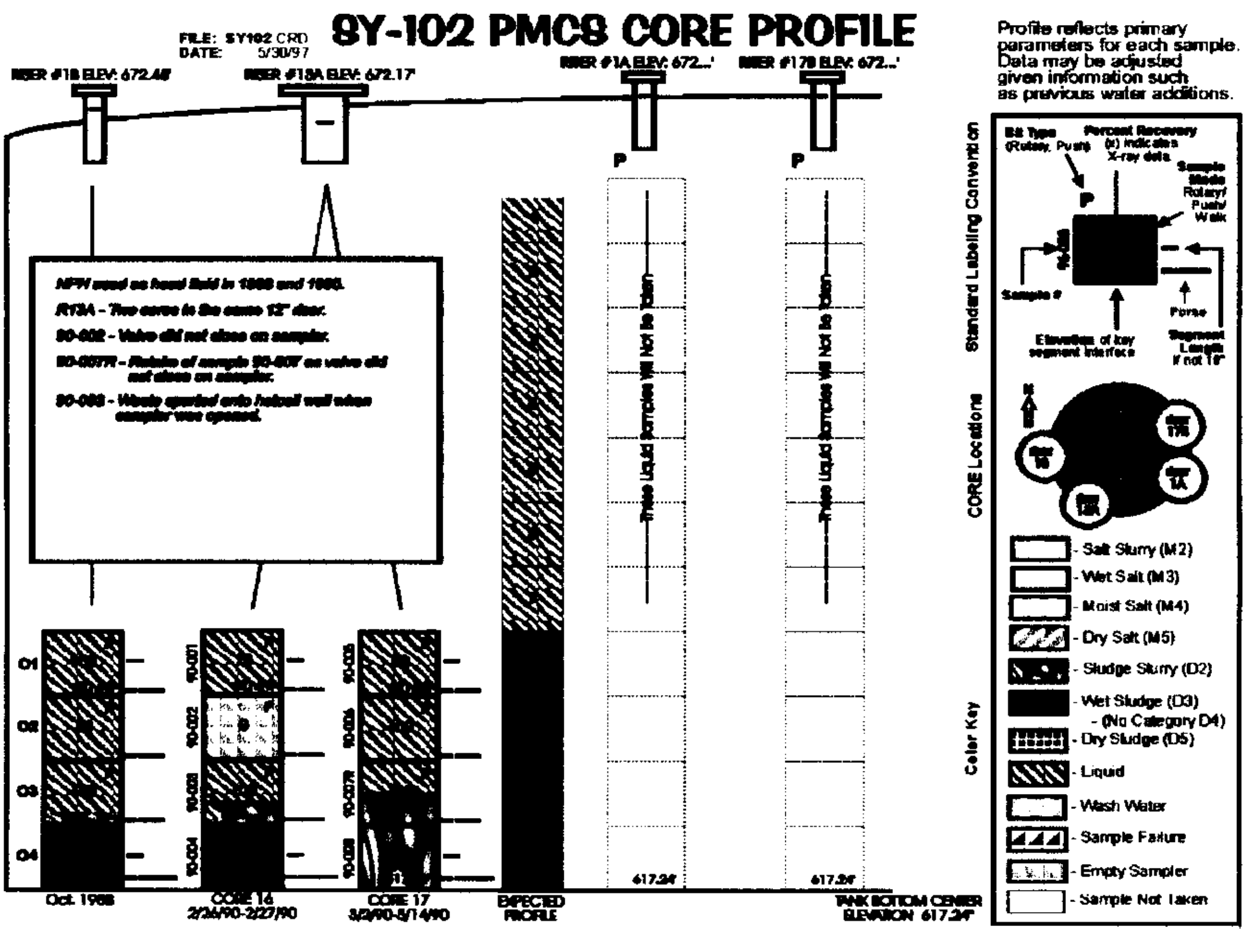
## Core Sample Profiles AW-103, SY-102

### AW-103



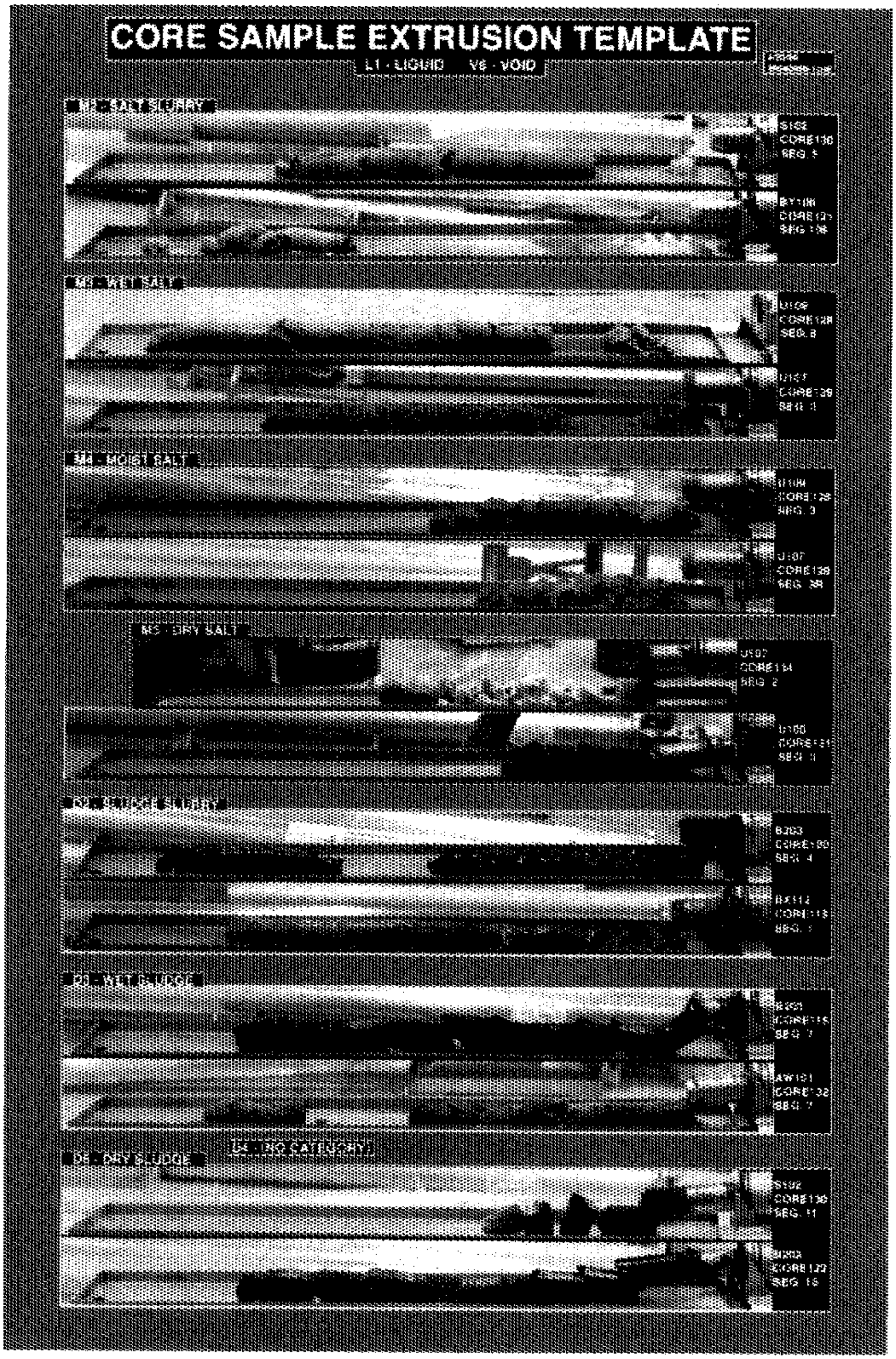
# APPENDIX B continued

## SY-102



# APPENDIX C

## Pictorial Core Sample Template

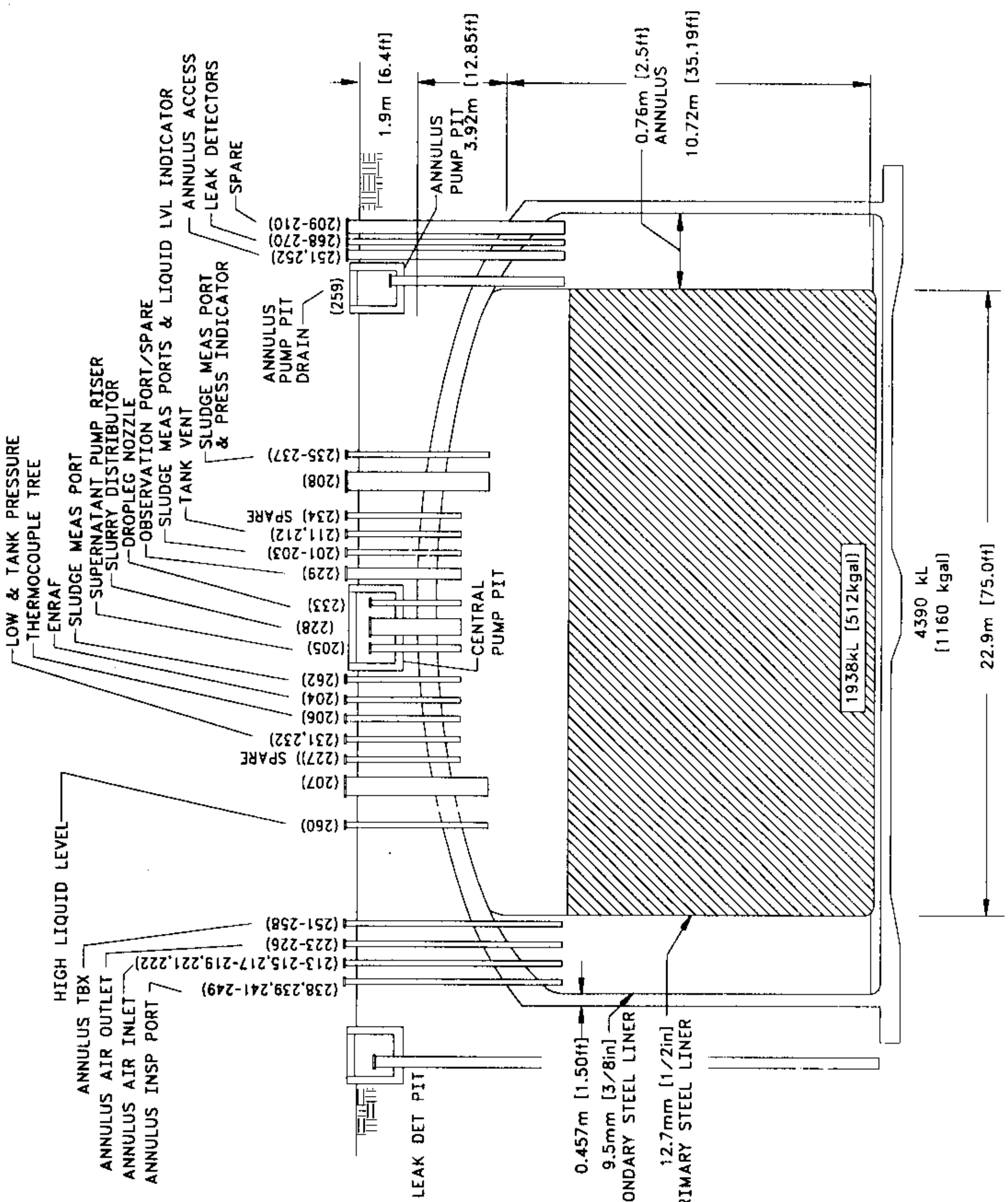


# APPENDIX D

## Tank Profiles AW-103, SY-102

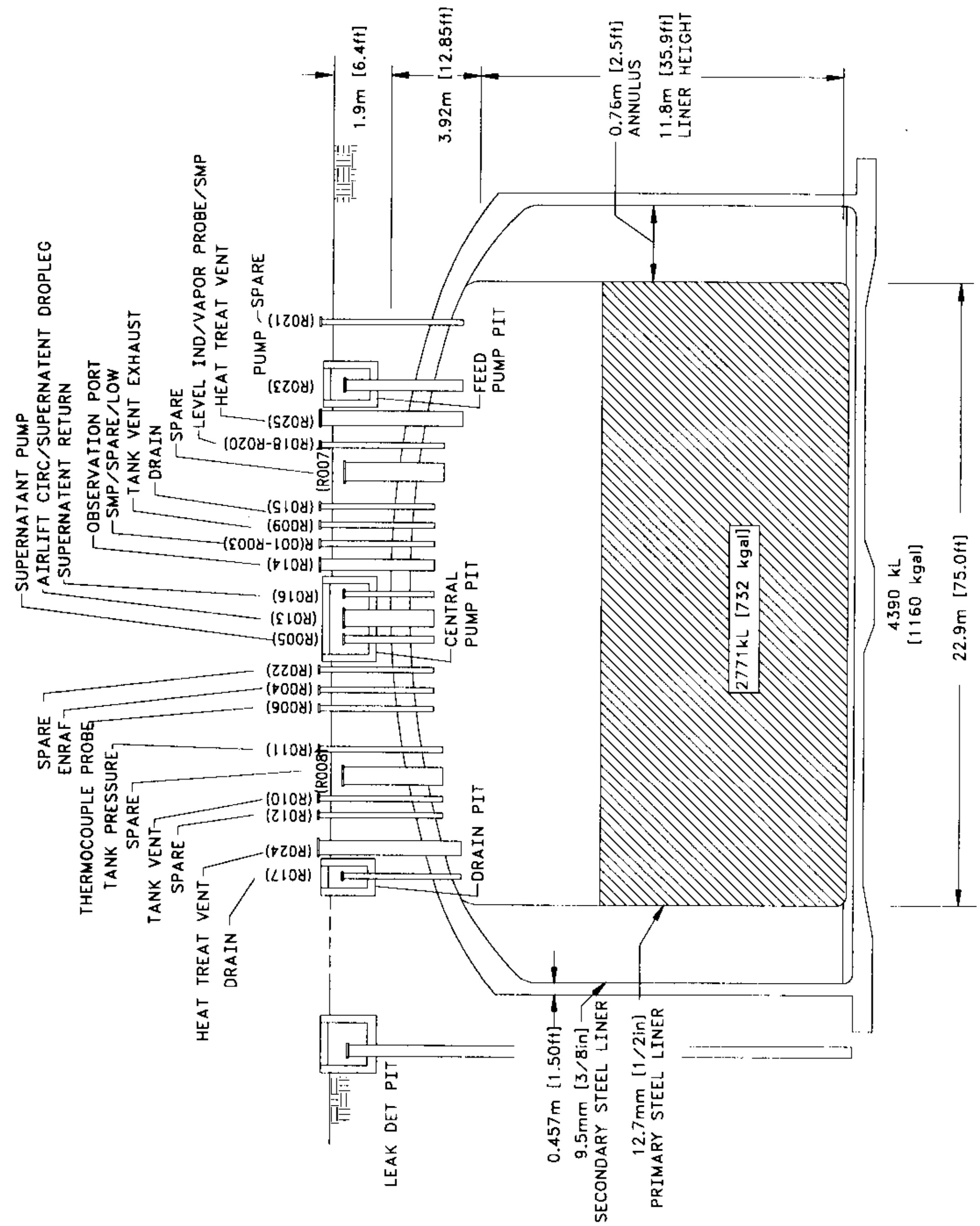
(Reference TWINS Database)

## AW-103



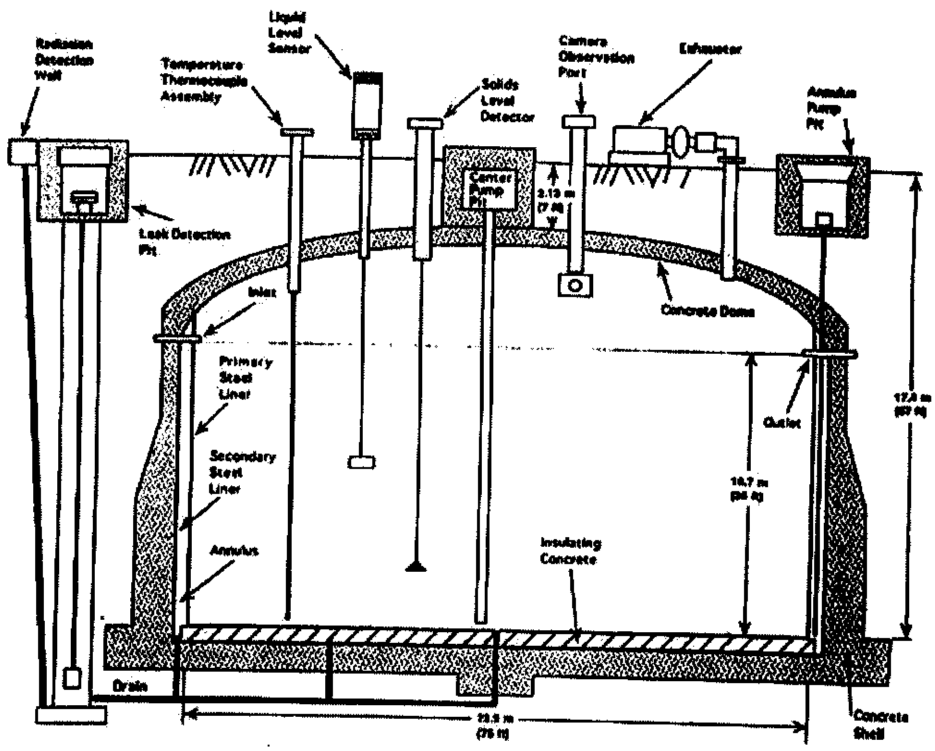
# APPENDIX D continued

## SY-102



# APPENDIX E

## Typical Double Shell Tank Cut-away



# APPENDIX F

## Interoffice Memo Attachment (Crawford 1999)
## 5 pages

**INTEROFFICE MEMO** LOCKHEED MARTIN

| | | |
|---|---|---|
| From: | Process Development | 82400-99-020 |
| Phone: | 376-8676 R3-73 | |
| Date: | April 13, 1999 | |
| Subject: | UPDATE OF ESTIMATED RETRIEVAL EFFICIENCIES FOR PHASE 1 HIGH-LEVEL WASTE FEED TANKS | |

To: T. M. Hohl R3-73

| cc: | | | | |
|---|---|---|---|---|
| | A. B. Carlson | R3-73 | C. P. Shaw | R3-73 |
| | J. S. Garfield | R3-73 | T. W. Staehr | R3-74 |
| | R. A. Kirkbride | R3-73 | G. E. Stegen | H3-26 |
| | T. H. May | R3-73 | W. L. Willis | R3-73 |
| | D. J. Moore | H3-27 | AFC File/LB | R3-73 |
| | R. M. Orme | R3-73 | TWRS DIMC | R1-29 |
| | D. E. Place | R3-73 | | |

Reference:

1. Fow, C. L., C. M. Ruecker, P. A. Scott, and G. A. Whyatt, 1987, "*Development and Demonstration of Technology for Retrieving Waste from Double-Shell Tanks, Pilot-Scale Retrieval Tests Using Simulated NCAW*," 7W21-87-15, Pacific Northwest Laboratory, Richland, Washington.
2. Grams, W. H., 1995, "*Double-Shell Tank Retrieval Allowable Heel Trade Analysis*," WHC-SD-WM-TA-162, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
3. Powell, M. R., Y. Onishi, and R. Shekarriz, 1997, "*Research on Jet Mixing of Settled Sludges in Nuclear Waste Tanks at Hanford and Other DOE Sites: A Historical Perspective*," PNNL-11686, Pacific Northwest National Laboratory, Richland, Washington.
4. Shekarriz, A, J. N. Chung, C. T. Crowe, and D. Sprecher, 1998, "*Physics of Jet Mixing in Rheologically Complex Mixtures*," Letter Report dated April 1998, Pacific Northwest National Laboratory, Richland, Washington.

Knowledge of the quantity of sludges that can be retrieved from high-level waste (HLW) tanks using mixer pumps is required to predict the amount of HLW glass that will be produced. Current retrieval efficiencies are based on an equation that is only valid for a narrow range of sludge shear strengths. This letter documents the change in method for estimating retrieval efficiencies of HLW sludge to one that is based on more experimental data and valid for a greater range of sludge shear strengths. A peer review of three methods concluded that the following equation should be used to determine the effective cleaning radius (ECR) of HLW sludge (peer reviewers: T. W. Crawford, T. M. Hohl, T. H. May, R. M. Orme, C. P. Shaw, and T. W. Staehr):

$$ECR = K \cdot U_0 \cdot D \cdot \tau_s^{-a}$$

where:

ECR - Effective Cleaning Radius (cm)
K - Constant (3.0)

T. M. Hohl
Page 2
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$U_o \cdot D$ - Jet Velocity times Jet Diameter (27,300 $cm^2/s$)
$\tau_s$ - Sludge Shear Strength ($dyne/cm^2$)
n - Experimental Constant (0.46)

The ECR and corresponding retrieval efficiency based on this equation was estimated for double-shell tanks 241-AW-103, 241-AY-101, 241-AY-102, 241-AZ-101, 241-AZ-102, and 241-SY-102. The results of these calculations are shown in Table 1. Performance enhancement mixing technologies would supplement mixer pumps in tanks 241-AW-103 and 241-SY-102 to increase retrieval efficiencies. Should testing of mixer pumps in 241-AZ-101 *demonstrate that the ECR is less dependent on sludge shear strength (as suggested in Shekarriz,* 1998), then supplemental mixing technologies may not be required.

Table 1. High-Level Waste Tank Retrieval Efficiencies

| Tank | Effective Cleaning Radius (ft) | Retrieval Efficiency[a] (%) | Retrieval Efficiency Including Supplemental Technology (%) |
|---|---|---|---|
| AW-103 | 19 | 48 | 90[b] |
| AW-104 | 32[c] | 90 | -- |
| AW-105 | <41[c] | 90[d] | -- |
| AY-101 | 35[c] | 95 | -- |
| AY-102 | 23 | 64 | -- |
| AZ-101 | 42 | 90[e] | -- |
| AZ-102 | 28 | 80 | -- |
| SY-102 | 21 | 58 | 80[f] |

[a]From Fow, et al. (1987), Fig. 8.9, pg. 8.14.
[b]Estimated retrieval efficiency of 90% leaves a heel of 10% or 13 inches sludge.
[c]From Grams (1995), Table 2, pg. 16.
[d]Grams (1995) reports this as 99+%. A conservative engineering judgement reduced the estimated retrieval efficiency to 90%. A 10% heel is equivalent to 10 inches of sludge.
[e]Due to low solids volume in AZ-101, the previous retrieval efficiency of 90% (Grams, 1995) was retained. A 10% heel is equivalent to ~2 inches of sludge.
[f]Estimated retrieval efficiency of 80% leaves a heel of 20% or 6 inches sludge.

Three different equations, derived from sludge mobilization studies, were found that predicts the ECR of a mixer pump in HLW sludge. The first equation (the one current ECRs are based on) was developed in fiscal year (FY) 1987 to support the forthcoming AZ-101 mixer pump test (Fow, et al., 1987). Pacific Northwest Laboratory conducted a series of ten 1/12-scale sludge mobilization tests. Most tests were conducted using simulant shear strengths of around 10,000 $dynes/cm^2$ which was the estimated shear strength of AZ-101 sludge at the time. It was

T. M. Hohl
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not the purpose of this work to develop a correlation between ECR and sludge shear strength. However, the data were used to develop a preliminary correlation between ECR and shear strength. The equation, which is similar to the one chosen to estimate future ECRs, is:

$$ECR_{87} = 17.3 \cdot U_o \cdot D \cdot \tau_s^{-0.67}$$

where ECR and $D$ are in centimeters, $U_o$ is in centimeters per second, and $\tau_s$ is in dynes per square centimeter. This equation is unacceptable because it is only valid for a narrow range of sludge shear strengths.

The second equation, and the one chosen to estimate the ECR of HLW sludge in the future, was derived based on data from 45 1/25-scale sludge mobilization tests conducted during FY 1993 and FY 1994 (Powell, et al., 1997). This equation is reported as:

$$ECR_{94} = 4.0 \cdot U_o \cdot D \cdot \tau_s^{-0.46}$$

where ECR and $D$ are in centimeters, $U_o$ is in centimeters per second, and $\tau_s$ is in dynes per square centimeter. Based on the uncertainties in ECR measurement at 1/25-scale, it is recommended that a proportionality constant of 3.0 be used instead of 4.0 as an added degree of conservatism. This recommendation is followed for modeling full-scale ECRs in HLW sludges. This equation is valid for cohesive tank sludge. Sludge that has less cohesion than is implied by its shear strength is expected to yield a larger ECR than is predicted. A graphical representation of the $ECR_{94}$ and $ECR_{87}$ equations as a function of shear strength is attached (from Powell, et al., 1997).

A third equation for estimating the ECR of HLW sludges was derived in FY 1998. This equation is based on data gathered from testing from FY 1987 through FY 1998 (Shekarriz, 1998). The data was gathered and reduced using only dimensionless parameters for correlation development and curve fitting. This equation includes all the operational parameters of the previous equations ($U_o$, $D$, $\tau_s$) and adds slurry viscosity, slurry density, and supernate density to the function. This equation is reported as:

$$ECR_{98} = (0.91\ \tau_s^{*\,-0.17}\ Re^{0.2}\ Fr^{0.2})\ D$$

where:

$\tau_s^*$ = dimensionless shear strength or plascticy number = $\tau_s/(\rho_s U_o^2)$
Re = Reynolds number = $(\rho_s U_o D)/\mu_s$
Fr = Froude number = $U_o/[(\rho_s-\rho_w)gD/\rho_{sn}]^{1/2}$
$\tau_s$ - sludge shear strength (N/m²)
$U_o$ - nozzle exit velocity (m/s)
$D$ - nozzle diameter (m)
$\mu_s$ - slurry viscosity (N•s/m²)
$\rho_s$ - slurry density (kg/m³)
$\rho_w$ - water density (kg/m³)
$\rho_{sn}$ - supernate density (kg/m³)

The positive attributes of this equation are obvious; a large data set and more parameters to fine-tune the result. However, the lack of accurate, reliable viscosity measurements of sludge in HLW tanks at this time make ECR estimates from this equation questionable. Therefore, it is recommended this equation not be used until more reliable and applicable viscosity data becomes available.

Table 2 shows the calculated ECRs for a select group of tanks using each of the three equations (shaded cells indicate ECRs used to determine retrieval efficiencies). The trend of higher ECRs resulting from equations $ECR_{94}$ and $ECR_{98}$ reflects the lower dependence of shear strength on the ECR for these equations. This is the effect of the exponent associated with the shear strength component in the ECR equations. The exponents associated with the shear strength ($\tau_s$) component for equations $ECR_{98}$, $ECR_{94}$, and $ECR_{87}$ are -0.17, -0.46, and -0.67, respectively.

Table 2. Comparison of Calculated ECRs

| Tank | $ECR_{87}$[a] (ft) | $ECR_{94}$[b] (ft) | $ECR_{98}$[c] (ft) |
|---|---|---|---|
| AW-103 | 12 | 19 | 29 |
| AY-101 | 35 | --[d] | -- |
| AY-102 | 16 | 23 | 26 |
| AZ-101 | 37 | 42 | 37 |
| AZ-102 | 21 | 28 | 35 |
| SY-102 | 13 | 21 | 26 |

[a]Data published in Grams (1995), Table 2, pg. 16.
[b]Results based on shear strength data in Grams (1995), which corresponds with current tank characterization report data. Tank AY-101 did not have published shear strength data available.
[c]Results based on shear strength data in Grams (1995), which corresponds with current tank characterization report data. Slurry density, supernate density, and slurry viscosity obtained from current tank characterization reports. Tank AY-101 did not have published shear strength data available.
[d]No published shear strength data available, ECR published in Grams (1995) will be used.

Any questions regarding this information can be directed to me at 376-8676.

Sincerely,

Tom W. Crawford

Thomas W. Crawford
Senior Engineer

mrs

Attachment

ATTACHMENT
82400-99-020

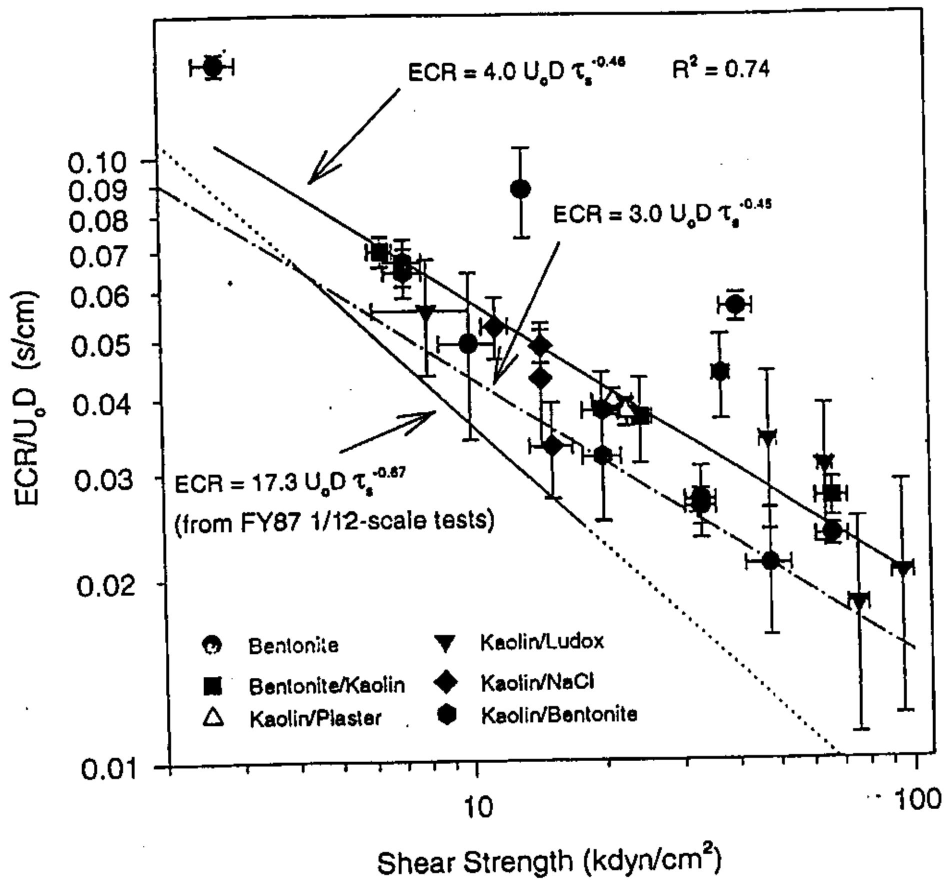


**Figure 4.6. 1/25-Scale Cohesive Sludge Mobilization Data**

# APPENDIX G

## Interoffice Memo Attachment (Akins 1999)
## 7 pages

**INTEROFFICE MEMO** LOCKHEED MARTIN

| | | | |
|---|---|---|---|
| From: | Process Development | | 82400-99-047 |
| Phone: | 376-2745 R3-73 | | |
| Date: | August 23, 1999 | | |
| Subject: | VISCOSITY REPORT | | |

| | | | |
|---|---|---|---|
| To: | | T. W. Crawford | R3-73 |
| | cc: | J. S. Garfield | R3-73 |
| | | W. L. Willis | R3-73 |
| | | C. P. Shaw | R3-74 |
| | | T.W. Staehr | R3-74 |
| | | AFC File/LB | R3-73 |
| | | TWRS DIMC | R1-29 |

Please find attached, the Viscosity report submitted by Jared Akins on the completion of the project that was assigned to him for his internship with Numatec Hanford Corporation.

Tom W. Crawford for
Jared Akins

mrs

Attachment

# 82400-99-047
# ATTACHMENT

## "Viscosity Report"

(6 pages including cover page)

**Viscosity Impacts on Retrieval Percent**

Prediction of waste removal is currently a Retrieval Engineering topic of investigation. Directly impacting waste removal is viscosity, which is an unknown physical property for many tanks. Viscosity is defined as the property of a fluid that allows it to develop and maintain a tangential frictional force, or shear stress. Essentially viscosity is a measure of how well a fluid flows, for example honey has a larger viscosity than water. The effective cleaning radius, in which viscosity is a parameter, impacts the amount of solids removed from each tank. Solids retrieval directly impacts the volume of High-Level Waste (HLW) glass produced. Hence, an equation that predicts waste viscosity would be a valuable aid.

During evaporator campaigns in the 1980's, viscosity measurements were taken for a few tanks along with temperature, sodium concentration, and specific gravity of the evaporator slurries. Dan Reynolds authored an internal memo in 1988 (Reynolds 1988), concerning viscosity of evaporator slurries. An attempt to fit the viscosity data was made in his memo and was found to be difficult with the existing computer software. The best fit found in 1988 had a regression coefficient of 0.69 in which temperature, specific gravity, and sodium concentration were used as variables. The conclusion of the memo expressed a need for additional studies on the amount and type of solids present.

An improved viscosity predictive equation and its impact on waste retrieval is the subject of this letter. Sodium concentration and temperature correlated well with viscosity, but attempts to correlate specific gravity and temperature were unsuccessful. An equation with a regression coefficient of 0.91037 was found for the correlation of viscosity with sodium concentration (M) and temperature (°C). The data used for the development of this equation is found in Dan Reynolds internal memo issued in 1988 (Reynolds 1988). The best-fit equation is the Lorentzian equation seen below.

Lorentzian Viscosity Equation.

$$z = \left[\frac{63.918641}{1+\left(\frac{T+27.743587}{32.91558}\right)^2}\right] + \left[\frac{53.981677}{1+\left(\frac{Na-12.38734}{1.0091059}\right)^2}\right] + \left[\frac{403.65883}{\left[1+\left(\frac{T+27.743587}{32.91558}\right)^2\right]\cdot\left[1+\left(\frac{Na-12.3834}{1.0091059}\right)^2\right]}\right]$$

The evaporator slurries were high in sodium content and thus the Lorentzian viscosity equation above appears to work well for tanks with high sodium concentrations. A comparison with other known viscosity values for tanks SY-101, AZ-101, and AW-105 is shown below in Table 1.

Table 1. Comparison of Measured and Predicted Viscosity

| Tank/Waste Description | Measured Viscosity ($N{\cdot}s/m^2$) | Predicted Viscosity ($N{\cdot}s/m^2$) | Percent Difference |
|---|---|---|---|
| SY-101/As is liquid | .03 | 0.0198 | 34% |
| SY-101/Salt sludge+Salt crust | .03 | 0.0235 | 28% |
| AZ-101/Supernatant | .003 | .00715 | 114% |
| AW-105/1:1 Dilution of supernatant to sludge | .03 | .0158 | 47% |

The Lorentzian equation appears to be a reasonable correlation for viscosity. An equation that predicts viscosity for a larger number of tanks would require a parameter describing solids content. Currently there is not any viscosity measurements in which they also measured solids content.

The equation offered above is the best conservative viscosity approximation at the present time. Previously viscosity was approximated using critical Reynolds and critical velocity numbers, which approximate minimum flow rates of slurries that keeps solids suspended in solution. A comparison with previous approximations shows the Lorentzian equation to predict a higher viscosity.

Table 2. Comparison of Viscosity Predictions

| Tank | Critical Re Method of Viscosity Approximation ($N{\cdot}s/m^2$) | *Lorentzian Approximation* ($N{\cdot}s/m^2$) |
|---|---|---|
| AW-103 | 0.00604 | 0.02059 |
| AY-102 | 0.00947 | 0.01527 |
| AZ-101 | 0.01850 | 0.01568 |
| AZ-102 | 0.0014 | 0.0071 |
| SY-102 | 0.0078 | 0.0835 |

The impact of higher slurry viscosity results in less waste being retrieved. The equation used to predict waste retrieval is based on the effective cleaning radius (ECR) of a mixer pump. The ECR of a mixer pump is the radius of waste that the mixer pump suspends into the supernatant. The ECR equation used now is based on jet velocity ($U_0$), jet diameter (D), and sludge shear strength ($\tau_s$).

$$ECR = 3.0 \bullet U_0 \bullet D \bullet \tau_s^{-0.46}$$

Another ECR equation was developed in 1998, using dimensionless parameters shown below (Shekarriz 1998).

$$ECR = (0.91 \bullet \tau_s^{*-0.17} \bullet Re^{0.2} \bullet Fr^{0.2}) \bullet D$$

$\tau_s^*$ = dimensionless shear strength or plasticity number = $\tau_s/(\rho_s \bullet U_0^2)$
Re = Reynolds number = $(\rho_s \bullet U_0 \bullet D)/\mu_s$
Fr = Froude number = $U_0/[(\rho_s - \rho_w) \bullet D/\rho_{sn}]^{1/2}$

$\tau_s$ = Sludge shear strength (N/m²)
$U_0$ = Nozzle exit velocity (m/s)
D = Nozzle diameter (m)
$\mu_s$ = slurry viscosity (N•s/m²)
$\rho_s$ = slurry density (kg/m³)
$\rho_w$ = water density (kg/m³)
$\rho_{sn}$ = supernatant density (kg/m³)

The Shekarriz ECR equation is an improved predictive equation of waste retrieval because of the large number of parameters involved and it was drawn from a large data set. Presently this equation can not be used with accuracy because of the lack of viscosity measurements. The Shekarriz ECR is inversely proportional to viscosity; thus the high viscosity predictions of the Lorentzian equation result in a smaller effective cleaning radius. Below is a comparison of the ECR predictions, using the Critical Reynolds viscosity predictive method and the Lorentzian viscosity predictions.

Table 3. Comparison of ECR predictions

| Tank | ECR using Critical Reynolds viscosity predictions (ft). | ECR using Lorentzian viscosity predictions(ft) |
|---|---|---|
| AW-103 | 27.4 | 21.4 |
| AY-102 | 26.5 | 24.1 |
| AZ-101 | 37 | 27.2 |
| AZ-102 | 34 | 31.7 |
| SY-102 | 26 | 16.3 |

Weight percent retrieval is also affected by the larger viscosities predicted by the Lorentzian equation. Weight percent retrieved is defined as the percentage of total waste removed by a mixer pump. A comparison of the weight percent retrieved using the Lorentzian viscosity and the Critical Reynolds viscosity is shown below.

Table 4. Weight Percent Retrieval Comparison

| Tank | Weight Percent Retrieval using Critical Reynolds viscosity predictions | Weight Percent Retrieval using Lorentzian viscosity predictions |
|---|---|---|
| AW-103 | 76% | 64% |
| AY-102 | 73% | 39% |
| AZ-101 | 90% | 76% |
| AZ-102 | 94% | 88% |
| SY-102 | 73% | 27% |

*Note: Weight percent retrieval are found using Figure 8.9 of Fow 1987.

As shown in Table 4 weight percent retrieval decreases with the new Lorentzian viscosity predictions.

The amount of waste that can be retrieved from tanks directly impacts the amount of High Level Waste (HLW) glass produced by the private contractor. Currently the percent of waste retrieved depends upon an ECR equation that can only be used for a small number of tanks. An improved ECR equation developed by Shekarriz requires viscosity data that is unknown for most tanks. The Lorentzian viscosity equation derived earlier is presented as a conservative prediction of viscosity. Further viscosity measurements are needed to provide a wide source of data for better viscosity predictive equations. Included in the viscosity measurements should be solids content and type. This will help correlate a wider number of variables to viscosity and will result in an equation that is applicable to various types of tank waste.

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