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FEB 0 6 2015

15-TF-0008

The Honorable Jessie H. Roberson, Vice Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004

Ms. Vice Chairman:

TRANSMITTAL OF DEFENSE NUCLEAR FACILITIES SAFETY BOARD RECOMMENDATION 2012-2 IMPLEMENTATION PLAN DELIVERABLE FOR ACTION 5-1

This letter provides the deliverable responsive to the Action 5-1 Deliverable of the U.S. Department of Energy, Office of River Protection (ORP) Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2012-2, Hanford Tank Farms Flammable Gas Safety Strategy. Action 5-1 is to evaluate potential means to reduce the inventory of retained flammable gases in double shell tanks (DSTs) in a controlled manner.

Attachment 1, RPP-RPT-58280, *Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks*, Rev. 0, evaluates five options for reducing flammable gas conditions by periodically disturbing the settled solids layer of radioactive waste stored in DSTs. The five options were investigated for technical applicability, maturity, safety, cost, and time to implement.

Attachment 2, *White Paper on the Preferred Strategy for Managing Hazards Associated with Retained Flammable Gas in Double-Shell Tanks*, provides the Tank Operations Contractor, Washington River Protection Solutions LLC (WRPS), recommendations to ORP for managing hazards associated with retained flammable gas in DSTs. The recommendation provides a high-level overview of the risks associated with the retained flammable gas hazards in DSTs and the current safety controls applied to mitigate these risks.

ORP agrees with WRPS' final recommendation that the retained gas inventory reduction strategies should not be deployed at this time in lieu of other tank waste mission efforts (e.g., retrieval of single-shell tanks, pump-out of the DST 241-AY-102 primary tank, mitigation of tank waste vapors, etc.).

ORP remains committed to ensuring safe operations of the Hanford tank farms and will continue its work on Defense Nuclear Facilities Safety Board Recommendation 2012-2 and other efforts to reduce tank waste mission risks.

Kevin W. Smith
Manager

TF:JJL

Attachments

Distribution: Page 3

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ATTACHMENT 1

15-TF-0008

RPP-RPT-58280, Rev. 0

Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks

DOCUMENT RELEASE AND CHANGE FORM

Prepared For the U.S. Department of Energy,
Assistant Secretary for Environmental Management
By Washington River Protection Solutions, LLC., PO Box 850, Richland, WA 99352
Contractor For U.S. Department of Energy, Office of River Protection, under Contract DE-AC27-08RV14800

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RELEASE

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Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks

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Rev.

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Basis is required for Yes:_________

b. Does the change increase the probability of existing failure modes? ☐ **Yes** ☒ **No**
Basis is required for Yes:

c. For Safety Significant equipment, does the change require a modification to Chapter 4 of the DSA and/or FRED? ☐ **Yes** ☐ **No** ☒ **N/A**
Basis is required for Yes:

7. Description of Change and Justification (Use Continuation pages as needed)

This report evaluates five options for reducing flammable gas conditions by periodically disturbing the settled solids layer of radioactive waste stored in double-shell tanks. Although no discriminating requirements or criteria were established, the five options were investigated for technical applicability, maturity, safety, cost, and time to implement.

8. Approvals

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Other Approver	GOETZ, TOM	GOETZ, TOM	12/10/2014
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[Start Continuation Here]

RPP-RPT-58280, Rev. 0

Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks

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Key Words: flammable gas, double-shell tank, DST, liquid waste, settled solids, pulse jet mixer, PJM

Abstract: This report evaluates five options for reducing flammable gas conditions by periodically disturbing the settled solids layer of radioactive waste stored in double-shell tanks. Although no discriminating requirements or criteria were established, the five options were investigated for technical applicability, maturity, safety, cost, and time to implement.

APPROVED
By Julia Raymer at 2:15 pm, Dec 17, 2014

Release Approval Date

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HANFORD RELEASE

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Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks

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EXECUTIVE SUMMARY

In September 2012, the Defense Nuclear Facilities Safety Board (DNFSB) issued DNFSB Recommendation 2012-2, *Hanford Tank Farms Flammable Gas Safety Strategy*[1] that identified five recommendations and associated activities. The U.S. Department of Energy (DOE) responded to this recommendation with the *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2012-2, Hanford Tank Farms Flammable Gas Safety Strategy*[2]. This document satisfies Action 5-1, providing an evaluation report of potential options for reducing the inventory of the retained flammable gases in Hanford Site double-shell tanks in a controlled manner.

Hanford Site double-shell tanks contain liquid waste and settled solids. Radioactive waste generates gas by radiolysis of water and various soluble organic compounds along with complex chemical reactions. A fraction of generated gas is retained in the settled solids and can accumulate to quantities that may experience sudden release and exceed the lower flammability limit in the tank headspace. Exceeding the lower flammability limit can only occur in tanks that have relatively high gas inventories and small headspaces. This report defines the settled waste layer in terms of five waste characteristics:

- Strong, high shear strength sludge, deep waste
- Strong, high shear strength sludge, shallow depth
- Weak, low shear strength, saltcake/slurry, deep waste
- Weak, low shear strength, saltcake/slurry, shallow depth waste
- Tanks with settled solids and floating crust

Methods for periodic controlled release of flammable gas were selected by how effectively and controllably they could disturb the settled solids waste layer. Assuming that all of the gas is released from the waste being disturbed, existing calculations can be used to estimate the fraction of the settled solids layer that must be periodically disturbed to prevent the tank headspace from ever becoming flammable during hypothetical large gas releases.

To choose technologies effective for controlling flammable gas retention, a broad survey of technical solutions offered by industry, academia, and government sources (foreign and domestic), previously employed solutions, and promising novel concepts was performed. A list of 30 alternatives was considered. Screening criteria were applied and five options were selected for detailed evaluation.

The five options in no particular order of priority or preference are:

- **Option 1–Mixer Pump:** Configured as either a submersible pump and drive motor in the tank or a drive motor outside the tank connected to the pump by a long shaft.

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[1] DNFSB, 2012, Approval of Recommendation 2012-2, *Hanford Tank Farms Flammable Gas Safety Strategy* (http://www.dnfsb.gov/sites/default/files/Board%20Activities/Recommendations/rec_2012-2_20376.pdf; accessed 10/22/2014).

[2] DOE, 2013, Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2012-2, *Hanford Tank Farms Flammable Gas Safety Strategy* (http://www.dnfsb.gov/sites/default/files/Board%20Activities/Recommendations/Implementation%20Plans/ip_rec-id_20376_1.pdf; accessed 10/22/2014).

- **Option 2–Pulsed Air Mixer:** Demonstrated at the Oak Ridge National Laboratory and tested in limited extent for Hanford Site double-shell tank application.
- **Option 3–Pulse Jet Mixers:** Includes two configurations designed by AEA Technology of the United Kingdom, and an in-tank Russian pulsation mixer pump.
- **Option 4–Sonic Agitation:** Conceptually similar to a previous Tank SY-101 evaluation[3].
- **Option 5–Existing Technologies and Waste Management Techniques:** Implement operations, equipment, and proven techniques already in place on the Hanford Site. This option is presented as a potential option; however, given its wide scope of potential actions, it was not addressed in the same detail as the other four specific solutions.

These five options were further investigated for technical applicability, maturity, safety, cost, and time to implement. The following descriptions provide a brief overview of the mechanisms used by each option to release gas from the settled solids and maintain a reduced flammable gas inventory.

Mixer pumps use a fluid jet to mobilize and suspend the settled solids layer and release accumulated gas. The power and configuration needed for mixer pump deployment depends on riser availability and waste shear strength. These characteristics vary from tank to tank and will dictate how the initial degassing will be effected to prevent sudden releases of gas above the 25% lower flammability limit during operation, and how the pump system will be operated to maintain lower gas accumulations. Mixer pumps are the only technology previously deployed in a Hanford Site double-shell tank. The mixer pumps will be effective in all waste configurations.

Pulsed air mixers inject pulses of compressed air between horizontal plates to create a steady release of bubbles. The bubbles create a large-scale circulation current to mix the waste and gradually releases accumulated gas. This steady release mechanism does not appear to provide for a sudden release of gas above the 25% lower flammability limit during operation. There is no in-tank suction phase as part of this mobilization mechanism. The technology is expected to be effective in weak, low shear strength saltcake and slurry wastes in any operating depth. However, in strong, high shear strength waste, the technology may not be able to set up the desired circulation current to be effective.

Pulse jet mixers operate by periodically applying a vacuum to draw fluid waste into the bottom of a charge vessel followed by a pulse of compressed air to forcibly eject the waste to mix the surrounding solids and release retained gas. Pulse jet mixers have a more limited range than conventional mixer pumps and may require more numerous installations or more frequent/longer periods of operation. Thus, additional evaluation of how the PJM system would be operated to achieve the target degassing level and maintain the lower gas accumulation is needed. Similar to mixer pumps, PJMs will need to prevent sudden releases of gas above the 25% lower flammability limit during degassing and operation. The PJMs system is expected to be most effective in weak, low shear strength saltcake and slurry

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[3] WHC-SD-WM-ER-164, 1993, *Tank 101-SY Hydrogen Mitigation by Low Frequency Vibration, Rheological Analysis and Feasibility Assessment*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

wastes. However, the necessary pressures needed to mobilize deep slurries and high shear sludge may prove prohibitive at tank scale.

Sonic agitation uses an eccentric, rotating mass to create acoustic pressure waves in the waste. The pressure waves fluidize the waste, allowing accumulated gas held in the waste to escape. This change in the waste's physical characteristics provides for the steady release of gas and does not appear to provide for a sudden release of gas above the 25% lower flammability limit during operation. The technology is anticipated to be effective in all waste configurations. The number and power of the sonic probes will be dictated by the waste characteristics. Further testing is needed at tank scale.

Cost and schedule rough-order-of magnitude estimates have been assembled for the selected candidate technologies. Baseline costs include the following commonalities.

- **General Project Support:** A typical multi-year program of support staff and management, permit preparation, and technology development.
- **Design:** A typical multi-year program to mature technologies towards implementation including engineering, demonstration, technical optimization studies.
- **Procure:** Vendor-provided capital equipment costs that may include requirements such as commercial grade dedication qualification.
- **Construction:** In some cases, risers may need to be modified and other associated Hanford Site Tank Farm infrastructure development would need to be prepared.

Costs are for initial implementation in a single, first tank. Once baseline testing, maturation plans, permitting, designs, vendor qualifications of equipment specifications (such as commercial grade dedication), safety basis documentation, and other baseline requirements that are common to subsequent tanks are completed, overall deployment costs may likely be reduced. Initial implementation cost range from \$16M to \$18M for technology options. A relatively small percentage, between 2% to 15% of the total costs leading up to and including initial deployment, is for capital equipment.

This report evaluates five options, describing their respective attributes, while not ranking or down-selecting them, per se. Technical applicability, maturity, cost and schedule to implement, and safety basis implications were addressed. There are advantages and disadvantages to each option presented in this comparison.

CONTENTS

APPENDICES

FIGURES

TABLES

TERMS

Acronyms

ALC	air lift circulators
AEA PJM	AEA-made Fluidic pulse jet mixer
BOE	basis of estimate
DOE	U.S. Department of Energy
DST	double-shell tank
ECR	effective cleaning radius
GAAT	Gunite™ and Associated Tanks
LANL	Los Alamos National Laboratory
LFL	lower flammability limit
ORNL	Oak Ridge National Laboratory
PJM	pulse jet mixer
PNNL	Pacific Northwest National Laboratory
ROM	rough order of magnitude
SME	subject-matter expert
SMP	submersible mixer pumps
SRS	Savannah River Site
SST	single-shell tank
SwRI	Southwest Research Institute
USQD	Unreviewed Safety Question Determination
WRPS	Washington River Protection Solutions, LLC
WTP	Hanford Tank Waste Treatment and Immobilization Plant

Units

%	percent	kg	kilogram
cm	centimeter	lbf	pound force
ft	feet	lbm	pound mass
ft/s	feet per second	m	meter
g/mL	grams per milliliter	mm	millimeter
gal	gallon	m/s	meters per second
gpm	gallons per minute	oz.	ounce
hp	horsepower	Pa	Pascal
hr	hour	psig	pounds per square inch gauge
Hz	Hertz	vol%	volume percent
in.	inch	wt%	weight percent

TRADEMARK DISCLOSURE

Gunite is a trademark of Gunite Supply & Equipment, Monrovia, California.

Pulsair is a registered trademark of Pulsair Systems, Inc., Bellevue, Washington.

1.0 INTRODUCTION

In September 2012, the Defense Nuclear Facilities Safety Board (DNFSB) issued DNFSB Recommendation 2012-2, *Hanford Tank Farms Flammable Gas Safety Strategy*, which identified five recommendations and associated activities. The U.S. Department of Energy (DOE) responded to the recommendation with the *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2012-2, Hanford Tank Farms Flammable Gas Safety Strategy* (DOE 2013).

1.1 PURPOSE

This report addresses Action 5-1, to develop options to reduce inventory of the retained flammable gas in Hanford Site double-shell tanks (DSTs), in the DOE's Implementation Plan, responding to Recommendation 2012-2 (DOE 2013), which states:

Evaluate means to reduce the existing inventory of retained flammable gases in a controlled manner. Since these gases will continue to generate until the tank contents are processed, evaluate methods to reduce the future retention of flammable gases in these tanks or to periodically mix them to prevent the future accumulation of flammable gas inventories that could cause the tank headspace to exceed the LFL if rapidly released

1.2 OBJECTIVE

The objective of this document is to evaluate potential methods to reduce the inventory of retained gas in DSTs in a controlled manner in response to sub-recommendation 5 of Recommendation 2012-2.

1.3 SCOPE

This report describes methods to reduce the inventory of retained flammable gases in DSTs in a controlled manner and build upon the lessons learned from remediation of Tank SY-101 (WHC-EP-0516, *Mitigation/Remediation Concepts for Hanford Site Flammable Gas Generating Waste Tanks)*. Each of these methods performs periodic waste disturbance to controllably reduce retained gas within regulatory and safety requirements.

The evaluation includes a discussion of the technical viability of each of the examined options including safety basis implications, a rough-order-of-magnitude (ROM) cost to implement each option, and the summary schedule to implement each option. This report does not make a final recommendation as a path forward or provide a down selection from the five options presented. While technical merit, ROM cost and schedule, and safety basis impacts are discussed, a final ranking or recommended course of action is not within the scope of this document.

2.0 DOUBLE-SHELL TANK WASTE AND GAS RELEASE BEHAVIOR

The 28 Hanford DSTs were built between 1968 and 1986 to create space for liquid waste from the aging single-shell tanks (SSTs) that had begun to leak. To take full advantage of the added tank space, liquid waste from the SSTs was concentrated in evaporators into a thick slurry. Tanks SY-101 and SY-103 and a number of the tanks in AN Farm received the highest concentration waste, while the AW Tank Farm and the rest of the AN tanks received more dilute streams. The AY and AZ tanks received waste from tanks with the highest heat load, while the AP Farm received mostly untreated liquid.

2.1 GENERAL DOUBLE-SHELL TANK WASTE TYPES AND CONFIGURATION

The waste in the DSTs can be broadly classed as either "sludge" or "saltcake." Sludge is generally a dark gray/brown or even black clay-like solid consisting of water-insoluble metal oxides and hydroxides. Saltcake is a lighter gray/brown material that can also appear clay-like in core samples. Its primary constituents are highly soluble sodium nitrate, phosphate, and carbonate salts.

When waste of either type is pumped into a storage tank the solids settle out leaving a liquid layer above. All the DSTs contain liquid waste, while some of tanks have a supernatant layer over a settled solids layer of saltcake or sludge. As of the writing of this report, settled solid layers range from less than 0.5m to about 6 m in thickness.

2.2 INDUCED GAS RELEASES

It is theoretically possible for outside waste disturbances to produce large gas releases. While large releases from chemical changes (e.g., dilution) and heating/cooling have been postulated, only a major physical disturbance is considered sufficient to cause a sudden large release (PNNL-13933, *Review of the Technical Basis of the Hydrogen Control Limit for Operations in Hanford Tank Farms*). Only those tanks with relatively high gas inventories and small headspaces pose a flammability risk. Some potential disturbances are discussed below.

2.2.1 Mixing

The large mixer pump was installed in Tank SY-101 only after a large spontaneous gas release event occurred, ensuring a relatively low gas inventory. In addition, initial operations were intentionally slow and gentle. This early mixing did induce a small gas release, apparently from a nearly buoyant volume of waste that did not release in the prior spontaneous event. Subsequent full-speed pump runs caused additional small but measurable gas releases, decreasing over time. Flammable gas concentrations were far below the lower flammability limit (LFL) in each of the remaining releases.

Mixing in Tank SY-101 did have an unexpected consequence that led to an entirely new safety issue and remediation campaign. The gas generation rate in this tank remained high after mixing and the small gas bubbles mobilized by regular mixing accumulated with their attached solids under the crust layer. The thickening gassy layer (termed "bubble slurry"), containing up to 50% gas fraction, caused the waste surface level to rise to a record level, requiring a separate remedial action to address (PNNL-13933).

2.2.2 Dilution

A formal safety issue was declared for Tank SY-101 in 1998 when the combination of a very large and increasing volume of retained flammable gas in the bubble slurry layer and small and decreasing headspace to dilute a gas release became critical. Subsequent studies concluded that the only practical, permanent, and certain cure was dilution with water to reverse what the evaporators had done two decades earlier. More than 600,000 gal of liquid waste was pumped out of Tank SY-101 into Tank SY-102 to make room for addition of 525,000 gal of dilution water. A two-stage dilution process added 373,000 gal near the bottom and 152,000 gal on top of the waste. This dissolved the crust and a large fraction of the remaining solids, thereby removing the potential for large spontaneous gas releases of any kind. It is important to note that, even while freeing the large gas volume in the bubble slurry, the dilution process did not trigger any large sudden gas releases.

Dilution in Tank SY-101 occurred after a long period of mixing and the dilution water was introduced with the aid of the mixer pump. Diluent can be added, and will be effective over time (i.e., dissolve soluble solids), without mixing. However, stirring the waste speeds the process. Experience with Tank SY-101 shows that bottom dilution, even with mixing, releases gas held in the dissolving matrix relatively slowly (PNNL-13267, *Results of Waste Transfer and Back-Dilution in Tanks 241-SY-101 and 241-SY-102*). There is no mechanism for a large rapid release from top dilution.

2.2.3 Physical Disturbance

This category would include mechanical stirring, fluid jet or gas bubble mixing, insertion of sampling or measurement tubes, sonic vibration, or any similar disturbance. Besides high power jet mixing in Tank SY-101, there have been many minor disturbances (core sampling, ball rheometer and cone penetrometer insertion, fluid transfers, etc.) in DSTs with high retained gas volumes, and no significant induced gas releases have been observed. Therefore, it would be reasonable to conclude that relatively small local physical disturbances are not likely to pose an immediate hazard.

2.2.4 Earthquakes

Some DSTs that retain sufficient gas to make their headspace flammable if all retained gas were suddenly released (PNNL-11668, *Earthquake-Induced Response and Potential for Gas Mobilization in Hanford Waste Tanks*) are at risk due to outside influences. The only outside influence mechanism currently postulated to induce such a release is an earthquake. Since many complex variables contribute to the effects of a particular seismic event, such as magnitude, epicenter/hypocenter, and local geology, it is beyond the scope of this report to specify. Seismic motion might cause equipment or tank features to strike a spark for ignition in combination with gas released from the physical disturbance or the gas-laden waste. One preventative measure for such an accident is to keep the waste volume sufficiently low (which also makes the tank headspace volume high) to prevent the tank headspace from becoming flammable. This solution is impractical with existing DST volume constraints. The alternative, which is the focus of this report, is to periodically disturb the waste and release sufficient retained gas in a controlled manner to prevent flammability in a subsequent earthquake-induced release.

2.3 FLAMMABLE GAS HAZARD CLASSIFICATION

The settled waste layer can be defined in terms of five waste characteristics:

- Strong, high shear strength sludge, deep waste
- Strong, high shear strength sludge, shallow depth waste
- Weak, low shear strength, saltcake/slurry, deep waste
- Weak, low shear strength, saltcake/slurry, shallow depth waste
- Tanks with settled solids and floating crust

For example, based on the above description, Tank AN-101 is considered a strong, high shear strength deep waste tank and Tank SY-103 is a weak, low shear strength deep waste with a floating crust. For the purposes of defining 'deep,' an operating definition of 3.05 m (120 in.) will be used. This operating definition is based on simulant testing described in RPP-RPT-26836, *Gas Retention and Release from Hanford Sludge Waste*.

Selection of methods for periodic controlled release of flammable gas is intended for only those tanks that pose an induced gas release hazard. Assuming that a control method releases all of the gas from the volume of waste disturbed, the calculations described in RPP-10006, *Methodology and Calculations for the Assignment of Waste Groups for the Large Underground Storage Tanks at the Hanford Site* can be used to estimate the fraction of the settled solids layer that must be disturbed to prevent the tank headspace from becoming flammable in large gas releases.

The chosen technologies must degas a significant fraction of the settled solids volume in order to ensure a large earthquake-induced gas release cannot make the tank headspace flammable. Such an earthquake is conservatively assumed to release 50% of the gas retained in the waste. The required fraction of the waste volume that must be degassed (i.e., disturbed sufficiently to release all retained gas) is conservatively given by:

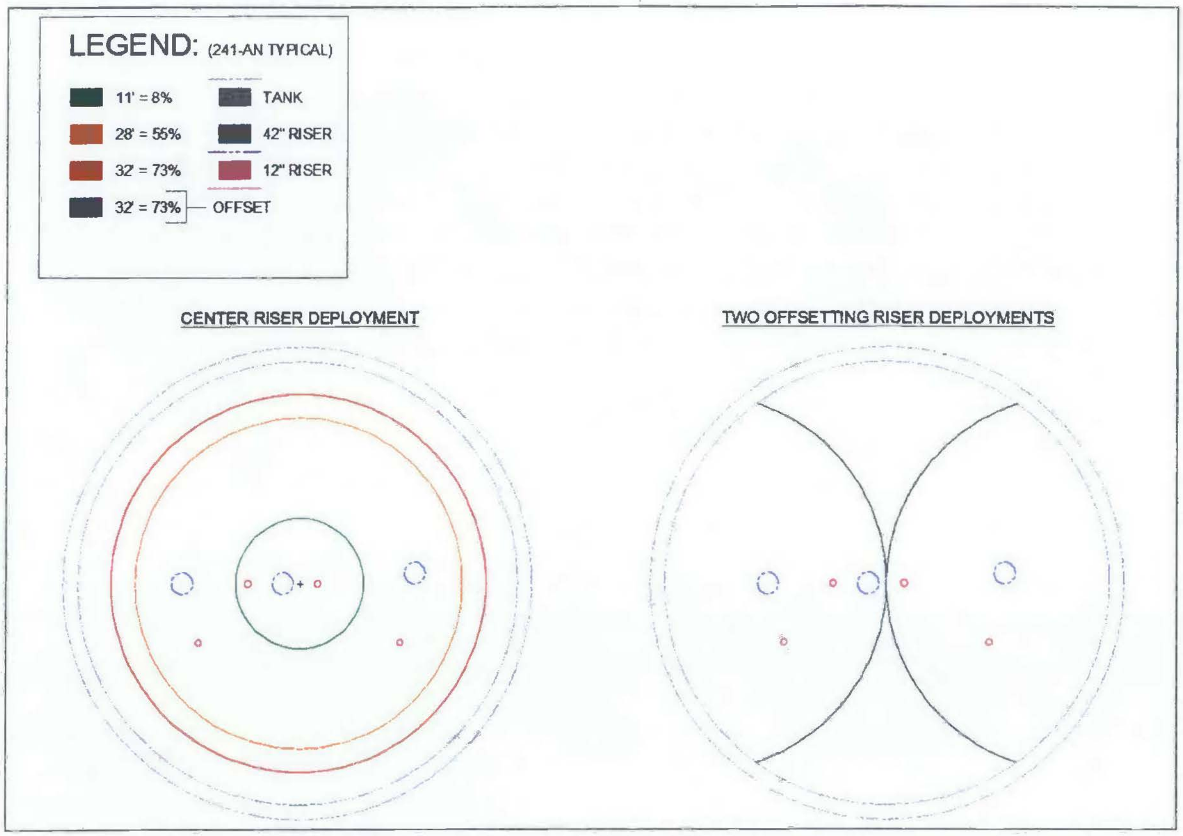
$$Required\ fraction\ degassed\ =\ 1-\frac{100\%}{\%LFL_{50\%\ Retained\ Gas}}$$

where the denominator in the fraction is the percent of the LFL calculated to result from an instantaneous release of 50% of the retained gas.

The degassing process would initially be performed in small and measured steps with adequate monitoring to ensure flammable gas concentrations are maintained well below the LFL throughout. After the initial process, tank waste levels would be monitored to detect a gas buildup requiring another degassing step.

Equipment to disturb the waste and release the gas would be inserted into the tanks through existing risers. For effective degassing, a selected technology must have a sufficient effective range. Figure 2-1 illustrates the range required on a generalized plan view of a typical DST. Two configurations were considered; a central installation in one riser, and off-set installations in two risers. A horizontal range of 28 ft. (orange line) in a central riser is necessary to affect 55% of the volume assuming the range is uniform vertically. This is more than enough to effectively bring a tank to safe levels.

Figure 2-1 Spheres of Radial Influence with One Versus Two Deployment Locations



3.0 METHOD FOR CHOOSING TECHNOLOGY OPTIONS

Technology options were categorized in a table describing how they could potentially change gas generation and retention behavior in the tanks toward a more favorable safety environment. The practical mechanisms regarding how the technologies worked and could implement these changes were critically evaluated by the team. Additionally, any prior history with the various mechanisms was evaluated in context. For example, in-tank mixing targets the mechanical properties of the waste. High powered mixing was successfully used in the past to reduce gas retention for a time, but in the long term, it resulted in undesirable changes to gas retention behavior. Future mixing technologies must consider a different operating regime over the lifecycle of the DSTs to be successful. In the case of dilution, dilution permanently alters the waste to reduce the retention of flammable gas, but increases overall tank volume and reduces headspace. DST storage space is at a premium and will not be freely available. Less mature technologies that did not generate additional waste volume or change waste properties undesirably were given credit, provided the maturity window was within the near-term (approximately 4 years).

The technology evaluation method for degassing settled solids involved several steps:

1. A focused literature search and review of DOE-centric applications emphasizing the Hanford Site, the Savannah River Site (SRS), and the Oak Ridge National Laboratory (ORNL) was performed,
2. Input was solicited from other related commercial and government organizations with similar challenges,
3. Internet searches, in-person discussions, and electronic communications were performed as part of developing a framework for discussion during an elicitation and selection meeting.

3.1 TECHNOLOGY OPTIONS AND CATEGORIES

Generally, the technology options were categorized by describing the features of hydrogen generation and retention. Plausible actions that focused on changing those conditions toward a more favorable safety environment were then considered. For example, mixing or moving waste targets the mechanical properties of the waste and waste environment. Waste transfers would be performed specifically to dilute or alter the distribution of flammable gas-generating or retaining waste inventory; or increase headspace volume among tanks. Dilution alters the waste to reduce the retention of flammable gas, but can increase overall tank volume, reducing headspace.

Each option was viewed within a broad range of constraints and opportunities. Options at this point were not precluded from consideration because even impractical ideas at this stage could be recast or combined into better approaches with the appropriate input.

Constraints:

- Maintain structural integrity of tank and instrumentation
- Maintain the headspace flammable gas concentration below the LFL at all times
- Minimize generating additional waste volume

- Maintain waste compatibility
- No adverse changes in gas retention behavior (e.g., no creation of bubble slurry, no increase in settled solids depth)
- Maintain tank temperature within operating specifications

Opportunities:

- Waste does not have to be fully or continuously mobilized to release retained gas. However, the minimum waste volume to be mobilized and frequency of mobilization needs to be quantified.
- Retrieval and waste management activities provide potential opportunities to adjust/redistribute tank inventories to reduce the flammable gas hazard.
- Retrieval and waste management activities provide potential tank infrastructure upgrades to release flammable gas under control. Waste mobilization as part of a flammable gas mitigation strategy requires many of the same types of controls, surveillance techniques and supporting structures, systems, and components as full-scale retrieval. These types of options could be considered within the context of an accelerated retrieval schedule.

Thirty of the options that were considered emerged as initial candidates meriting further discussion. This initial group covered a wide range of technical approaches (physical, chemical, operational; combination). However, the goal of this effort was to finally limit the recommended technologies to no more than five of the most promising candidates.

After focused discussions, an initial screening was performed to narrow the selection to a Yes/No decision. A seven-point list of criteria was developed for the screening process, consisting of:

1. **Point of Application:** Deployed in-tank with minimal external interfaces
2. **Maturity:** Proven in similar conditions/missions or previously developed for use at the Hanford Site
3. **Simplicity:** Few moving parts, ease of installation and use, reliability
4. **Dependency:** Whether the 'Option' relies upon another site program or system
5. **Applicability:** Number of tanks the technology might be applicable to
6. **Secondary Effects:** Results in changes to tank space or more waste generation
7. **Effective Range:** Surgical versus general impact on tank contents

3.2 EVALUATION PROCESS

Each of the thirty candidates was assigned a recommendation of: Yes-1, Yes-2, or No. The "No" conclusion was applied where the group thought the technology should not be considered further as it had one or more fatal flaws to effectively mitigate the risk. A "Yes-1" or "Yes-2" conclusion was applied where the group believed the candidate option had no apparent fatal flaws. More specifically, the Yes-1 had some significant merit in one or more categories that showed particular advantages.

Actions or capabilities of other projects were not considered; selections were based on their ability to directly address flammable gas retention. However, inter-project dependencies (or leverage) were considered in the choosing between recommendations Yes-1 and Yes-2, where addressing flammable gas retention could be considered in the larger context of waste feed delivery.

In making the final selection, the consensus was that several technologies represented variations on a theme, rather than a distinctly different method of addressing flammable gas retention. The summary table of the screening data is provided in Appendix A. These variations were consolidated and the evaluation is based on a 'flagship' technical method that embodies the most qualified solution in that category.

3.3 SAFETY BASIS IMPLICATION DETERMINATION

This report is not intended to comprise a formal major modification determination or evaluation as described in DOE-STD-1189-2008, *Integration of Safety into the Design Process*. A separate evaluation will be required for any selected alternative. However, a brief description of the determination process is provided to allow a relative comparison of the level of safety basis effort required for the five options as part of the evaluation in Section 4.0.

DOE-STD-1189-2008 provides six evaluation criteria for use in determining whether a proposed change to an existing facility is a major modification. These criteria are listed below.

1. Does the modification add a new building or facility with a material inventory greater than or equal to Hazard Category 3 limit or increase the hazard category of an existing facility?
2. Does the modification change the footprint of an existing Hazard Category 1, 2, or 3 facility with the potential to adversely affect any safety class or safety significant safety function or associated structure, system, or component?
3. Does the modification change an existing process or add a new process resulting in the need for a safety basis change requiring DOE approval?
4. Does the modification utilize new technology or government furnished equipment not currently in use or not previously formally reviewed or approved by DOE for the affected facility?
5. Does the modification create the need for new or revised safety structures, systems, or components?
6. Does the modification involve a hazard not previously evaluated in the Documented Safety Analysis?

The WRPS contract requirements include implementation of DOE-STD-1189-2008 for new stand-alone projects and major facility modification projects (Contract Number DE-AC27-08RV148000). Therefore the six evaluation criteria provide a reasonable basis for concluding that a proposed modification will have a major impact to the existing safety basis documentation, and require significant safety basis development work.

This safety basis development work, as defined in DOE-STD-1189-2008 and as governed by the WRPS procedural infrastructure, includes the performance of hazards analysis, accident analysis, and control selection, and development of a Safety Design Strategy, Conceptual Safety Design Report, Preliminary Safety Design Report, and Preliminary Documented Safety Analysis. These safety basis documents are approved by DOE at the appropriate stage of design in order to ultimately obtain authorization for procurement and construction.

Prior to obtaining authorization for operations, the Documented Safety Analysis and Technical Safety Requirements must be updated and approved by DOE. These processes are governed by existing WRPS procedures:

- TFC-ENG-DESIGN-C-47, *Process Hazards Analysis*
- TFC-ENG-DESIGN-C-45, *Control Development Process for Safety-Significant Structures, Systems, and Components*
- TFC-ENG-DESIGN-P-43, *Control Development Process for Safety-Significant Safety Instrumented Systems*
- TFC-ENG-SB-C-06, *Safety Basis Development*

Proposed activities or processes that can be anticipated to result in a positive Unreviewed Safety Question Determination (USQD), and therefore a change to the safety basis that would require DOE approval, but which not otherwise be defined as a major modification or as subject to the requirements of DOE-STD-1189-2008, will be defined as having a moderate impact to the existing safety basis.

Proposed activities that can be anticipated to result in a negative USQD, such that any identified change to the safety basis would not require DOE approval, will be defined as having a minor impact to the safety basis.

4.0 OPTIONS SELECTED AND DETAILED DESCRIPTION

The five options resulting from the initial screening are provided here, in no particular order of priority or preference.

- **Option 1–Mixer Pump:** Configured as either a submersible pump and drive motor in the tank, or a drive motor outside the tank and pump inside the tank rotated by a long shaft.
- **Option 2–Pulsed Air Mixer:** Demonstrated at the Oak Ridge National Laboratory and tested in limited extent for Hanford Site DST application.
- **Option 3–Pulse Jet Mixers:** Includes two pulse jet mixing system configurations: one designed by AEA Technology of the United Kingdom, and an in-tank Russian pulsation mixer pump (PMP).
- **Option 4–Sonic Agitation:** Conceptually similar to a previous Tank SY-101 evaluation (WHC-SD-WM-ER-164, *Tank 101-SY Hydrogen Mitigation by Low Frequency Vibration, Rheological Analysis and Feasibility Assessment*).
- **Option 5–Existing Technologies and Waste Management Techniques:** Implement operations, equipment, and proven techniques already in place on the Hanford Site. This option is presented as a potential option; however, given its wide scope of potential actions, it was not specifically addressed as with the other four options.

Sections 4.1 through 4.5 provide descriptions of the selected options. For Options 1 through 4, descriptions of technology functionality, development status, deployment configuration, constraints, ROM costs and schedule estimates, and safety basis, are given. Option 5 is not considered in full depth of analysis, but is described in limited detail.

The common ROM estimating bases and assumptions for the implementation costs and schedules figures include:

- Costs and schedules to implement are ROM estimates using best available data from technology vendor-provided estimates, subject matter expert (SME) interviews, published DOE and DOE contractor reports, and WRPS internal sources.
- In general, costs are based on implementation of one technology unit (e.g., a single mixer pump) per tank, unless specifically noted. Best available data, such as from previous demonstrations and deployments, was used to suggest where more than one unit may be required to release retained gas in a single tank application. Further empirical test data will result in refinements and confirmation of these estimates.
- Costs specific to design and construction for each option are based on 2011 estimates for Tank AY-102 mixer pumps as previously planned at the Hanford Site for mixing and mobilization for the retrieval mission (WRPS 5.3.2.13.2 and 5.3.2.6.5.4, respectively).
- "Project Support" and "Other Costs" for each option entail provisions for project support staff for a 4-year duration (WRPS Project Manager basis is a 0.5 full-time equivalent) and permitting from Washington State Department of Health and Washington State Department of Ecology (WRPS 5.3.11.1.1.1, 5.3.11.1.1.2, 5.3.11.1.1.4, 5.3.11.1.1.6, and 5.3.11.1.1.9).

- All costs are presented in 2014 dollars. For cost data sources predating 2014, the Consumer Price Index, as published by the Federal Bureau of Labor Statistics, was used to escalate costs to 2014 dollar values.
- Cost estimates assume some use of existing Hanford Site Tank Farm infrastructure where available. Some technologies include self-sufficient utility sources, such as compressed air, and are described as necessary when provided by vendor.
- Costs portrayed in this report section are for initial implementation in a single, first tank. Costs are typically highest for the first implementation. Once baseline testing, permitting, designs, vendor qualifications of equipment specifications (such as commercial grade dedication), safety basis documentation, and other common baseline requirements are completed, subsequent deployment costs will be significantly reduced overall. Initially costs to procure capital equipment are relatively small compared to these other common, front-end-loaded, baseline costs. After numerous tank implementation procurement cycles, equipment costs, and labor costs will represent a relatively higher part of the total because the marginal costs associated with equipment qualification and set-up are reduced.
- Development of infrastructure and facilities to maintain radiological contaminated equipment were not included in the cost estimates. Installed equipment for options 1 through 4 would require maintenance and repair during the mission.

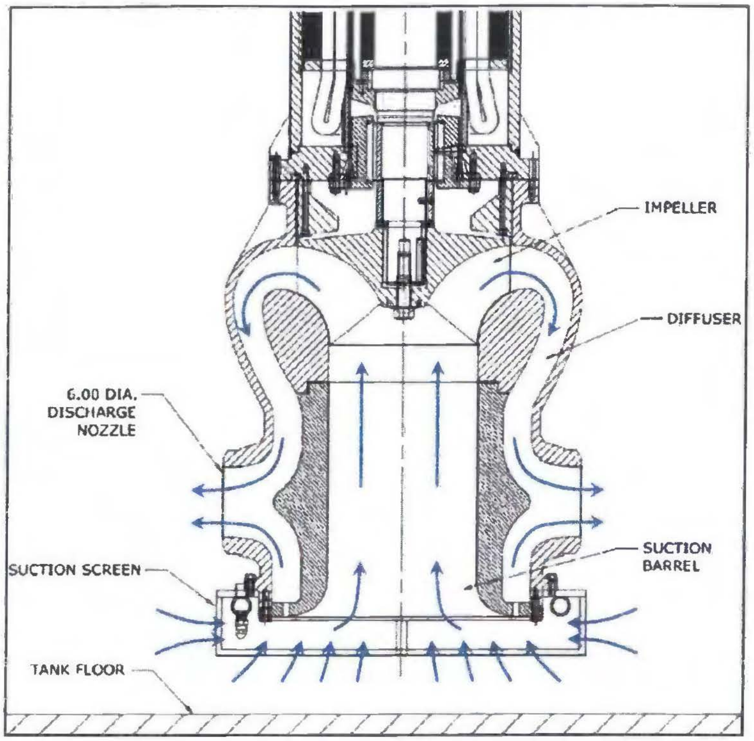
4.1 OPTION 1–MIXER PUMP

Mixer pumps, also referred as submersible mixer pumps (SMPs), use a high-velocity fluid jet to mobilize and suspend the solids in the settled solids layer when the drive motor is submersed in the tank. They operate by acquiring fluid through a bottom suction port and discharging the fluid horizontally at high speed through opposed nozzles. As the solids bed is mobilized by breaking away large pieces and/or eroding the bed surface, the retained gas bubbles therein are released. Periodic operation of one or two mixer pumps installed in the settled solids layer can effectively reduce the overall flammable gas inventory.

Figure 4-1 shows internal circulation in a mixer pump. Process fluid is drawn into the bottom of the mixer pump through an inlet suction screen and discharged through two diametrically opposed nozzles machined in the pump-motor casing. The inlet screen is designed to prevent large objects from entering and potentially damaging the pump internals, and to control vortex formation at the pump inlet. The pump-motor assembly mounts at the end of a long mast. The entire assembly rotates on a slewing gear allowing the jets to sweep horizontally around the waste tank. Mixer pumps are designed to be suspended vertically in a tank through a large riser and permanently submerged in the process fluid.

Submersible mixer pumps are considered a mature technology and have been successfully used to mobilize and retrieve waste from four waste tanks at SRS (Davis and Stover [2007], *Waste on Wheels Bulk Waste Retrieval System a Program for Accelerating Waste removal from Savannah River Waste Tanks*). At the Hanford Site, the waste feed delivery system is planning to use SMPs in combination with transfer pumps to mix and transfer batches of waste to the Hanford Tank Waste Treatment and Immobilization Plant (WTP).

Figure 4-1 Typical Mixer Pump

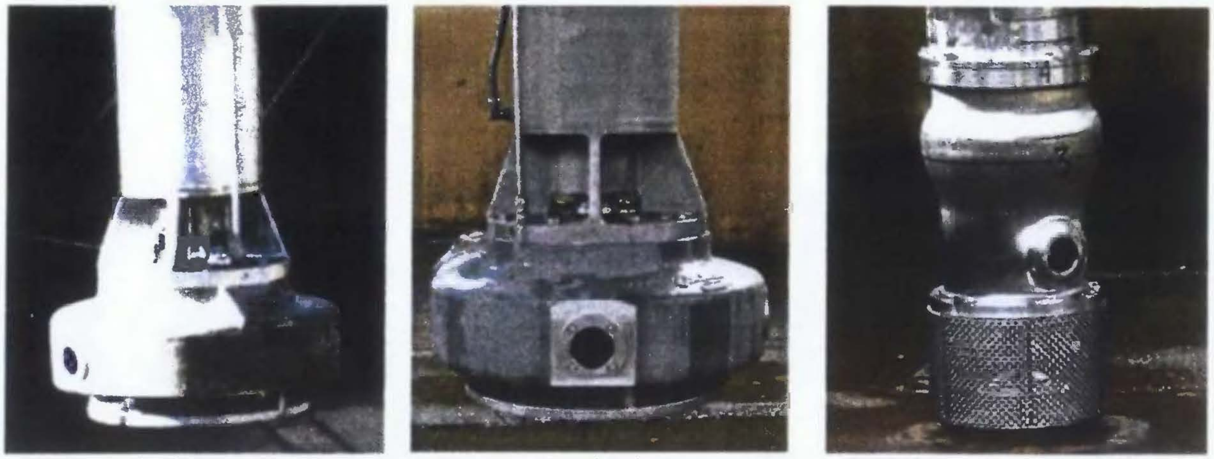


Curtiss-Wright Electro-Mechanical Corporation of the Curtiss-Wright Flow Control Company specially designed and manufactured SMPs for use in SRS waste tanks, and has also designed a Hanford SMP. In these designs the drive motor and the pump are coupled and submersed in the tank. The SRS pumps are rated at 7600 gpm and are driven by a close-coupled 305-hp electric motor (Figure 4-2) mounted on a long mast. The Hanford SMP is a 10,400-gpm pump using a 367-hp electric motor. It is designed to operate in the high-dose radioactive process fluid for a minimum of 10,000 hr of intermittent operation at 100% rated capacity with minimal maintenance. Operation of a Hanford SMP is similar to the SRS submersible mixer pump. However, no Hanford SMPs have been fabricated, tested, or operated to date.

Beside successful deployment of SMPs at SRS, other mixer pump configurations have been used at Hanford to mitigate gas releases in Tank SY-101 (PNL-9959, *Mitigation of Tank 241-SY-101 by Pump Mixing: Results of Full-Scale Testing*), and to test sludge mixing in Tank AZ-101 (RPP-6548, *Test Report, 241-AZ-101 Mixer Pump Test*; PNNL-17043, *Initial Investigation of Waste Feed Delivery Tank Mixing and Sampling Issues*). The Tank SY-101 mixer pump was a spare mixer pump for the Hanford Site Grout Program and was modified for Tank SY-101 deployment. In contrast to an SMP shown in Figure 4-1, the Tank SY-101 pump suction was at about the 260-in. elevation that remained in the supernatant and the jet nozzles were at 28 in. above the tank bottom (PNL-9959). The Tank AZ-101 mixer pumps design in-take fluid suction from the tank bottom and jet nozzles configurations were similar to the SMP design. However, each Tank AZ-101 mixer pump drive motor was outside the tank with pump rotated by a long-shafted turntable.

In addition to SMP configuration, a long-shafted mixer pump, referred as the standard slurry pump or conventional mixer pump shown in Figure 4-2, is also currently used at SRS for waste retrieval and has been used to mobilize waste for retrieval in at least eight SRS waste tanks. These 1200-gpm pumps, driven by a 150-hp electric motor, represent a design developed in the 1970s; they are a robust and widely used technology. The operational concept is similar to the SMPs except the motor is located above the waste on top of the tank. The pump connects to the motor with a long shaft through a liquid-filled column. The column is pressurized with water to prevent the migration of contamination up the spinning shaft and outside of containment. For the submerged motor configuration, the motor must be hardened to withstand submerged conditions within a high radiation field. In both configurations, the pump body is rotated on a slewing bearing, which causes the jet streams to sweep transversely.

Figure 4-2 Mixer Pump Configurations Used at the Savannah River Site



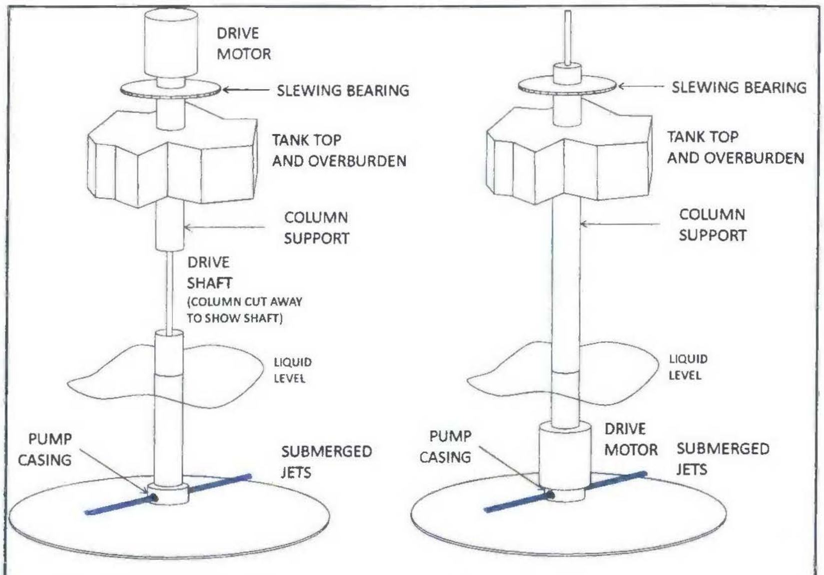
Standard Slurry Pump *Quad Volute* *Submersible Mixer Pump*

Figure 4-3 illustrates the following two mixer pump design configurations:

- Long-shafted mixer pump, the standard slurry pump
- Submersible mixer pump

As shown in Figure 4-3, the pump is driven by a top-side motor connected with a long shaft in the long shaft (slurry pump) configuration or is a directly coupled motor submersed in the tank in the submersible mixer pump configuration. For the long shaft configuration, the shaft is supported by intermediate bearings inside a pump column that is pressurized with water (or air) to prevent contamination migration to the tank top. For the submerged motor configuration, the motor must be hardened to withstand submerged conditions within a high radiation field. In both configurations the pump body is rotated on a slewing bearing, which causes the jet streams to sweep transversely.

Figure 4-3 Two Design Configurations of Mixer Pump in Parallel Comparison



Long Shaft Configuration
Drive motor outside of tank with pump rotated by long shaft

Submerged Motor Configuration
Drive motor directly coupled to pump with motor submerged in waste

The application for mixer pumps in this report is to periodically mobilize and suspend settled solids in the DSTs; the pump would be operated initially to release retained gas in a controlled manner and then subsequently operated to prevent large gas releases that could exceed the LFL. The effectiveness of mixer pumps in releasing retained gas within the waste bed depends on the waste properties, pump size, number of mixer pumps in the tank, pump location, and duration of mixer pump operation.

4.1.1 Deployment Options

This evaluation does not consider mixer pump performance and configuration for maximum effective cleaning radius (ECR) or retrieval of tank waste. However, considerations for predicting the ECR are similar to estimating the percentage of waste volume disturbed sufficiently to release retained gas. The option of using a single mixer pump at a higher horsepower in a tank central riser or pump pit is depicted Figure 4-4 as compared to installing two (or more) smaller mixer pumps in off center risers is shown in Figure 4-5.

The option of one large mixer pump such as a 300- to 600-hp centrifugal SMP assumes a design similar to the 300-hp, 7600-gpm, SRS submersible pumps, or a larger Hanford SMP (10,400 gpm) using a 367-hp electric motor installed in central riser or the pump pit. In both the SRS and Hanford Site designs, the SMP has a 32 in. diameter inlet at the bottom and two 6-in. diameter, D, nozzles with the jet center-line 9 in. above the inlet. The expected exit jet velocity, U_o, is 60 ft/s (18.3 m/s) and the U_oD is assumed to be 29.5 ft^2/s. The ECR of SMP in SRS tanks was estimated to be 52 ft. in SRS sludge waste (V-ERS-G-0003, *Waste removal Technology Baseline: Technology Development Description*).

An undisturbed settled solids layer of SRS PUREX (plutonium-uranium extraction) sludge is estimated to have shear strength on the order of 200-500 Pa at 30-40 wt% solids, with an expected shear strength up to 2000 Pa or greater for sludges with wt% solids greater than 50% (V-ESR-G-00003, *Waste Removal Technology Baseline: Technology Development Description*). With similar salt slurries or sludge shear strength waste in a Hanford Site DST, a single 300-hp mixer pump at tank center would be capable of a 25-ft reach leaving a 12-ft ring of solid waste remaining around the periphery. This would directly disturb and release gas from roughly 50 vol% of the waste. An additional volume of the settled solids would slump into the disturbed region releasing additional gas.

Figure 4-4 Single 300- to 367-hp Mixer Pump in Central Riser

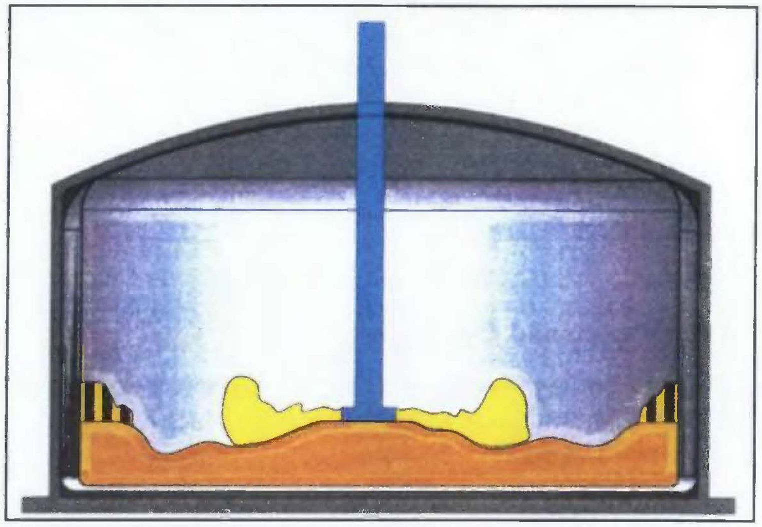
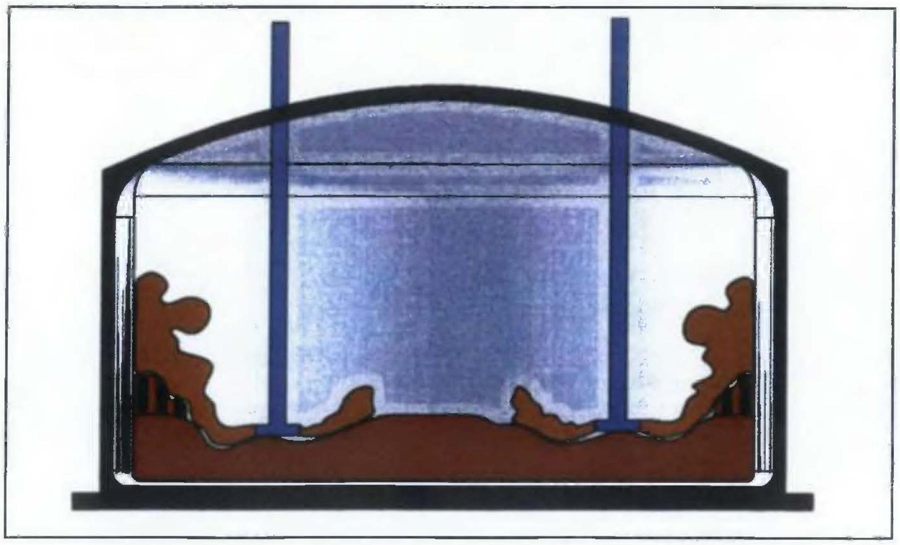


Figure 4-5 Two 150-hp Mixer Pumps in Outer Risers



The two-pump option assumes mixer pumps similar to SRS 150-hp standard slurry pumps at 1200 gpm. The pumps would be installed in two diametrically-opposed outer risers 22 ft from the tank center. The 150-hp standard slurry pumps were used in tanks with less than 24 in. risers at SRS. The expected U_oD is estimated to be 13.6 ft^2/s and the ECR in SRS tanks is approximately 32 ft (V-ESR-G-00003) based on a 200-500 Pa waste shear strength.

The number of risers of 20 in. or greater diameter in Hanford DSTs is listed in Table 4-1.

Table 4-1 Double-Shell Tank Risers 20 in. or Greater

Tank Numbers	Numbers and Sizes of Risers ≥ 20 in.
AN-101 – AN-107	3 x 42 in.
AP-107	4 x 42 in.
Remaining AP Tanks	3 x 42 in.
AW-101 and AW-102	3 x 42 in., 1 x 36 in., 2 x 20 in.
AW-103 – AW-106	3 x 42 in.
AY-101 and AY-102	3 x 42 in., 4 x 34 in., 1 x 20 in.
AZ-101 and AZ-102	7 x 42 in., 1 x 20 in.
SY-101 – SY-103	3 x 42 in., 2 x 20 in.

4.1.2 Waste Type Application and Constraints

Mixer pumps are a robust technology with broad industry acceptance and previous application in the Hanford Tank Farms. Mixer pumps are able to remove/reduce retained gas under all tank waste configurations described in Section 2.3. Prospective leverage of this technology with other Hanford projects exists.

In general, the overall cost and potential effectiveness associated with mixer pumps is dictated by supernatant and settled solids layer depths and shear strength. Tanks with a crust and deep sludges would require a cavity or passage be excavated through the solids to receive the pump column before installation. Testing to determine the ECR as a function of the settled solids shear strength and mixer pump U_oD parameters on scaled tank configurations may be needed to determine the power and number of mixer pumps.

Another constraint in using mixer pumps in DSTs is interference of mixer pump deployment and operation in the presence of air lift circulators (ALCs). Tanks with ALCs are listed below:

- AN-107: 21
- AY-101, AY-102, AZ-101, and AZ-102: 22 per tank
- AW-102 and SY-102: 2 per tank

4.1.3 Estimated Implementation Costs and Schedule

Estimated ROM costs and schedule to implement have been assembled to show expected effort needed to implement this option. These costs are based on mixer pump installations at the Hanford Site for mixing tank waste. It is assumed that certain design and physical modifications would enable use of these pumps to release retained gas as described above.

The mixer pump as used for the present mission at the Hanford Site indicates that it could be expedited for a new mission of flammable gas mitigation through mixing action based on its initial mission of mixing to effect mobilization for retrieval activities.

A testing program to satisfy engineering and safety at the Hanford Site would be required prior to implementation. The test program staff would need equipment and operation-specific training. Transfer of waste to make room for equipment and some tank risers may require modifications or preparations to accommodate installation of the mixer pumps. Preparation for installation may also include removal of some already installed equipment to accommodate the mixer pumps depending on the tank, design, and deployment configuration. The field operation would be an intensive and focused activity, but relatively short in duration. Operation of this equipment would likely be intermittent, punctuated by review of efficacy, not a continual operation.

Procurement of a single set of mixer pumps with required associated peripheral equipment, not already part of the existing Hanford Site Tank Farm infrastructure is estimated at $2807K for the first tank. (Basis of Estimate [BOE]: 5.03.02.06.06.02 AY-102 Mixer Pumps). This estimate assumes two 300-hp pumps. Some initial evaluations, as discussed in the Deployment Options section above, indicate that one 300-hp pump or two 150-hp pumps might be adequate to achieve the desired gas release, and cost savings could be realized. The baseline estimate of twin 300-hp pumps is shown in the cost basis (Figure 4-6).

Figure 4-6 Rough-Order-of-Magnitude Cost and Schedule Estimate to Implement ($K)

Year 1	Year 2	Year 3	Year 4	
General Project Support				
Management			499	**1,753**
Permitting			18	
Technology Readiness Assessment			1,236	
Design	1,390			**1,390**
		Procure 2,807		**2,807**
		Construct		**12,400**
			Total	**18,350**

4.1.4 Safety Basis Implications

Mixer pump installation and operation was previously examined by WRPS Nuclear Safety, as documented in RPP-49053, *Safety Design Strategy for the Waste Feed Delivery Integrated AY-102 Upgrades Project.* The major modification evaluation documented in RPP-49053 concluded that mixer pump operation would add a process or activity not authorized in the existing safety basis. This would result in the need for a safety basis change requiring DOE approval, and would also create the need for new or revised safety structures, systems, or components, thus constituting a major modification.

Based on the design available at the time of evaluation, mixer pump operation was determined to require new safety significant systems, new specific administrative controls, and development of a tailored suite of DOE-STD-1189-2008 safety basis documentation. Although development of new or revised mixed pump design information would require new evaluation and development of new safety basis documentation, the conclusions derived in the previous evolution are considered a valid basis for the determination that the safety basis impact of this option is defined as major.

4.1.5 Technical Viability

The mixer pump is planned to disturb the waste and initiate periodic small-scale gas releases that will reduce the overall inventory in the tank so that in a triggering event, such as an earthquake, insufficient gas remains to reach the LFL in the tank headspace even if all the waste were disturbed (50% retained gas release fraction assumed). Waste characteristics vary from tank to tank and will dictate how the initial degassing will be effected to prevent sudden releases above the 25% LFL during operation and how the pump system will be operated to maintain lower gas accumulations. Each small-scale release is intended to remain well below 25% of the LFL.

However, depending on the degree of confidence in the waste surveillance data and tank modeling, there remains an opportunity for the mixer pump itself to unintentionally trigger a larger than anticipated gas release. Thus, this option needs to consider:

1. What fraction of the retained gas must be initially released to reach the LFL
2. The system will initially be started very gently, in stages, with only gradual increases in mixing intensity and duration
3. Only one mixer pump will initially be operated at a time in multi-mixer installations
4. Gas monitoring will allow mixing to be shut down if flammable gas concentrations begin to rise faster than expected
5. Quantifying the routine operating basis for maintaining the retained gas volume below the LFL once the initial gas release goal is achieved

Improved surveillance instrumentation and understanding the scale of the mixer pump's effectiveness in the various tank environments, especially the range of supernatant to settled solids layer depths will be essential in applying this option.

The installation and operation of a mixer pump provides an increased chance of an inadvertent release of waste from a tank. Some of the DSTs considered for mitigation have deep settled solids layers that will require significant waste intrusive staging and preparation before installation can occur.

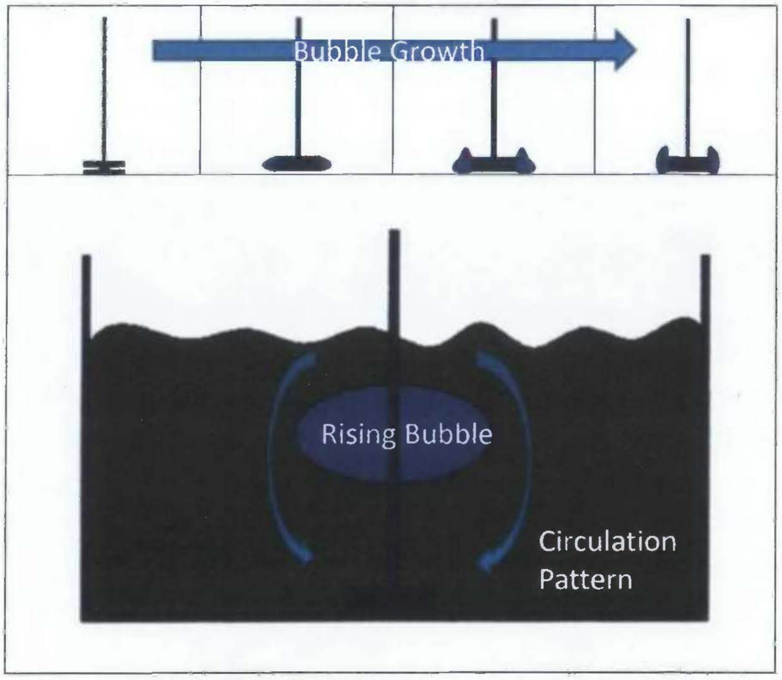
4.2 OPTION 2–PULSED AIR MIXER

Pulsed air mixing applies timed pulses of compressed air or inert gas (as opposed to continuous flow sparging) to introduce large air bubbles into the waste through the gap between pairs of circular accumulator plates. These plates are near the tank floor and mix and suspend settled solids in the supernatant. Periodic operation of an array of pulsed air accumulator plate pairs can disturb the waste to effectively reduce the overall flammable gas inventory. These plate pairs are placed in the settled solids layer near the tank bottom at several locations. Pulsed air mixers require no moving mechanical parts within a tank.

The growth of a pulsed air bubble around the accumulator plates is illustrated in Figure 4-7. When a pulse of compressed air is supplied between the accumulator plates, the growing bubble expels liquid outward and forms a torus-shaped bubble or cloud of bubbles that grow outward beyond the edges of the accumulator plates to a maximum distance R_{pulse} from the plate center. Mixing occurs as fluid is forced up and outward by the bubble and subsequently is drawn back into the low-pressure area under the bubble while it rises. This creates a broader circulation pattern in the surrounding fluid which produces mixing.

The waste will be mobilized by the pulsed air bubble out to a distance from the center of the plate characterized by the bubble pulse radius, R_{pulse}. The intensity of mixing depends on the pulsing frequency, pulse duration, size of accumulator plates, and gas pressure. Pulse frequency, duration, and injection pressure are adjustable by varying sequential gas injection valve actuation times.

Figure 4-7 Pulsed Air Mixing Gas Bubble Growth and Bubble-Induced Circulation Pattern



The pulsed air mixer is a commercially available technology from Pulsair® Systems Inc. of Bellevue, Washington, and is used extensively in the lubricating oil industry, municipal wastewater treatment plants, and similar applications. Throughout this section, the phrase "pulsed air mixing" refers exclusively to the mixing technology marketed by Pulsair Systems, Inc.

Limited testing of pulsed air mixing systems in a 1/12-scale DST and a bench-scale model was conducted between 1995 and 1997 (PNNL-11200, *Retrieval Process Development and Enhancements FY96 Pulsed-Air Mixer Testing and Deployment Study*; PNNL-11584, *Retrieval Process Development and Enhancements Pulsed-Air Mixing DOE Site Assessment*; and PNNL-11690, *Bench-Scale Feasibility Testing of Pulsed-Air Technology for In-Tank Mixing of Dry Cementitious Solids with Tank Liquid and Settled Solids*). These tests evaluated the effectiveness of pulsed air mixing in:

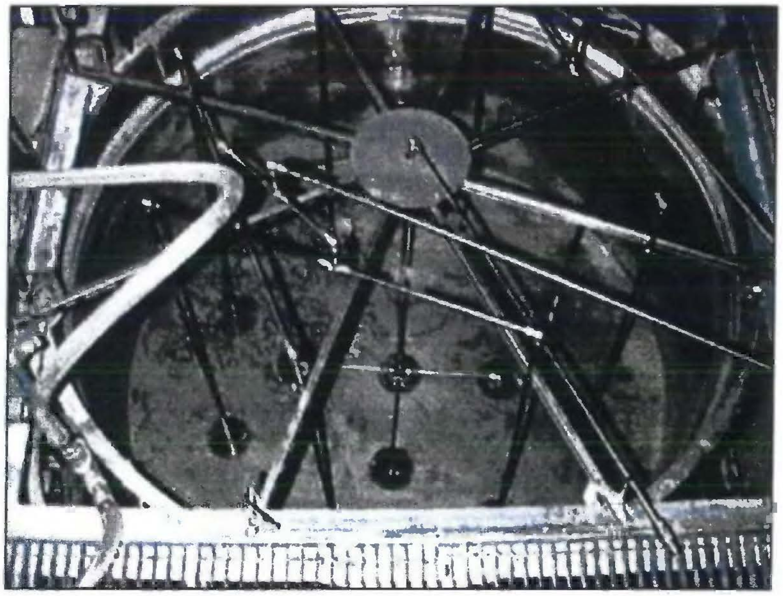
- Mobilization and mixing of waste in specific tank geometries

- Mixing of waste slurries to maintain suspension
- Mixing of grout with residual waste heels

Tests conducted in a 1/12-scale DST in 1995 showed an estimated 54 wt% of a sludge simulant with 500 Pa shear strength could be mobilized by an array of 13 accumulator plates using the tank floor as the bottom plate (PNNL-11200). Measurements at the end of testing showed a greater radius of settled solids mobilization around the center plate than the remaining twelve plates due to insufficient air supply. An estimated 80 wt% of sludge mobilization was predicted if adequate pulse pressure was distributed equally to all 13 plates.

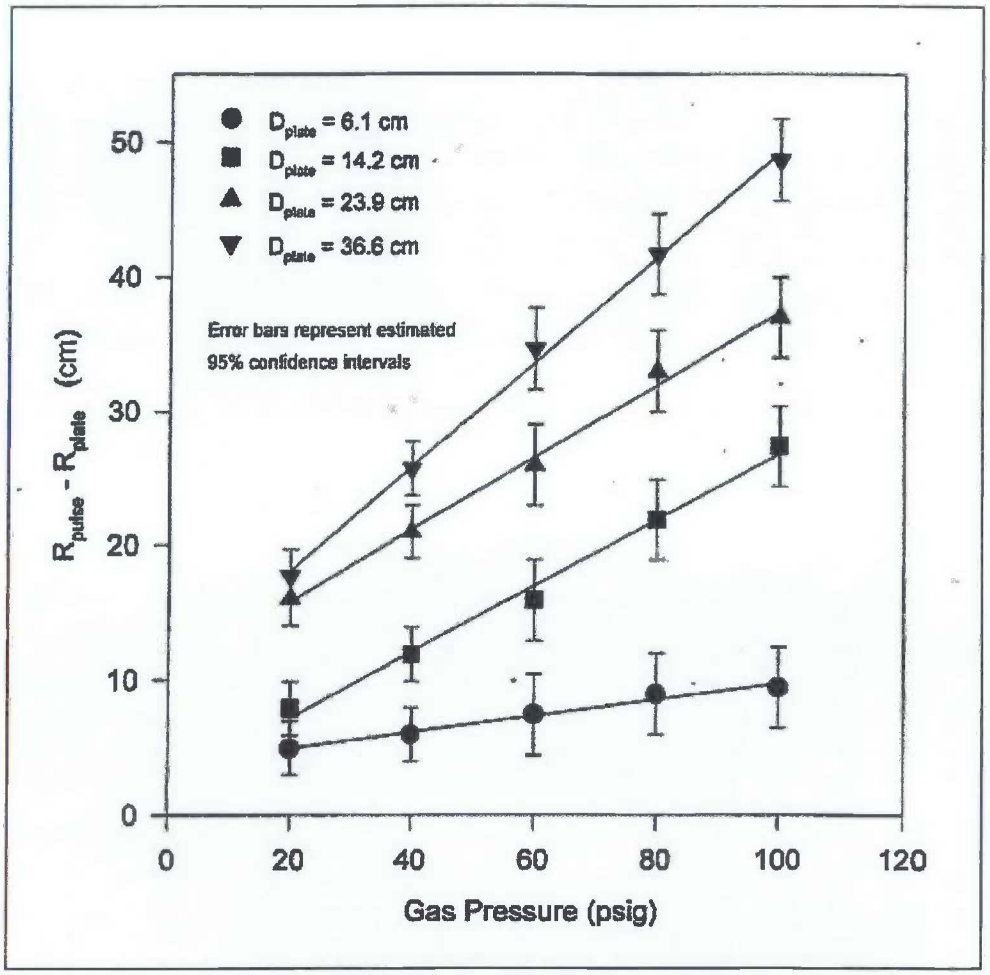
Slurry mixing tests in Kaolin clay at approximately 14.5 wt% solids (PNNL-11200 and PNNL-11584) used a similar configuration of 13 double-plate accumulators (instead of using the tank floor as the lower plate) on the floor of the 1/12-scale DST to assess suspension uniformity (see Figure 4-8). Testing was conducted with various accumulator plate sizes and gas pulse pressures.

Figure 4-8 Pulsed Air Mixing Plate Testing Installation in 1/12-Scaled Double Shell Tank



The solids suspension performance was found to be well characterized by the R_{pulse}. It was estimated that the fluid velocities within R_{pulse} were high enough to prevent solids settling and probably high enough to mobilize soft to moderately strong cohesive sludge (PNNL-11200). Testing as a function of plate size and gas pressure showed larger accumulator plate diameter and increased gas pressure both increased R_{pulse}. A plot of pulse radius versus plate diameter and pressure is shown in Figure 4-9. The pulse radius is not expected to continue increasing linearly with pressure but should reach a finite value, as the air velocity is eventually limited to the sonic velocity (about 330 m/s for air).

Figure 4-9 Pulse Radius beyond Plate versus Plate Diameter and Injection Pressure



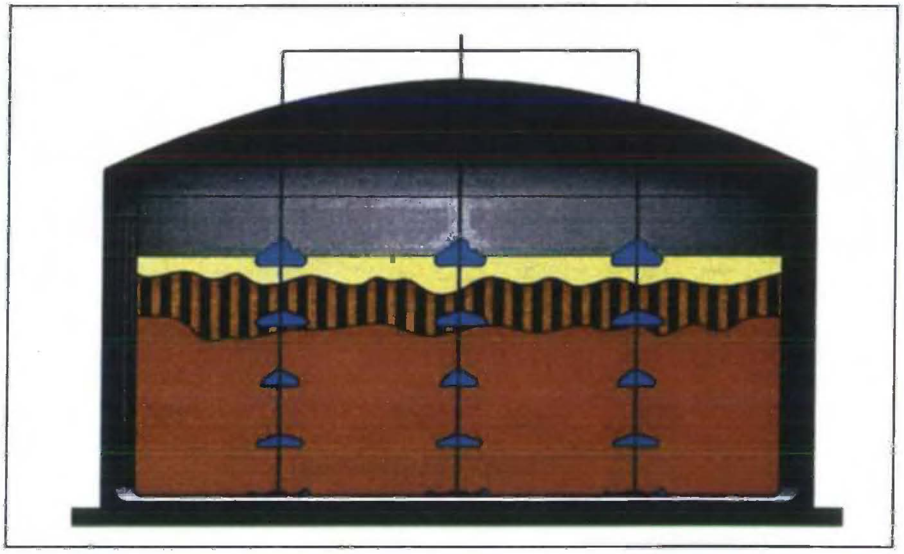
Source: PNNL-11200, 1996, *Retrieval Process Development and Enhancements FY96 Pulsed-Air Mixer Testing and Deployment Study*, Pacific Northwest National Laboratory, Richland, Washington.

A pulsed air mixer system comprised of three in-tank mixing assemblies was placed in service at Gunite™ and Associated Tanks (GAAT) Tank W-9 in June 1998 after a period of cold testing (ORNL/TM-2001/149, *Gunite™ and Associated Waste Conditioning System: Description and Operational Summary*). The GAAT Tank W-9 was used to condition radiochemical sludge slurry and supernatant from nine of the inactive Gunite tanks at ORNL. The pulsed air system was reliable, experiencing only a few non-serious failures during GAAT deployment, and operated continuously for week-long periods over 3 years. Maintaining a continuous air supply between pulses was recommended to prevent waste accumulation and clogging between plates during normal operation (ORNL/TM-2001/142/V2, *The Gunite™ and Associated Tanks Remediation Project Tank Waste Retrieval Performance and Lessons Learned*). The DOE in conjunction with Pacific Northwest National Laboratory (PNNL) and the University of Washington performed three technology demonstrations for specific use on Hanford DSTs on two scaled sizes between 1995 and 1996 (DOE/EM-0462, *Innovative Technology Summary Report—Pulsed Air Mixer*). These demonstrations resulted in successful mixing applications.

4.2.1 Deployment Options

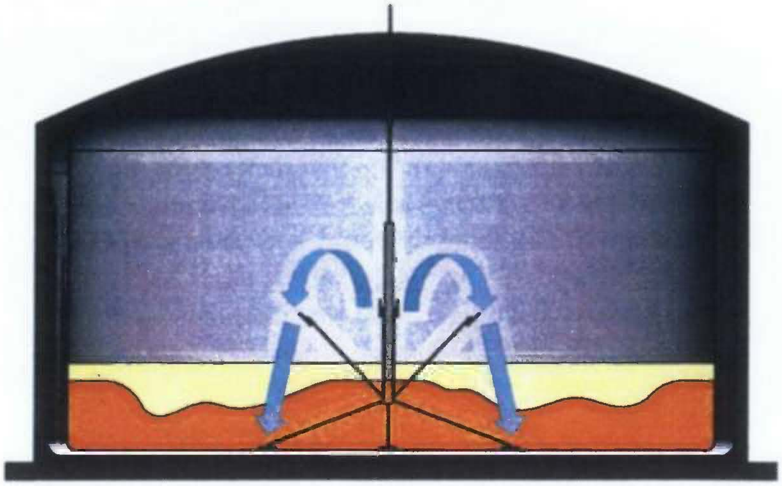
The fraction of the tank volume covered by an array of pulsed air mixers is limited by the number of available risers. Also, since the pulse radius is directly proportional to the accumulator plate diameter, it is preferable to deploy the largest possible accumulator plates that can be inserted in tank risers. In a tank with a deep settled solids layer, an array of individual accumulator plates can be lowered to the tank bottom through separate risers as shown in Figure 4-10. The plate diameter is sized close to the riser diameter to maximize bubble-pulse mixing radius. Estimation of tank inventory coverage depends on the number of available risers. There are between 3 and 8 risers available per tank and the configurations vary greatly.

Figure 4-10 Deployment Configuration in Deep Solids Layers



Alternatively, a folding telescoping configuration (Figure 4-11) of a central accumulator plate and three or four satellite accumulator plates at the ends of folding arms can be deployed through a central riser or two diagonally opposed outer risers. This design requires an unobstructed area of sufficiently shallow solids depth to allow the telescoping section to unfold above it.

Figure 4-11 Deployment Configuration in Waste with Telescopic Capacity



4.2.2 Waste Type Application and Constraints

The pulsed air mixer may be able to reduce retained gas inventory. It has been successfully applied in various industries in degassing settled solids. However, this technology is likely limited to weak, low shear-strength saltcake/slurry waste layers (shallow or deep). The pulses may not be able to establish a recirculation current needed to maintain reduced retained gas conditions with high shear strength wastes.

The telescoping configuration requires a solids layer sufficiently shallow to allow the telescoping arms to unfold. However, tanks with a low solids level generally do not retain a large gas volume and thus do not warrant additional degassing. In this case, deploying this option in tanks with low settled solids in anticipation of changing future conditions warrants consideration because of the difficulty in installation after settled solids levels increase.

The accumulator plates in the telescoping configuration, once unfolded, can only be lowered to the top of the solids layer. The pulsed air mixing action would then be expected to excavate cavities allowing the plates to be lowered further. Alternatively, a cavity could be water-lanced out prior to deployment to place the plates initially closer to the tank bottom.

4.2.3 Estimated Implementation Costs and Schedule

Rough-order-of-magnitude cost estimates have been assembled for implementing this option. Enabling assumptions include the availability of existing infrastructure adequate to support this technology. Cost information used was derived from DOE/EM-0462 (Office of Science and Technology Reference #1510) and the vendor, Pulsair Systems, Inc. These costs are based on recent implementation of pulsed air mixers at industry sites, and include experience from previous demonstrations at the Hanford Site, and deployments at ORNL used for mixing tank waste in 1999.

Operation of this equipment would likely be a periodic activity punctuated by review of efficacy, not a continual operation. Transfer of waste to make room for equipment and some tank risers may require modifications or preparations to accommodate installation.

The technology vendor, Pulsair Inc., having performed work at numerous DOE locations including the Hanford Site and ORNL, estimates capital equipment in a typical new 90-ft diameter tank costs approximately $100,000 (BOE: Pulsair Systems, Inc., 2014). An air compressor system is estimated at $10,000 and an administrative program to qualify a 'Commercial Grade Dedication' of Pulsair equipment is estimated at $246,000. The estimated system cost is based on configuration of single accumulator plates mounted to the tank bottom and formation of air pulses between the tank bottom and an accumulator plate. Additional cost to configure the system as a double plate configuration, and any telescoping format design influenced by the number of available tank risers and settled waste layer depth, are not considered in the ROM estimates.

A complete equipment system includes the air connection valve manifolds through to the discharge plates, programmable logic controller and a compressed air system. This estimate assumes that the Hanford Site Tank Farms would furnish some support utilities from existing infrastructure (not including the vendor supplied compressed air system that is part of this ROM cost). Total cost to implement a pulsed air system in a tank is shown in Figure 4-12. Further designs would need to be carried out as applied to existing tank specific specifications.

Figure 4-12 Rough-Order-of-Magnitude Cost and Schedule Estimate to Implement ($K)

Year 1	Year 2	Year 3	Year 4	
General Project Support				
Management		499		**1,753**
Permitting		18		
Technology Readiness Assessment		1,236		
Design	**1,390**			**1,390**
		Procure 356		**356**
		Construct		**12,400**
			Total	**15,899**

4.2.4 Safety Basis Implications

The installation and use of pulsed air mixers has not been previously evaluated by WRPS Nuclear Safety. Examination of this option against the evaluation criteria for major modifications indicates that the installation and use of pulsed air mixers would:

- Add a process or activity not authorized in the existing safety basis, therefore resulting in the need for a safety basis change requiring DOE approval
- Utilize new technology or government furnished equipment not currently in use or not previously formally reviewed or approved by DOE for the Hanford Site Tank Farms
- Create the need for new or revised safety structures, systems, or components

In addition, the hazards inherent to the introduction of compressed air below the surface of the solids layer in a waste tank is a hazard not previously evaluated in the Documented Safety Analysis. RPP-13303, *Tank Farm Documented Safety Analysis*, currently addresses the hazards inherent to compressed air blowout of transfer lines (primary piping and hose-in-hose transfer lines). The hazardous events identified as resulting from this activity include the release of air below the waste surface in a DST. Examination of the specific hazardous conditions documented in RPP-15188, *Hazard Evaluation Database Report*, shows a single hazardous condition dealing with an air blow accident that releases air below the surface of the supernatant waste layer in a DST; this hazardous condition is assumed to affect only the supernatant layer.

It can therefore be concluded from the limited information available that the installation and use of pulsed air mixers would constitute a major modification. Safety basis implications can be assumed to include new safety significant systems, new specific administrative controls, and development of a tailored suite of DOE-STD-1189-2008 safety basis documentation. The safety basis impact of this option is defined as major.

4.2.5 Technical Viability

Pulsed air mixing is planned to regularly disturb the waste to initiate small-scale gas releases that will reduce the overall flammable gas inventory in the tank so that in the event of a triggering event, such as an earthquake, insufficient gas remains to reach the LFL even if all the waste were disturbed (50% release fraction assumed). Each small-scale release is intended to remain well below 25% of the LFL as well.

However, depending on the degree of confidence in the waste surveillance data and tank modeling, there remains an opportunity for the pulsed air mixer itself to unintentionally induce a triggering event and release more gas than anticipated, especially during start up. Thus, this option needs to consider:

1. What fraction of the retained gas must be initially released to reach the LFL
2. The system will initially be started very gently, in stages, with only gradual increases in mixing intensity and duration (the steady release mechanism for this option does not appear to provide for a sudden release above the 25% LFL during operation)
3. Only one pulsed air mixer/array will initially be operated at a time in multi-mixer installations
4. Gas monitoring will allow mixing to be shut down if flammable gas concentrations begin to rise faster than expected
5. Quantifying the routine operating basis for maintaining the retained gas volume below the LFL once the initial gas release goal is achieved

A large portion of the supporting equipment will be located above ground within the tank farm. Above-ground structural failures have the potential to release waste, if as part of the mixing action, a path to the environment exists and material and energy can travel down that path in the event of a failure. This option uses a substantial amount of in-tank piping to accomplish its goal. However, since there is no suction phase to draw waste into this piping, the potential for release of waste through above ground portions of the system is limited.

4.3 OPTION 3–PULSE JET MIXERS

A pulse jet mixer (PJM) is an intermittent jet mixing system. Compressed air is sequentially directed through each side of a jet pump pair to supply a partial vacuum then pressure to a charge vessel or pulse tube in the following three-stage process.

1. Applying a vacuum draws a volume of tank contents into the pulse tube.
2. Air pressure then forcefully ejects the fluid back into the tank through the nozzle.
3. Air pressure is vented at the end of the fluid pulse to prevent ejection of air into the waste (termed "pressurized release") and hold the level in the pulse tube to start the next cycle.

Retained gas is released from the highly agitated and turbulent region near the PJM nozzle during jet pulsing cycle. This region is termed the PJM cavern. The size of the cavern region depends on of the applied pressure, nozzle exit velocity, nozzle diameter, and drive time, along with the rheological properties of the fluid being mixed. The transition between the cavern and the surrounding unmixed region can be very abrupt.

The fluid velocity is highest at the PJM nozzle and decreases approximately with the square of the distance from the nozzle. The wall of the cavern forms where fluid velocities are so low that the flow-induced stresses no longer overcome the shear strength of the waste. Detailed discussion about cavern formation in non-Newtonian fluids and associated scaling is described in PNWD 3551, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*.

The charge vessel and discharge nozzle can be designed as separate process units with the discharge nozzle suspended vertically in a tank through a riser and the charge vessel installed above ground as part of system support infrastructure (Figure 4-13). Alternatively, a charge vessel coupled with a jet nozzle can be suspended as a unit vertically though a tank riser of adequate diameter (Figure 4-14). Both configurations require above ground systems including the jet pump pairs, off-gas treatment and valve control system.

Figure 4-13 Operation of Pulse Jet Mixer, Charge Vessel and Discharge Nozzle Configuration

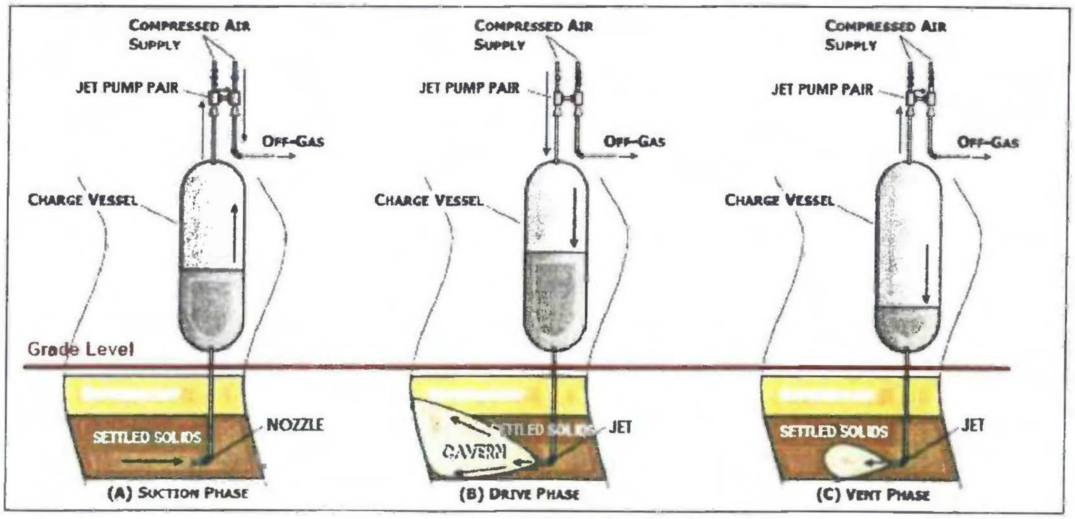
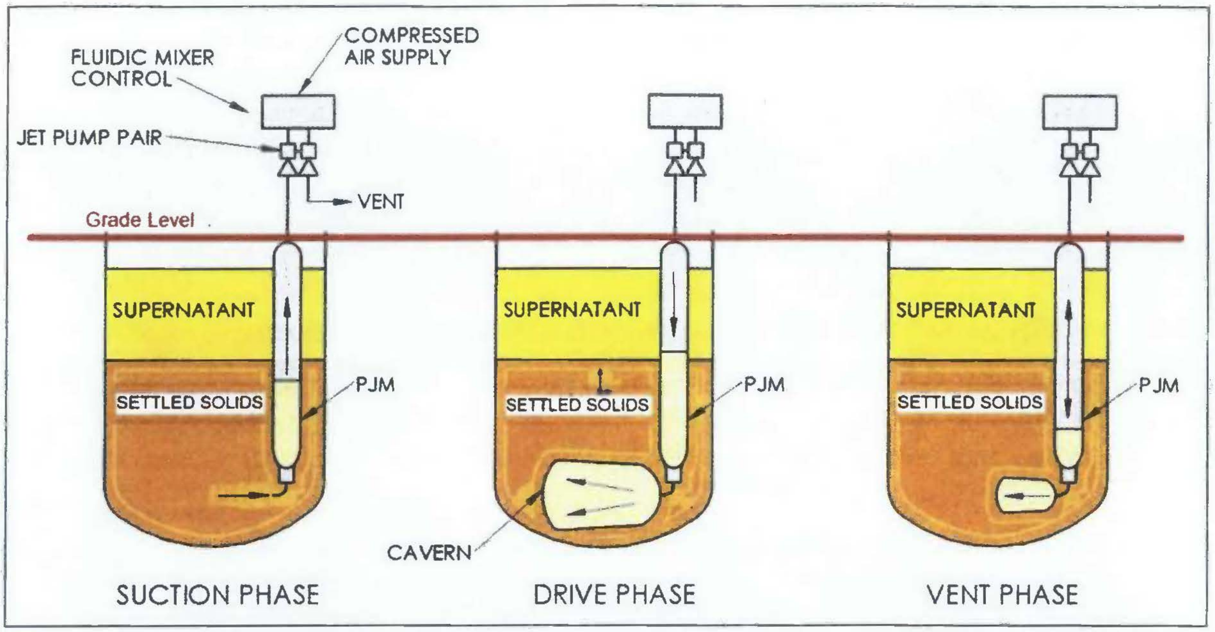


Figure 4-14 Operation of Pulse Jet Mixer, Pulse Tube Configuration



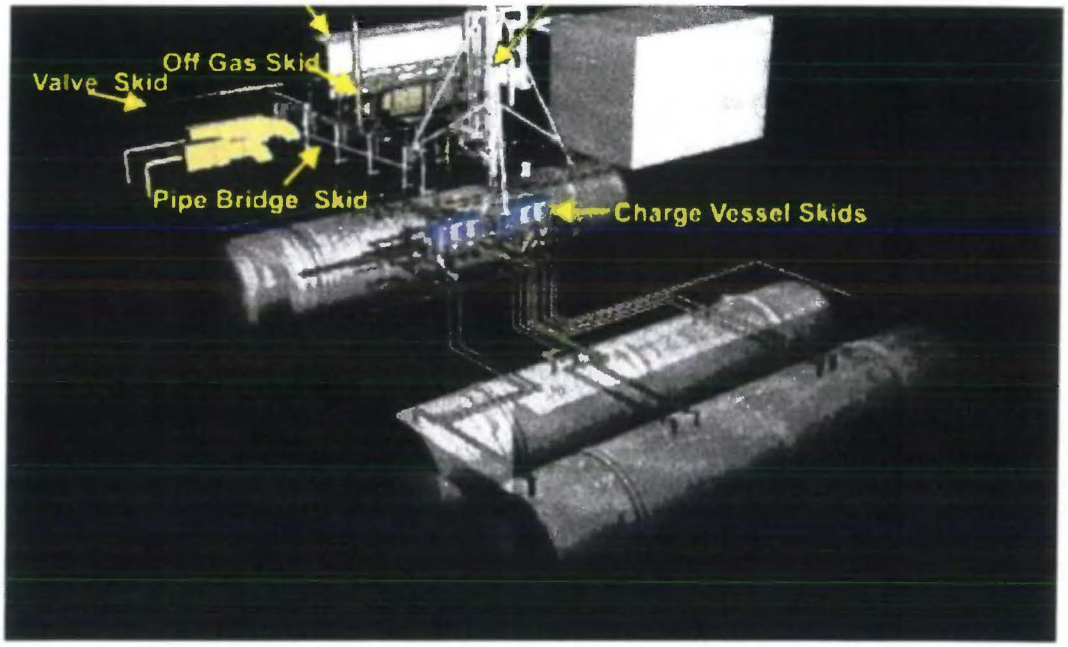
The AEA-made Fluidic pulse jet mixers (AEA PJM) are currently used in international nuclear applications for mixing radioactive liquids and slurries (DOE/EM-0447, *Innovative Technology Summary Report—AEA Fluidic Pulse Jet Mixer, Tanks Focus Area*). For example, the pulse tube configuration is used at the nuclear fuel processing plant at Sellafield in West Cumbria, United Kingdom. The AEA PJM is effective in mixing slurries that require minimal shear stress to initiate flow in the time scales of AEA PJM suctions and drives phases. In certain applications, process fluid must be added to produce flowable slurry for system operation. The PJM system has no moving parts within the tank to require maintenance.

In 1998, AEA Technology of the United Kingdom designed and fabricated a pulse jet mixing system for mobilization and retrieval of remote-handled transuranic sludge from Tank W-21, a 50,000-gal horizontal waste storage vessel at ORNL. The laboratory measurements of shear strength by shear vane system for core samples from Tank W-21 were in the range of 3.5 to 8.5 Pa (ORNL/TM-13358, *Characterization of the BVEST Waste Tanks Located at ORNL*). In contrast, the range of shear strengths in settled solids in Hanford Site DSTs is roughly 10 to 300 Pa in saltcake and 300 to 7000 Pa in sludge.

The pulse jet system demonstrated to remove Tank W-21 waste consisted of seven modular equipment skids, depicted in Figure 4-15. The operation removed about 88% of the sludge in the tank (ORNL/TM-13578, *Demonstration of Fluidic Pulse Jet Mixing for a Horizontal Waste Storage Tank*). The PJM system used fluidic jet pumps and charge vessels in above ground configuration connected with the existing in-tank piping to submerged nozzles for mixing the settled solids with existing supernatant. Pulse frequency and nozzle location were both adjusted during the removal operations.

A total of 64,000 gal of liquid was required to transfer 6300 gal of settled solids to the Melton Valley Storage Tanks in six campaigns of pulse jet mixing operations followed by sluicing, and added acid dissolution for heel removal. Supernatant liquid was added at the start of each pulse jet mixing period, and slurries were produced and transferred with estimated properties ranging from 0.24 wt % undissolved solids in campaign 6 to 4.6 wt% undissolved solids in campaign 3 (pages 35-59 of ORNL/TM-13578). The slurry bulk densities were 1.1 to 1.27 g/mL (Table 4, ORNL/TM-13578). In the first campaign, an estimated discharge pressure of 240 psig at a flow rate of 57 gpm in 3-in. diameter pipes was used and the resulting slurry had 2.16 wt% undissolved solids. The results may provide an estimate of typical slurry solids loading under these PJM operating conditions and configuration. No data about the size of the cavern region, or the effective PJM clearing radius under these PJM operating condition was reported.

Figure 4-15 AEA Fluidic Pulse Jet Mixer Installed at the Oak Ridge Site

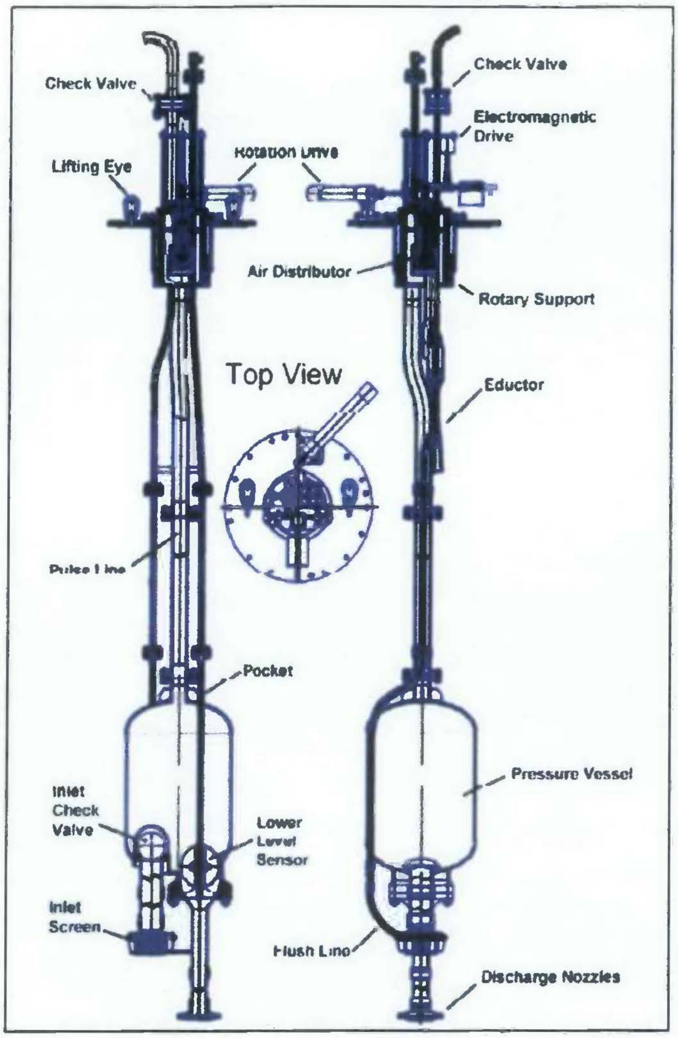


Source: ORNL/TM-13358, 1997, *Characterization of the BVEST Waste Tanks Located in ORNL*, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

The in-tank pulse tube configuration of the PJM system is planned for mixing applications in WTP vessels. The original WTP engineering, procurement, and construction contractor, British Nuclear Fuels, Ltd, incorporated PJM technology into the WTP design for mixing of solids-containing vessels, and to maintain uniform vertical and horizontal distribution of solids in fluid within vessels. A number of technical issues about PJM mixing performance in large vessels containing above 5 wt% solids have been raised at WTP. Plans to resolve these issues are being considered (DOE/ORP-2014-03, *U.S. Department of Energy Approach for Resolution of Pulse-Jet-Mixed Vessel Technical Issues in the Waste Treatment and Immobilization Plant*).

A third system design, referred as Russian PMP is configured as in-tank system shown in Figure 4-16 (ORNL/TM-2001/141, *Cold Testing of a Russian Pulsating Mixer Pump at Oak Ridge National Laboratory, Oak Ridge, Tennessee*; PNNL-13533, *Russian Pulsating Mixer Pump Deployment in the Gunite and Associate Tanks at ORNL*). This design uses a rotating index jet nozzle. As depicted in Figure 4-16, the entire system assembly is suspended vertically in a tank through a riser.

Figure 4-16 In-Tank Configuration of Russian Pulsating Mixer Pump



The Russian PMP design suffers from a number of system integration and operational limitations that require careful evaluation for use in flammable gas release mitigation. These concerns include:

- The moving parts of the Russian PMP reside within tank. This makes the maintenance of each system complex and costly and reduces system life expectancy.
- The point load of the mounting mast raises dome-loading concerns.
- The venting phase of operation increases the duty load of tank ventilation system.
- Placing a large pressure vessel inside a waste tank raises serious safety concerns.

The most limiting constraint of the Russian PMP is that all components except the inlet suction and discharge nozzle must be above the waste level. This limits the application of the system to

Hanford Site tanks with very shallow settled solids layers that do not pose a flammable gas hazard.

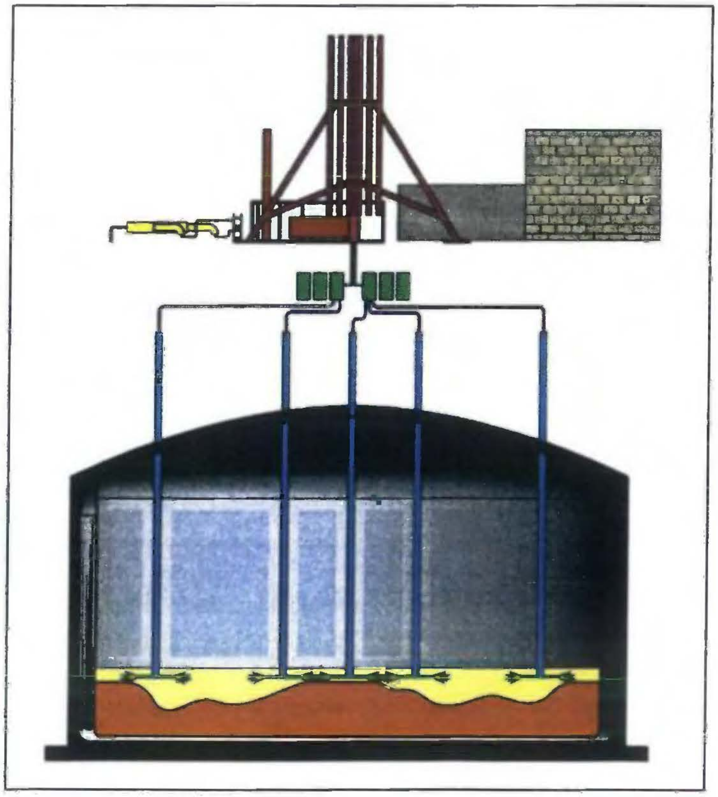
4.3.1 Deployment Options

The effectiveness of PJMs in releasing retained gas within the waste bed depends on the number of PJM pulse tubes inserted in the waste and the size of cavern produced. The cavern size in turn depends on applied pressure, nozzle exit velocity, nozzle diameter, and drive time along with the rheological properties of the fluid being mixed. The percentage of tank coverage by PJMs is limited by the number of available risers in a DST and the size of riser if the optional pulse tube configuration is considered.

Based on these factors, the system deployment options for the decoupled charge vessel and discharge jet nozzle configuration in tanks containing a deep solids layer is shown in Figure 4-17. The figure depicts discharge nozzles lowered to the tank bottom through separate risers while the charge vessels are integrated in above ground processing systems that include jet pump pair assemblies and an off-gas treatment system.

The option of deploying the PJM pulse tube configurations is similar to illustration in Figure 4-17, with the exception that the number of pulse tubes inserted in the waste bed is further limited by the number of risers with adequate diameter. Installation of pulse tubes in tank risers may decrease the percentage of tank inventory disturbed by mixing if similar size of cavern formation for both configurations is assumed.

Figure 4-17 Deployment of AEA Pulse Jet Mixer System–Decoupled Charge Vessel and Discharge Jet



4.3.2 Waste Type Application and Constraints

This technology can be applied to weak, low shear-strength saltcake/slurry waste layers (shallow or deep) to suspend settled solids and reduce retained gas. However, the operation of the PJM under high pressures to reduce retained gas in high shear strength sludges or deep weak shear strength slurry waste introduces possible pressurization events that the other prospective technologies do not, putting it at a relative disadvantage.

The main constraint in using a PJM system in DSTs is the waste layer rheology, which requires minimal shear stress to initiate inflow during the AEA PJM suction phase. If the shear stress is too high, provisions must be made to introduce supernatant liquid (or water) during suction to produce flowable slurry.

The Russian PMP is constrained for use only in tanks with a shallow solids layer. Since such tanks retain little flammable gas, there is limited application. Additionally, in contrast to the pulsed air mixer, there is no potential benefit in a preemptive deployment of this option in anticipation of changing tank conditions.

4.3.3 Estimated Implementation Costs and Schedule

Estimated ROM costs and schedules have been assembled to show implementation of Option 3 for these two vendor sources and technology sub-types using the best available information. These ROM costs for the AEA PJM are founded on the most recent implementation at ORNL after being used in the UK nuclear program (DOE/EM-0447). The basis for the Russian PMP ROM estimates are derived from deployments at ORNL and SRS and cost estimates for the Hanford Site's W-211 Project (WHC-SD-WM-CBA-001, *Life-Cycle Cost Analysis of the Advanced Design Mixer Pump*). The W-211 Project mixed 10,000 gpm inside a 1,000,000-gal tank, 75 ft. in diameter.

Minor design changes and physical modifications are assumed that would enable use of these PJM pumps to degas settled solids as described previously. A safety review, operational requirements review, and basic testing are assumed to suffice for final implementation. The field operation would be an intensive and focused activity but short in duration.

Capital equipment procurement of a single tank system of PJMs with associated peripheral equipment that is not part of the existing Hanford Site Tank Farm infrastructure is estimated at $787,000 for the AEA PJM. Figure 4-18 provides the AEA PJM cost and schedule details (a system smaller than the Russian PMP). For the Russian PMP the capital equipment costs are $1,142,000. Figure 4-19 provides the cost and schedule details.

The maturity of the PJM systems as used at ORNL, SRS, and as designed for use at the Hanford Site indicates that they could be developed for a new mission of flammable gas mitigation at the Hanford Site; however, there is some uncertainty about its potential effectiveness due to the marked difference in waste types. For example, the acidic and low solids waste at ORNL is significantly different than the high pH, high solids waste at the Hanford Site.

A demonstration at the Hanford Site would be required prior to implementation. The demonstration staff would need equipment and operation specific training. Transfer of waste to make room for equipment installation and some tank risers may require modification or preparation to accommodate installation of the PJM pumps. Preparation for installation would also include removal of some already installed equipment to accommodate the PJMs. This activity is excluded from the ROM cost estimate.

The cost and schedule to implement the PJM per tank is relatively well established based on DOE-sponsored studies for the AEA Fluidic PJM (DOE/EM-0447) and for the Russian PMP (DOE/EM-0662, *Innovative Technology Summary Report—Russian Pulsating Mixer Pump, Tanks Focus Area*).

Figure 4-18 Rough-Order-of-Magnitude Cost and Schedule Estimate to Implement AEA PJM ($K)

	Year 1	Year 2	Year 3	Year 4	
General Project Support					
Management				499	**1,753**
Permitting				18	
Technology Readiness Assessment				1,236	
Design		**1,390**			**1,390**
			Procure 787		**787**
			Construct		**12,400**
				Total	**16,330**

Figure 4-19 Rough-Order-of-Magnitude Cost and Schedule Estimate to Implement Russian PMP ($K)

	Year 1	Year 2	Year 3	Year 4	
General Project Support					
Management				499	**1,753**
Permitting				18	
Technology Readiness Assessment				1,236	
Design		**1,390**			**1,390**
			Procure 1,142		**1,142**
			Construct		**12,400**
				Total	**16,685**

4.3.4 Safety Basis Implications

The installation and use of PJMs has not been previously evaluated by WRPS Nuclear Safety. Examination of this option against the evaluation criteria for major modifications indicates that the installation and use of PJMs would:

- Add a process or activity not authorized in the existing safety basis, therefore resulting in the need for a safety basis change requiring DOE approval

- Utilize new technology or government furnished equipment not currently in use or not previously formally reviewed or approved by DOE for the Hanford Site Tank Farms
- Create the need for new or revised safety structures, systems, or components

In addition, the hazards associated with the introduction of compressed air below the surface of the solids layer in a waste tank, which could occur in off-normal operation of pulse jet mixers, is a hazard not previously evaluated in the Documented Safety Analysis. RPP-13303 currently addresses the hazards inherent to compressed air blowout of transfer lines (primary piping and hose-in-hose transfer lines). The hazardous events identified as resulting from this activity include the release of air below the waste surface in a DST. Examination of the specific hazardous conditions documented in RPP-15188 shows a single hazardous condition dealing with an air blow accident that releases air below the surface of the supernatant waste layer in a DST; this hazardous condition is assumed to affect only the supernatant layer.

It can therefore be concluded from the limited information available that the installation and use of PJMs would constitute a major modification. Safety basis implications can be assumed to include new safety significant systems, new specific administrative controls, and development of a tailored suite of DOE-STD-1189-2008 safety basis documentation. The safety basis impact of this option is defined as major.

4.3.5 Technical Viability

Pulse jet mixers offer several potential operational advantages for flammable gas mitigation: Few or no moving parts inside a tank, simplicity in operation, and low operation and maintenance costs (DOE/EM-0447). They also have a long development history at the Hanford Site for nuclear waste processing, where prospective safety issues have been identified and are in the process of being addressed (DOE/ORP-2014-03). However, the safety basis implications of this option are still being addressed at WTP. Some of these same safety and performance issues impact any potential deployment to address flammable gas mitigation (as part of Mixing Requirement No. 8 of DOE/ORP-2014-03) and remain to be resolved through testing and analysis. These include:

- Performance of the system in non-Newtonian fluids
- Mobilizing waste with wt% solids greater than 5%
- Frequent pressurized releases of the system that may lead to equipment damage

Because of the relatively small effective mobilization radius per PJM, this option requires several installations per tank. Pulsed jet mixers have a more limited range than conventional mixer pumps and may require more numerous installations or more frequent/longer periods of operation. Thus, additional evaluation of how the pulsed jet mixer system would be operated to achieve and maintain the lower gas accumulation is needed.

Deploying a broad number PJMs to the DSTs will introduce significant new infrastructure and resource demands to the various tank farms where they are deployed. Because of this resource demand, the lifecycle benefit for this option is less clear. However, flammable gas mitigation requires only that the gas inventory be reduced. It does not require all the retained gas be released, or that all the gas must be released from that waste that is disturbed. This factor may greatly reduce the number of PJMs required if they are strategically placed.

The PJM option is planned to regularly disturb the waste and initiate small-scale gas releases that will reduce the overall flammable gas inventory in the tank so that in the event of a triggering event, such as an earthquake, insufficient gas remains to reach the LFL, even if all the waste were disturbed (50% release fraction assumed). Each small-scale release is intended to remain well below 25% of the LFL as well.

However, depending on the degree of confidence in the waste surveillance data and tank modeling, there remains an opportunity for the PJMs to unintentionally induce a triggering event and release more gas than anticipated, especially during start up. Thus, this option needs to consider:

1. The PJMs will initially be started at low output, in stages, with only gradual increases in throughput and duration; the limited range of this option suggests that much longer durations will be needed to effect the necessary degassing
2. This operation includes initially using only one PJM at a time in multi-mixer installations
3. Gas monitoring will allow mixing to be shut down if flammable gas concentrations begin to rise faster than expected
4. Quantifying the routine operating schedule for long-term flammable gas mitigation once the initial gas release goal is achieved

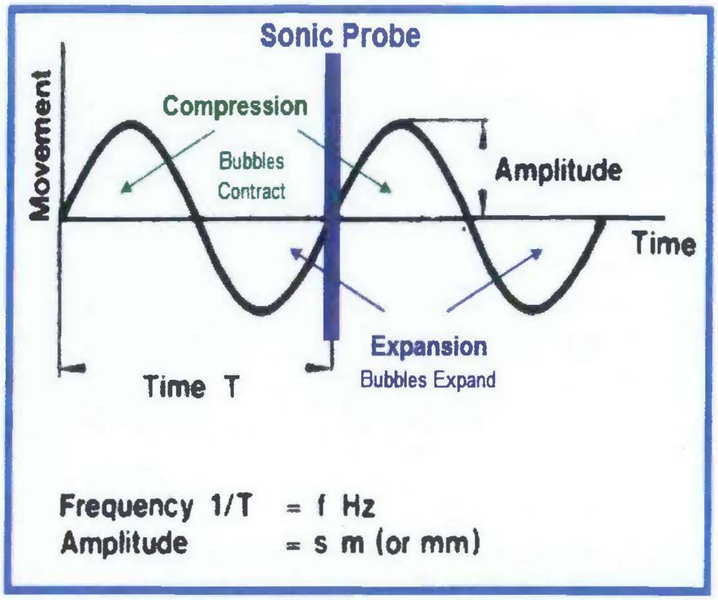
A large portion of the supporting equipment will be located above ground within the tank farm. Above-ground structural failures have the potential to release waste, if as part of the mixing action, a path to the environment exists and material and energy can travel down that path in the event of a failure. This option requires a substantial amount of in-tank piping and employs suction and pressurization to move waste within the tank mixing apparatus to accomplish its goal. Thus, there are many potential pathways for waste to get out of the tank.

4.4 OPTION 4–SONIC AGITATION

This technology involves the application of low frequency sonic vibration to change the yield strength of the settled solids layer and release trapped gas. The vibration is introduced by a "sonic probe" consisting of a motor-driven rotating eccentric mass enclosed in a cylindrical housing. Energy propagates through the waste as an acoustic wave, changing the solid structure of the waste to allow trapped gas bubbles to escape. Periodic operation of a sonic probe inserted in several tank risers in turn or one large sonic probe in a central riser is projected to disturb the waste sufficiently to release a large fraction of the flammable gas inventory. This controlled release would occur over an appropriate amount of time to ensure that the LFL is not approached.

Low Frequency (less than 200 Hz) sonic vibrators are the standard method worldwide for removing trapped air bubbles from fresh concrete. The vibration propagates to the medium in contact with the vibrator as acoustic waves as shown in Figure 4-20. The frequency, amplitude, wavelength, and velocity of the wave describe the vibrator's performance characteristics. Most concrete vibrators operate with wave amplitude of 0.5 mm to 2.0 mm.

Figure 4-20 Sinusoidal Vibratory Motion



The acoustic wave degasses the slurry by causing any trapped bubbles to contract and expand as shown in Figure 4-20, impacting the surrounding material and allowing bubbles to rise and escape. The energy absorbed by the bubbles attenuates the wave as it propagates until it becomes ineffective at a given distance, which is termed as the acoustic range. Attenuation also occurs in the yielded, degassed fluid, but the acoustic range is much higher in the region cleared of bubbles. Low frequencies in the order of 40 to 150 Hz (PNNL 10105, *Assessment of Selected Alternative Mitigation Concepts for Hanford Flammable Gas Tanks*) provide the best acoustic range in material representative of DST settled solids layers. This characteristic frequency is also a function of the tank's physical configuration (e.g., its base harmonic), thus it is slightly different in each tank.

Because the acoustic range decreases with increasing gas content, an inherent safety mechanism is present that ensures a large volume of waste will not suddenly release gas when sonic vibration is applied. The effective range grows slowly as gas is released and rises away from around the probe. Furthermore, the application of sonic energy does not cause incremental waste heating or other undesirable side effects in the tank. The low frequency energy input is effectively transmitted through the waste with no measurable increase in waste temperature. This is in contrast to high frequency ultrasonic (greater than 20,000 Hz) energy that is absorbed completely only a few inches from the transducer placed in a similar waste material. In addition, the durations needed for degassing are anticipated to be on the order of minutes to an hour.

The effectiveness of sonic probe vibration in releasing retained gas within the waste bed depends on the waste shear strength and the gas content within the waste layer, which influences the acoustic attenuation length. The sonic probe target oscillation frequency is adjustable and is intended to be tuned to a specific natural harmonic of the tank waste being treated in order to provide optimal effectiveness. The process of "tuning" is relatively straightforward and involves monitoring current draw on the drive motor during operation. When the sonic probe frequency matches a specific harmonic of the tank waste, the current draw on the motor will suddenly increase, indicating harmonic coupling has occurred. This target frequency of oscillation is then maintained to eliminate the trapped gas within the waste material.

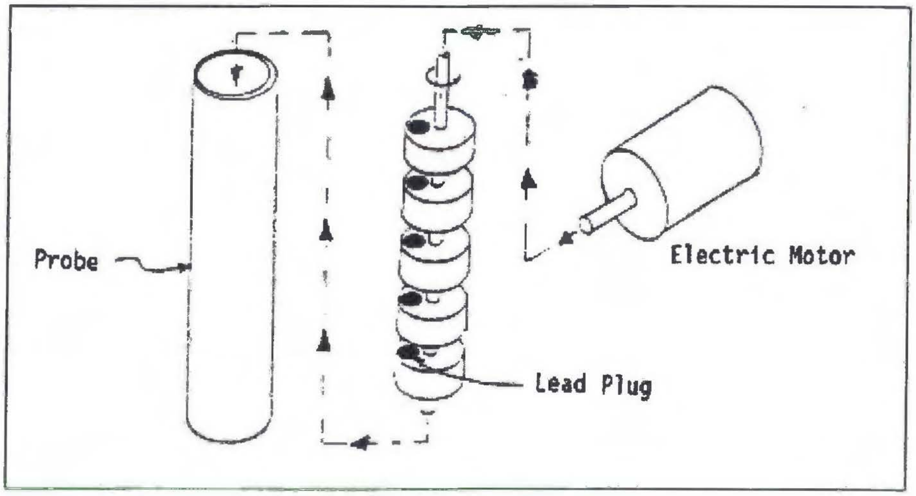
Extensive testing for application on Hanford Site waste tanks was performed in the 1990s. For example, a test of a commercial concrete vibrator operated at 186 Hz and 900 lbf centrifugal force was used in a 1/25th scale DST to successfully degas a cornmeal simulant (WHC-SA-2350-S, *Sonic Processing Probe for Mitigation and Remediation of Liquid Nuclear Waste in Storage Tanks*). The sonic probe was evaluated as a potential technology for Tank SY-101 gas mitigation.

Sonic agitation was performed on actual tank waste in a laboratory at PNNL to evaluate its effectiveness. An interesting observation from the testing was that sonic agitation not only fluidized the waste material such that it lost its original cohesiveness, but the waste also stayed in its new fluidized state for weeks after the single short application of sonic agitation. This change in waste characteristic provides for the steady release of gas and does not appear to provide for a sudden release above the 25% LFL during operation.

A conceptual design of a full-scale sonic probe was completed in 1992 (WHC-SD-WM-RPT-041, *Tank 241-SY-101 Hydrogen Mitigation by Low Frequency Vibration Feasibility Assessment*). The system consisted of a large single probe located near the center of the tank powered by a remote electric motor. The probe consisted of a large tube with whirling unbalanced weights on roller bearings shown in Figure 4-21. As the shaft rotates, the eccentric mass causes the outer tube to vibrate. The full-scale probe was designed to operate a 5070 lbm (2300 kg) active element 16 ft in length and 12 in. in diameter suspended in a 12-in. tank riser (WHC-SD-RPT-041).

The design concept had a total of 5880 in.-oz (65.6 kg-cm) imbalance distribution among 28 segments. Each segment had two shielded roller bearings that supported the eccentric mass. The segments drive shafts were connected by a heavy-walled bellows providing vibration isolations between the segments (PNNL-10105).

Figure 4-21 Sonic Probe Concept for Tank SY-101 Gas Mitigation



In 1996, a design package for the sonic probe for installation in Tank SY-101 was completed by the Southwest Research Institute (SwRI) under contract to the Los Alamos National Laboratory (LANL), in accordance with the statement of work by Westinghouse Hanford Company and is included as Appendix B of this report. The design work was not taken to final completion due to the decision to continue with the mixer pump concept for Tank SY-101 mitigation. Significant design work was completed to address design integrity and acceptance testing, manufacturing and operation constraints, and develop maintenance and handling requirements. The design package consisted of the following five design elements.

1. Active section with speed augmenter: This active section was an adaptation of the original sonic probe. Essentially, an eccentric mass internal rotary vibrator similar to a concrete vibrator spun in a rigid housing operating at 30 to 70 Hz. The length of the active element and the speed augmenter was 10 ft constructed from a series of nine imbalanced steel weights rotating about a common axis concentric to the vertical axis. The system included a total of 26.14 lbm of imbalanced mass, a shaft and a coupler.
2. Intermediate sections: The sonic probe was intended to be coupled with the mixer pump installation, and the portion of mixer pump design was used as the basis for installation in 12-in. riser. The design composed of a total of five intermediate sections of 8-ft length constructed of 6-in. diameter Schedule 80 pipe.
3. Upper section: The design of the upper section with seals was an adaption of an 8-ft intermediate section with a steel radiation shield. An inflatable bladder above the radiation shield sealed the region and provided a soft cushion against the riser wall. A 104.5-in. shaft interfaced with the motor shaft.
4. Support, isolations, and seals: The main support structure and isolation was the concrete slab above Tank SY-101 rather than the tank riser. The probe and motor were designed to float on the concrete slab connected to the riser by a bellows.
5. Drive motor/controller: The motor was a commercially available 125-hp vector-controlled system to obtain accurate speed control.

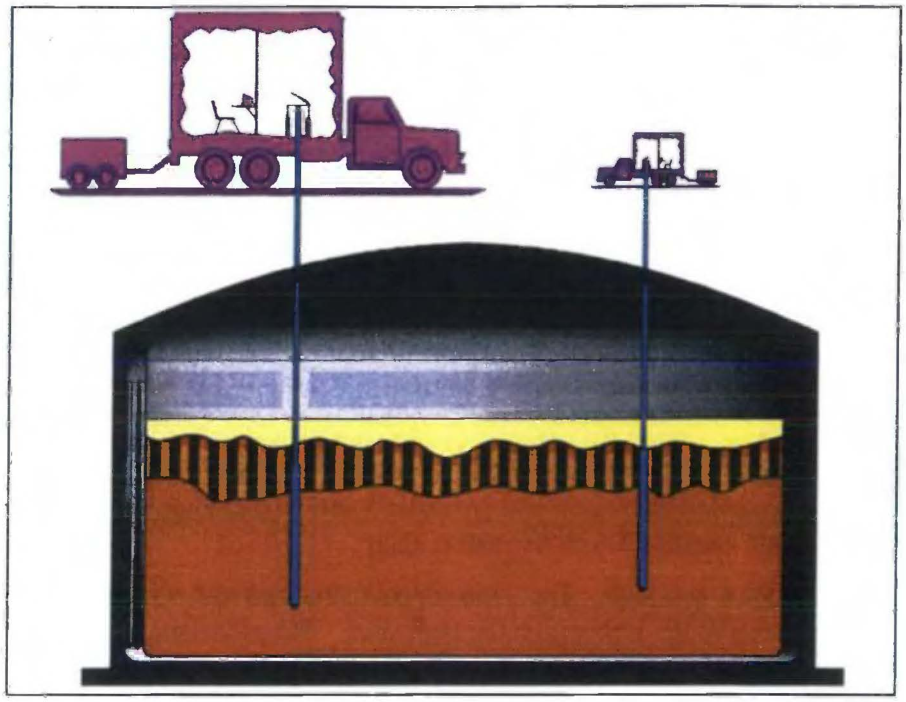
A sonic probe was installed on the Tank SY-101 mixer pump to serve as a method for dislodging waste that might clog the orifices on the pump head. The probe was not needed or used during the mixing campaign; however, it is worth noting that the safety reviews needed for installation of equipment into a Hanford Site waste tank were performed on the sonic probe. This historical information although potentially useful, is not directly applicable for future safety reviews because of substantial changes in safety infrastructure and requirements.

4.4.1 Deployment Options

The approach considered for Tank SY-101 in the 1990s was to install a single large sonic probe, of sufficient size to adequately release the trapped gas within the tank. No commercial concrete sonic probes were available of the size needed for a single Tank SY-101 probe, thus the plan was initiated for LANL/SwRI to design a larger unit was initiated, as described earlier. A similar single unit design could also be employed in the future, although a smaller unit would likely be sufficient given the present need to merely reduce the available flammable gas, not completely eliminate it.

In addition, a shorter portable sonic probe of adequate diameter could be deployed. The probe can be lifted up and down to cover the medium or may operate successfully placed near the bottom. As shown in Figure 4-22, the sonic probe can be installed on a truck to be deployed in several risers similar to a core sampling truck rather than a permanent installation. A mobile sonic probe would provide a larger percentage of tank inventory coverage with a single unit.

Figure 4-22 Truck Mounted Sonic Probe Deployment



4.4.2 Waste Type Application and Constraints

The sonic agitation technology has the ability to reduce retained gas over all potential waste configurations described in Section 2.3. Because of the self-induced impedance provided by the retained gas concentration, this feature provides a controlled gas release process.

Operational questions that would be need to be addressed for this option:

- What is the volume of sludge changed as a function of sonic probe acoustic range?
- What is the required run duration and frequency for a specific tank?
- What are the quantifying applicable attenuation mechanisms?
- What is the optimal design and implementation of this technology (e.g., mobile or fixed platform)?

The answers to these questions would define the optimal operational approach. For example, would a fixed installation for each tank of concern, operated periodically, or a mobile system that could be moved from tank to tank as needed be most appropriate?

4.4.3 Estimated Implementation Costs and Schedule

Cost elements on an estimated ROM basis have been assembled to show expected effort needed to implement this option. Cost information here is obtained from published literature on the technology, past project implementation, and from SME interviews conducted in June 2014. Minor design changes and physical modifications are assumed that would enable use of this system to release retained gas in a broader range of tanks. However, the maturity and extensive commercial application of the sonic probe technology indicates that it could be tailored for a mission of flammable gas mitigation at the Hanford Site.

Procurement of a single set of sonic probe equipment with required associated peripheral equipment that is not part of the existing Hanford Tank Farm infrastructure is estimated at $1M for the first tank, based on a 75-ft diameter tank. (M. Hall, personal communication, July 2, 2014).

Transfer of waste to make room for equipment and some tank risers may require modifications or preparations to accommodate installation. Preparation for installation may include removal of some already installed equipment to accommodate the sonic probe system. Additionally, a complete equipment system includes the deployment platform and a control system.

Because of the lack of published information, despite significant Hanford development and testing programs carried out in the 1990s, cost and schedule definition to implement the sonic probe system per tank is not well established. While there is relatively minor uncertainty associated with this option schedule, there is a relatively high cost uncertainty because sonication at this scale in the Hanford Site waste tank environment is a novel application and there are a limited number of potential vendors. Figure 4-23 provides cost and schedule ROM estimate details.

Figure 4-23 Rough-Order-of-Magnitude Cost and Schedule Estimate to Implement ($K)

Year 1	Year 2	Year 3	Year 4
General Project Support			
Management		499	**1,753**
Permitting		18	
Technology Readiness Assessment		1,236	
Design	**1,390**		**1,390**
		Procure 1,000	**1,000**
		Construct	**12,400**
			Total 16,543

4.4.4 Safety Basis Implementation

The installation and use of sonic probes has not been previously evaluated by WRPS Nuclear Safety. Examination of this option against the evaluation criteria for major modifications indicates that the installation and use of sonic probes would:

- Add a process or activity not authorized in the existing safety basis, therefore resulting in the need for a safety basis change requiring DOE approval

- Utilize new technology or government furnished equipment not currently in use or not previously formally reviewed or approved by DOE for the tank farms
- Create the need for new or revised safety structures, systems, or components

In addition, the hazards inherent to the use of sonic agitation below the surface of the solids layer in a waste tank is a hazard not previously evaluated in the Documented Safety Analysis. RPP-13303 currently addresses the use of ultrasonic testing for tank integrity assessments; this is a different technology, which is applied to the tank exterior. RPP-15188 also does not address hazardous conditions related to the use of sonic agitation.

It can therefore be concluded from the limited information available that the installation and use of sonic probes would constitute a major modification. Safety basis implications can be assumed to include new safety significant systems, new specific administrative controls, and development of a tailored suite of DOE-STD-1189-2008 safety basis documentation. The safety basis impact of this option is defined as major.

4.4.5 Technical Viability

The sonication option is planned to regularly change the waste retention characteristics and allow small-scale, highly distributed gas releases. Over time, this waste conditioning is anticipated to reduce the overall flammable gas inventory in the tank so that in the event of a triggering event, such as an earthquake, insufficient gas remains to reach the LFL even if all the waste were disturbed. This distributed small-scale release is also intended to allow the headspace to remain well below the LFL during degassing.

Unlike the other mitigation options, no significant "impulse" release of gas occurs as the system is engaged. However, depending on the degree of confidence in the waste surveillance data and tank model, there remains an opportunity for the waste environment to evolve gas more rapidly, unintentionally induce a triggering event and release more gas than anticipated, especially during start up. Thus, this option needs to consider:

- The sonication must initially be run in stages through its frequency range to determine the fundamental frequency for each tank and other operating parameters. Once those are obtained, gradual increases in power and duration to induce the necessary degassing behavior will be implemented.
- This operation uses only one sonic probe, but the degree of effectiveness for this option needs to be quantified to ensure that excessive sudden de-gassing does not occur.
- Gas monitoring to provide warning and shut down the sonic probe; and to increase in-tank ventilation, if flammable gas concentrations begin to rise faster than expected.
- Quantifying the routine operating basis for maintaining the retained gas volume below the LFL once the initial gas release goal is achieved.

Although a large portion of the supporting equipment will be located above ground within the tank farm, the amount of equipment is modest, when compared to the other options. Additionally, above ground structural failures do not have the potential to release waste. There are no potential pathways introduced by this method for waste to get out of the tank.

4.5 OPTION 5–EXISTING TECHNOLOGIES AND WASTE MANAGEMENT TECHNIQUES

There are several waste management processes that are part of normal Hanford Site Tank Farm operations that could be employed to degas settled solids. These existing processes would require modest incremental safety analyses, little or no additional training or equipment costs, and potentially rapid implementation.

4.5.1 Deployment Options

Several existing waste management processes could be employed to degas settled solids. The principal methods considered are:

- Strategic intra-tank farm transfer (i.e., movement/redistribution of waste from tank to tank)
- Transfer waste to new tanks, if they are constructed
- Dilution, using buffered water

These techniques may be applied concurrently or in a targeted fashion to reduce retained gas in select tanks, providing a near term, temporary, solution. Time and resources could then be spent on more complete, longer-term solutions (other options as identified previously in this report). Utilizing the limited DST space to dilute existing waste or spread waste solids among more tanks would curtail SST retrievals. The Tank Farm Contractor mission would change from a focus on safe storage and retrievals to simply safe storage. This would impact completion of existing Tri-Party Agreement (Ecology et al., 1989) milestones.

Intra-Farm Transfers

The flammable gas concentration after a gas release is inversely proportional to the volume of air in the tank headspace that dilutes the release. Simply removing liquid waste from a tank increases the headspace volume thereby decreasing maximum flammable gas concentration. Tanks with large headspace volumes have a greatly decreased potential for a flammable concentration to occur.

At the time of this report, Tanks AW-102 (2.1 m of waste) and AW-105 (3.8 m of waste) could potentially receive sufficient liquid waste to make flammable headspace concentrations impossible in at least two other tanks. However, they are not available for transfers since AW-102 is designated as the evaporator feed tank and Tank AW-105 is reserved for emergency storage space to receive waste from newly identified leaking tanks. Additionally, although planned evaporator campaigns will recover approximately 3 million gal of DST storage space, this 'freed' space is reserved to receive the SSTs waste as a regulatory compliance commitment to the State of Washington.

Transfer to New Tanks

Should new DSTs be constructed, the additional space could be used to reduce waste volume (either to increase headspace volume or allow space for addition of dilution water) and release flammable gas retention risks in current tanks. A more detailed study to quantify the optimal use and sequencing of freed tank volume would be needed; however, a range of opportunities exist to address flammable gas retention issues using the identified techniques within this option, if there is more storage volume.

Dilution

The objective of dilution is to dissolve soluble solids in the tank by adding a large volume of conditioned water. This reduces the depth of the gas-retaining settled solids thus reducing the maximum volume of gas that can be retained. The reduction of the flammable gas inventory in the tank also prevents an external event, such as an earthquake, from releasing enough gas to reach the LFL.

Experience with dilution of Tank SY-101 indicates that gas releases during dilution would be slow and the headspace should remain well below the LFL during the process. However, because of the lack of available DST volume to accommodate the large volume of water needed, dilution as a long-term option is considered unlikely.

4.5.2 Safety Basis Implications

This option is described as consisting of strategic intra-farm transfer; transfer of waste to new tanks, if constructed; and dilution using buffered water. These activities, with the exception of the construction of new tanks, are addressed in the existing Documented Safety Analysis (RPP-13303). Waste transfers are accomplished via an existing network of underground piping and hose-in-hose transfer lines; this network is reconfigured as necessary to support waste transfers, water additions, or chemical additions using valves, jumper assemblies, diversion boxes, and hose connections.

The existing analysis also addresses the hazards inherent to addition of water, aqueous solutions of sodium hydroxide or sodium nitrite, and incidental chemicals. Changes to the physical and administrative infrastructure supporting performance of these activities are evaluated through the Unreviewed Safety Question process. Continued use of these techniques is anticipated to require evaluation through the Unreviewed Safety Question process, and may require revision of RPP-13303, resulting from negative USQDs. The need for a safety basis change requiring DOE approval is not anticipated for these activities if performed using existing equipment, or equipment previously authorized for use in the tank farms. It is also anticipated that these activities can be performed using the existing safety significant systems and specific administrative controls.

It can therefore be concluded that this option as described, excluding the construction of new tanks, would not constitute a major modification and would be managed through the existing Unreviewed Safety Question process. The safety basis impact of this option is defined as minor.

5.0 CONCLUSIONS

This report has evaluated optional solutions to degas settled solids in certain Hanford Site DSTs. Only those tanks with relatively high gas inventories and small headspaces pose a flammability risk.

- A broad survey of technical solutions offered by industry, academia, and government sources; foreign and domestic; previously employed mature solutions as well as promising novel concepts was performed. A list of 30 prospective candidate solutions for further consideration was developed.
- The 30 candidate solutions were screened down to five options, which were investigated further for technical applicability, development history, safety, cost, and time to implement. The five options are: mixer pumps, pulsed air mixer, pulse jet mixer, sonic agitation, and existing technologies and waste management techniques.
- Mixer pumps use an intermittent high-velocity turbulent jet to mobilize and suspend settled solids to release retained gas. The mixer pump will be operated periodically to maintain a reduced retained gas inventory. This technology is anticipated to be effective in all waste configurations, and has been demonstrated to work in the Hanford Tank Farms. The number and size of mixer pumps will be dictated by the waste characteristics.
- Pulsed air mixer applies a steady stream of gas pulses to induce mechanical mixing of settled solids to release retained gas. The pulses set up a circulation current to maintain a lower retained gas inventory by continuing low-level gas releases over time. The technology is expected to be most effective in weak, low shear strength saltcake and slurry wastes in any operating depth. However, in strong, high shear strength waste, the technology may not be able to set up the desired circulation current to be effective.
- Pulse jet mixers use intermittent mechanical mixing of sludge by pressurization to move sludge and release retained gas. The PJM will be operated periodically to maintain a reduced retained gas inventory. The technology is effective in maintaining solids in suspension. It is expected to be most effective in weak, low shear strength saltcake and slurry wastes. However, the necessary pressures needed to mobilize deep slurries and high shear sludge may prove prohibitive at tank scale.
- Sonic agitation temporarily changes the flow behavior of the waste by applying sonic energy allowing the waste to release gas slowly during sonication. The sonic probe will be operated periodically to maintain a reduced retained gas inventory. This technology is anticipated to be effective in all waste configurations. The number and power of the sonic probes will be dictated by the waste characteristics. Further testing is needed at tank scale.
- Cost and schedule ROM were estimated for the four options.
- Flammable gas reduction options do not need to mobilize the waste fully and could operate in a very slow, measured way, maintaining the headspace at less than 25% of the LFL at all times during the off-gassing process. The retained gas reduction process will likely be intermittent, requiring long equipment lifecycles. The five options judged the

most promising to release retained gas in a controlled manner all have advantages and disadvantages. This evaluation does not rank the five options; however, technical applicability, maturity, cost and schedule to implement and safety basis implication are all discussed.

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APPENDIX A

SCREENING DATA SUMMARY

Flammable Gas Mitigation - Initial Screening Table

No.	Name	Description	Mitigating Technique	Outcome Advantages	Outcome Disadvantages	Cost ($)	Prospect for Down Selection Option	Other Notes
	Commercial Name or Common Industry Name	**General summary, mode of operation**	**Means by which flammable gas risk is diminished**	**Pros**	**Cons**	**Provide if available**	**Yes - 1 = Select** **Yes - 2 = Alternate** **No = Not Viable**	
1	**Russian Pulsating Mixer Pump**	Repetitiously draws waste into chamber under vacuum then forcefully expels through manifold of 4 nozzles embedded at strategic depths and rotating nozzle directions	Hydraulic agitation	• Few moving parts, especially in contact with waste • Inlet separate from outlet jets • No electrical parts in tank • Light weight dome loading	• Foreign (Russian) vendor • Pressure vessel • Installation and removal problems	175,000 Capital Equipment; Oak Ridge Hot Deployment 2001	Yes - 1	Numerous other competing mixers, but this one seems to have merit in a direct comparison study
2	**Advanced Waste Retrieval System**	Suction pickup system with video designed to be strategically placed into tank locations for targeted retrieval. Telescoping arm and remote control makes surgical placement rather than bulk conventional mobilization and sluicing.	Mechanical agitation	• May supplement other mixer technologies • Surgical • Ability to grind and break up chunks • Alternate to sluicing	• Requires existing retrieval pumps • Designed for West Valley • grinding may have adverse effect on waste • Lots of surfaces and moving parts • Very local, small effective area and collection only, suction only	630,00 Capital equipment cost 2001 Demonstration	No	Developed as an alternative to baseline retrieval of HLW tanks at WVDP, SRS and Hanford
3	**Fluidic Pulse Jet Mixer (AEA)**	Similar to Russian PMP, but may be deployed differently by making use of existing tank infrastructure	Hydraulic agitation	• No moving parts, especially in contact with waste • No electrical parts in tank • Light weight dome loading • Longer service life compared to in-tank exposed equipment with moving parts	• Foreign (UK) vendor • Pressure vessel • Requires existing infrastructure such as tank piping	550,00 Capital equipment cost 1999 Deployments	Yes - 1	Many deployments at Oak Ridge and in the UK Incremental approach; consider plurality of units and strategic location
4	**Low Frequency Sonic Probe**	Uses an eccentric rotating mass placed at end of a probe, actuated using air, hydraulic, or electrical force. The eccentric mass is contained in a durable sleeve such that no moving parts are in contact with the waste. Identical in design to units used commercially for degassing concrete	Pressure waves via sonic agitation	• No mechanical components in contact with the waste • No water added to the waste • Energy input is easily adjustable and feedback allows exact tuning for each unique tank contents. • Characterize physical properties & samples (solids/liquid/gas) • Needs only very small riser; could be left in situ; disposable tools are cheap	• Requires some operations training before use		Yes - 1	Sonic probe was extensively tested and verified as a candidate technology in a previous technology review (circa 1994) and was deemed one of three options for Hanford Tank Waste Hydrogen Mitigation. Sonic probes were even attached to the mixer pump installed in Tank SY-101 as a backup method in the event the mixer pump failed.

Flammable Gas Mitigation - Initial Screening Table

No.	Name	Description	Mitigating Technique	Outcome Advantages	Outcome Disadvantages	Cost ($)	Prospect for Down Selection Option	Other Notes
5	**Borehole Miner**	Robotic arm for surface removal of solids and liquids with small scale, high pressure sluicing and vacuum retrieval pump	Hydraulic agitation	• Surgical action • Small amount of water addition if needed	• Only effects small area • Pressures are a potential danger to tank integrity as a design/ operational issue • Addition of any water not a favorable approach	$3M capital equipment based on scale tank. Design and costs available for Hanford	No	Adapted from mining industry
6	**Confined Sluicing End Effector (on LDUA)**	Robotic arm for surface removal of solids and liquids with small scale sluicing and vacuum retrieval pump	Localized retrieval with small amount of water addition	• Surgical action • Small amount of water addition if needed	• High dome loading • Small area of influence, not a bulk impact	100,000 in 1998 deployment	No	Ability to deploy other end effectors on LDUA Hanford LDUA no longer at site
7	**Flygt Mixer**	Propeller mixer surrounded by a close-fitting shroud mounted to a vertical mast. The rapidly spinning propeller created a turbulent fluid jet.	Mechanical agitation for large volume stirring without water addition	• Able to disturb large volume • No fluid addition needed typically	• Large unbalanced thrust force • May not mobilize strong solids • Multiple mixers may be needed in some tanks • Mounting mast requires rotation, modifications here may improve operation		Yes - 2	Consider this as a tertiary option to Hanford and SRS Jet Mixers. May have some valued features.
8	**Pulsed Air Mixer**	Adjustable air pulse injected into tank waste beneath a horizontal steel plate.	Pneumatic agitation Bubbles move under the plates and mixes the tank content. As the bubbles rise, large-scale vertical circulation patterns are formed within the tank.	• Nitrogen gas or an alternative inert gas can be used to generate bubbles. • Powerful local disturbance without water addition • Able to disturb solids	• Oxygenating and carbonating waste by introducing ambient air • Disturbance may be limited to volume directly over plate		Yes - 1	
9	**Jet Ballast (UK-NNL)**	Multiple, strategically located air jet nozzles	Hydraulic agitation	• Solids disruption • No water added	• Foreign (UK) vendor • Not fully mature; still demonstrating • May not mobilize strong solids		No	UK - National Nuclear Lab
10	**Water Mist & Ultrasonic (UK)**	Inerting tank headspace with water misting produced by ultrasonic vibration	Multiple techniques	• Tests explore complex interactions of multiple techniques	• Foreign (UK) vendor • Inerting may not be effective with N2O in retained gas • Not fully mature; still demonstrating		Yes - 2	Sellafield, Ltd. Mitigating technique

Flammable Gas Mitigation - Initial Screening Table

No.	Name	Description	Mitigating Technique	Outcome Advantages	Outcome Disadvantages	Cost ($)	Prospect for Down Selection Option	Other Notes
11	**SPP Water Jetting (UK)**	Water nozzle to supplement Pulse Jet mixers	Hydraulic agitation	• Small amount of water addition if needed • Multiple interchangeable nozzles for adaptability • Improves effectiveness of mixer pumps	• Foreign (UK) vendor • Not fully mature; still demonstrating		No	UK - National Nuclear Lab
12	**Nitrojet**	Nitrogen liquid lance for powerful surgical penetration of solids	Agitation and inerting	Prevents flammability/explosion consequence of large gas release.	• Inerting may not be effective with high N_2O concentration in retained gas • Does not affect gas inventory		Yes - 2	
13	**Nitrogen Injection Ventilation (UK)**	Inject nitrogen to manage headspace environment	Inerting	Prevents flammability/ explosion consequence of large gas release.	• Inerting may not be effective with high N_2O concentration in retained gas • Does not affect gas inventory		Yes – 2	
14	**Argon Inerting**	Add argon gas to tank headspace	Added argon reduces headspace fuel gas and oxygen concentrations below flammability	Prevents flammability/ explosion consequence of large gas release.	• Cost • Inerting may not be effective with high N_2O concentration in retained gas		No	
15	**Crystaline Silicotitanate (CST) ion exchange media**	Use CST to remove Cs-137	Chemical/Removal	Directly reduces H_2 generation	Removing Cs alone is not enough to reduce FG generation according to Calcs		No	Even if CST extraction reduced H2 sufficiently, the secondary waste stream would need to be addressed.
16	**Sodium Tetraphenylborate**	Use sodium tetraphenyl borate to remove Cs-137	Chemical/Removal	Directly reduces H_2 generation	Removing Cs alone is not enough to reduce FG generation according to Calcs		No	Even if tetraphenyl borate extraction reduced H2 sufficiently, the secondary waste stream would need to be addressed. Use of tetraphenyl borate had unintended effects at SRS.
17	**Crossflow Filtration**	Solid/liquid separation	Mechanical	None	Ineffective		No	Was considered because particle size may have impacted gas retention characteristics; to the degree this technology can be applied and the condition in the tanks, it is not effective.
18	**Sludge Washing**	Solid/liquid separation--remove Cs-137 & Sr-90	Chemical/Removal	Directly reduces H_2 generation	High degree of dependencies on pathway to disposal, storage, secondary waste disposition		Yes - 2	Sludge washing is possible in concert with other waste feed delivery operations/design decisions. However, because of the degree of dependency on other project elements, it is not a stand-alone option. It also generates a secondary waste stream that needs disposition.

Flammable Gas Mitigation - Initial Screening Table

No.	Name	Description	Mitigating Technique	Outcome Advantages	Outcome Disadvantages	Cost ($)	Prospect for Down Selection Option	Other Notes
19	**TRUEX-SREX**	Solid/liquid separation–remove Cs-137 & Sr-90	Chemical/Removal	Directly reduces H_2 generation	Too cumbersome and complex in this application; requires acid chemistry		No	This technology is more suited to addressing INL acid wastes.
20	**Thermal Denitration**	Chemical addition to reduce NO3	Chemical/Removal	Reduces generation of N_2O in generated FG	Too cumbersome and complex in this application; requires acid chemistry		No	This technology is more suited to addressing INL acid wastes.
21	**SRS Jet Mixer Pump**	Draws waste in to eject out two diametrically opposing nozzles	Mechanical agitation	• Proven technology • Partial suspension of sludge bed to release retained gas is intended in this application as opposed to waste retrieval			Yes - 1	
22	**Hanford Jet Mixer Pump**	Baseline mixers. Draws waste in to eject out two diametrically opposing nozzles	Mechanical agitation	• Proven technology • Partial suspension of sludge bed to release retained gas is intended in this application as opposed to waste retrieval			Yes - 1	The effectiveness of mixer pumps depends on the sludge properties, pump size, number of mixer pumps in the tank, and duration of mixer pump operation.
23	**More Tanks**	Transfer waste from Hanford tanks containing retained gas in the settled solid layer to prevent explosion/deflagration by increasing headspace and reducing flammable gas volume.	Primary: reducing stored gas volume, primary. Secondary: increasing gas dilution volume	Prevent flammable gas retention and provides more options for waste feed delivery conditioning.	High cost, long schedule, controlled by different program/priorities		Yes - 2	Construction of new tanks has long been considered at various times.
24	**Redistribution of Supernatant**	Transfer supernatant from Hanford tanks containing retained gas in the settled solid layer to other tanks.	Increase headspace volume available to dilute gas release.	Applicable to several tanks	• Temporary solution; as retrieval progresses, DST space is at a premium. • Expensive • Complicated waste compatibility issues		Yes - 2	Compliments "new tank" option for construction. However, more tanks or disposition of waste becomes necessary as SST retrieval advances.
25	**Dilution**	Addition of water	Dissolve soluble solids to reduce volume of waste able to retain gas	• Simple & proven effective • Dilution does not require ongoing and periodic operations of mixing by various methods	Reduces available DST volume in near-term		Yes - 2	Impedes retrieval and other waste management operations until waste disposition path is opened or more tanks are available.
26	**Chemical Addition for Hydrogen Sequestration**	Pd addition	Chemical/Inerting	Directly sequesters H_2	It would likely not reduce H2 enough in this case.	Cost prohibitive at scale.	No	Although palladium will absorb 500x volume in H2; it was used in H-3 capture at Hanford, it is not a practical application in this case.
27	**Chemical Addition for Surface Tension Reduction**	Trisodium Phosphate (TSP) is used to change surface tension properties and reduce gas retention	Chemical	Straightforward application	Uncertain chemical and physical interactions in saturated tank wastes		No	Adding chemicals to the tank environment is a highly uncertain endeavor, with potentially undesired consequences. Significant testing to qualify this option would be needed.

Flammable Gas Mitigation - Initial Screening Table

No.	Name	Description	Mitigating Technique	Outcome Advantages	Outcome Disadvantages	Cost ($)	Prospect for Down Selection Option	Other Notes
28	**Sludge Reduction**	Acid digestion by addition of chemicals	Chemical dissolving	Reduce volume of waste able to retain gas	• Changes tank chemistry and may impact downstream processing treatments • The anticipated amount of acid necessary for a tank volume makes it not very compatible with the tank, therefore impractical		No	The use of an acid such as oxalic could be used to change the rheology of the sludge such that to prevent gas retention
29	**Air Lift Circulator**	Existing Hanford Equipment. Stream of air bubble injection from bottom of tank to supernatant layer	Air bubble rise agitation	Existing ALC in DSTs	Only one tank with sufficiently shallow solids to operate ALC		Yes - 2	Release retained gas in tanks with shallow settled solids layer where ALCs are not buried.
30	**Early Tank Retrieval**	Expedite remediation and tank closure schedule	Mechanical removal	Straightforward application	High degree of dependencies on pathway to disposal, storage, secondary waste disposition		Yes - 2	Accelerated retrieval is possible in concert with other waste feed delivery operations/design decisions. However, because of the degree of dependency on other project elements, it is not a stand-alone option.

AEA = AEA Technology
ALC = Air Lift Circulators
CST = Crystaline Silicotitanate
DST = double-shell tank
FG = flammable gas
HLW = high-level waste
INL = Idaho National Laboratory
LDUA = Light Duty Utility Arm
NNL = National Nuclear Laboratory (UK)
Pd = Palladium
PMP = pulsation mixer pump
SRS = Savannah River Site
TSP = trisodium phosphate
UK = United Kingdom
WVDP = West Valley Demonstration Project

APPENDIX B

FINAL DESIGN PACKAGE FOR THE SONIC RETRIEVAL PROBE (SRP)

(Produced from the best available copy)

FINAL DESIGN PACKAGE FOR THE SONIC RETRIEVAL PROBE (SRP)

for

WESTINGHOUSE HANFORD COMPANY
P.O. Box 1970
Richland, Washington 99352

SwRI Project 17-6356-171

Prepared by

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Glynn R. Bartlett

Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

July 1996

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EXECUTIVE SUMMARY

During this program, the LATA TRWS Task Team of Southwest Research Institute (SwRI) and LATA provided engineering services for the design of a Sonic Retrieval Probe (SRP). The work included design, analysis, and reporting in accordance with the requirements and deliverables specified in the updated Statement of Work (SOW) for the Sonic Retrieval Probe written by M. N. Hall, initially dated April 9, 1996. As a result of this effort, a design for the SRP has been developed to a stage where shop drawings can be produced and the probe fabricated.

The major design challenges that were defined at the opening of this program have been met. Based on the design presented in this report, the SRP will have an operational life in excess of the 500 hours specified in the SOW. A significant amount of effort was put into ensuring the design integrity, addressing manufacturing constraints, defining acceptance testing, identifying operational constraints, and developing maintenance and handling requirements. The uniqueness of the SRP required the use of specialized design procedures to ensure functionality. Consideration of fabrication procedures was made during the entire design process to ensure that the SRP could be built as well as maintained. Allowances were made for handling and installation requirements, since the SRP is designed for application in a number of tanks at the site. This concerted effort resulted in a robust design for the SRP.

SwRI has developed a design for the SRP that will satisfy the specification and has a very high probability of success during its design life.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Southwest Research Institute (SwRI) and LATA provided engineering services for the design of a Sonic Retrieval Probe (SRP). The work included design, analysis, and reporting in accordance with the requirements and deliverables specified in the updated Statement of Work (SOW) for the Sonic Retrieval Probe written by M. N. Hall, initially dated April 9, 1996. To accomplish the objectives of the program the following tasks were defined.

- **Task 1. Design**—During the program, the design was developed to the point that detailed shop and fabrication drawings can be developed by a competent design engineering firm.
- **Task 2. Analysis**—The analysis included definition of the loading, design calculations, dynamic analysis, stress analysis of critical areas, and detailed life assessment of the bearings and structure.
- **Task 3. Drafting**—Sufficient drawings have been provided so that the Final Design Package can be used as a bid package for the development of detailed shop and fabrication drawings. In addition, the AutoCad drawings files used to develop these drawings will be delivered under separate cover.

This document describes the design for the SRP prepared by SwRI in accordance with requirements defined by Westinghouse Hanford Company (WHC) (Hall, 1996).

The SRP is a transportable waste retrieval tool designed to enhance baseline mixer pump technology. The heart of the system is the active vibrating element, which consists of an eccentric mass internal rotary vibrator. The vibrator is driven by an electric motor through a long drive shaft. The active element, intermediate sections, support/isolator, and motor/controller form the SRP.

In this design, the SRP is supported by a structural assembly and an isolation system fixed to a slab on top of the tank. The vibration isolation system and support structure design minimizes transmission of energy to the tank structure through the riser. The SRP penetrates into the tank through a 150-pound, 12-inch flange to be located at riser No. 25, as defined by WHC Drawings H-2-37772, H-2-37773, H-2-37776, and H-2-37792. A double-seal system is provided at the interface between the flange and the SRP to contain the purge nitrogen in the interior volume of the SRP.

The SRP converts shaft power to compression sound waves, which propagate radially from the eccentric mass vibrator active element located inside the waste tank in direct contact with the waste sludge. The active element is powered by an AC electric induction motor located on top of the waste tank that is controlled by a variable frequency/speed drive remote to the tank. Coupling the electric motor with the active element is a drive shaft confined and supported by a flexible torque-tube system. Both the active element and flexible torque-tube are sealed to prevent any waste from getting inside the SRP.

For the purpose of this document, SRP design is discussed as five basic units: (1) Active Section with Speed Augmenter; (2) Intermediate Section(s); (3) Upper Section; (4) Support, Isolation, and Seals; and (5) Drive Motor/Controller. A perspective drawing of the SRP is given in Figure 1.

The active section is a direct adaptation of the design developed in SwRI Project 17-6355, "Conceptual Design of the Sonic Probe" (SwRI, 1994). The overall length of the active element is approximately 10 feet and includes nine active sections and the speed augmenter. The bearings and lubrication system were selected to achieve the specified service life. The speed augmenter was designed to ensure that the drive shaft rpm (20 Hz, 1200 rpm) is acceptable and the required frequencies can be obtained at the active section [30 Hz (1800 rpm) to 70 Hz (4200 rpm)]. As part of the analysis, the life of the active section was estimated based on the operating speed. Design allowances were made to break the seal weld and remove the attachment bolts at the interface to the lower intermediate section so that this unit can be serviced and transported as a separate item.

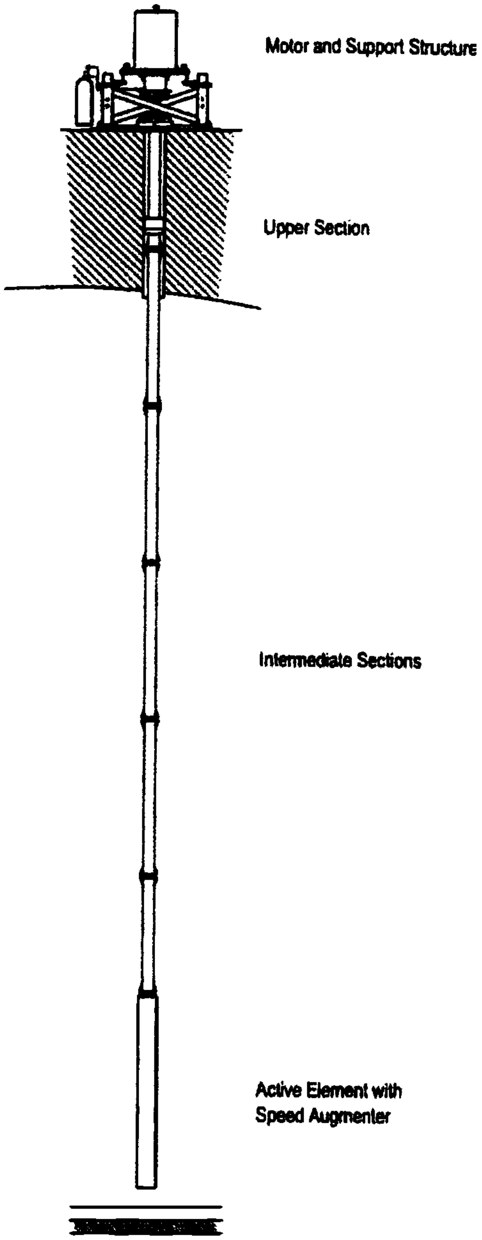
The intermediate column of the mixer pump design was used as a basis for the standard intermediate section of the SRP. Details were obtained from Lawrence Pump Inc. (LPI) "Installation, Operation and Instruction Manual" (LPI, 1996) and the detailed design drawing set for the advanced design mixer pump (ADMP). Modifications were made to accommodate installation in a 12-inch riser and selection of bearings and lubrication system to achieve the required 500-hour design life. A standard intermediate section is 8 feet long and consists of a stainless steel torque tube and a drive shaft. The drive shaft is supported by bearings located 9 inches from the ends of the torque tube. The drive shaft is also 8 feet long, but is offset to one side to facilitate installation of couplers between sections. The ability for remote separation of the intermediate sections

Weight Summary (lbs)

Active Element	2,200
Intermediate Upper Sections	2,800
Motor	1,800
Motor Support Plate	1,200
Support Structure	2,500
Total	10,500
Lift Weight (Includes Strongback)	15,000
Weight on Isolation Springs	8,000

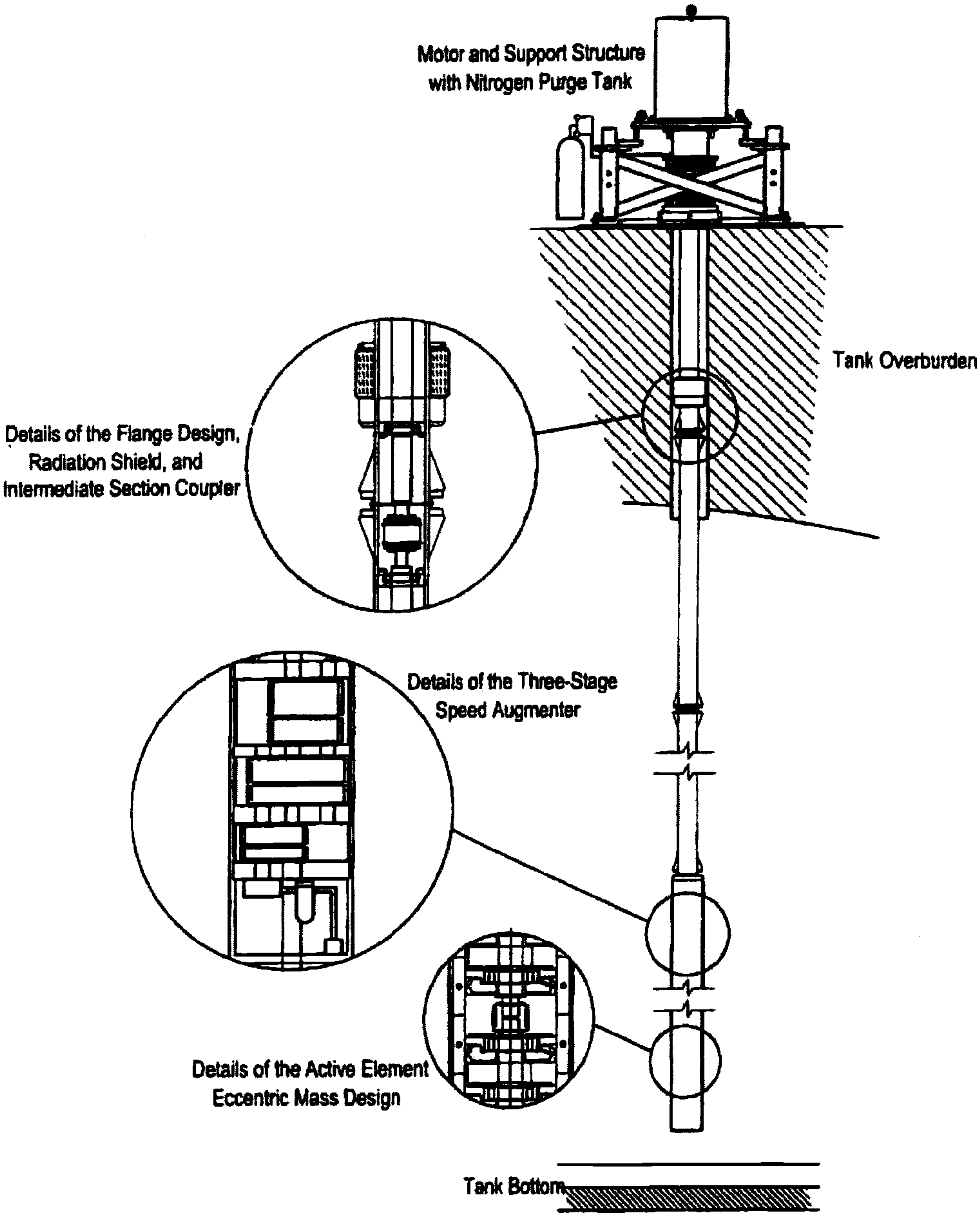
Operating Speeds

Drive Shaft	7.9 to 18.5 Hz 475 to 1105 rpm
Active Section	30 to 70 Hz 1800 to 4200 rpm



(a)

Figure 1. Sonic Retrieval Probe: (a) Overview of SRP Geometry; (b) Details of SRP



(b)
Figure 1 (Cont'd). Sonic Retrieval Probe: (a) Overview of SRP Geometry; (b) Details of SRP

provided by the LPI/ADMP design was also used as a basis for the design of those elements in the SRP. To allow for different length configurations of the SRP, special 4- and 6-foot sections are provided which can be inserted in the string as necessary. Again, the flange design makes allowances to break the seal weld and remove the attachment bolts so that the sections can be serviced and transported as separate items.

The design of the upper section is a direct adaptation of the intermediate section design. A radiation shield is provided as part of the upper section. The lower portion of the shield consists of two 3-inch-thick steel donuts, one welded to the inside diameter (ID) and one welded to the outside diameter (OD) of the torque tube. These are located just above the lower bearing support. An additional 3-inch-thick steel donut, with clearance for the drive shaft, is placed on top of the riser flange. An inflatable bladder is provided immediately above the lower radiation shield to seal the region and provide a soft cushion to ensure that the SRP does not bang into the walls of the riser.

The major structural support and isolation for the SRP is a concrete slab above the tank rather than to the riser. The probe and motor are designed to "float" on the concrete slab, and are connected to the 12-inch riser only by a bellows, to maintain confinement as required to plug the riser. The design of the support structure allows for variations in the height of the concrete slab as well as limited height adjustment of the entire SRP in 6-inch increments. The support structure is also designed to allow removal of the motor from the SRP for independent servicing. The isolation system is similar to that used on the original design of the Sonic Probe. The springs and isolation dampers were selected based on calculations for the operational loads of the SRP.

The motor specified is a commercially available system of the appropriate grade and class for the operating environment. It is a vector-controlled motor system which will allow accurate speed control as well as provide the required torque. The 125-hp electric motor is mounted on top of the probe to the vibration isolation support frame/SRP interface. To ensure proper operation of the lubrication systems, the direction of rotation of the motor must be counterclockwise. Allowance for a ratchet system built into the motor to prevent clockwise rotation is highly desirable.

The SRP is intended to be transportable and fit on any double-shell tank at Hanford. The design permits decontamination and reuse in different tanks. Installation in the tank can be accomplished with or without the motor attached to the probe. Several options are provided for storage and transportation. The entire SRP with motor can be placed in a horizontal cradle for storage or transportation. It is also possible to transport the system in sections. As indicated earlier, the motor support design permits removal of the motor from the assembly. The design of the attachment flanges between the intermediate sections and the intermediate section to active element allows for separation at these joints. This is accomplished by removal of the seal weld and then the attachment bolts. The individual sections can then be stored or transported in either horizontal or vertical orientations.

The SRP does not have a primary safety function (other than a riser plug) and therefore can be handled differently than the original design (SwRI, 1994). A double-seal system is provided at the interface between the flange and the SRP to seal the riser. In addition, radiation shields are also included in the design. The system exterior is designed to allow for easy decontamination. The decontamination system will be provided by WHC.

Table 1 is a summary of the design requirements established for the SRP by WHC.

WHC shall own the design of the SRP, and all intellectual property developed during this effort shall be owned by WHC.

This document is organized in the following format. Details of the final design are given for each of the major subsystems in Section 2. General descriptions, discussion of the design basis, drawings, and parts lists are included. A summary of the supporting design analysis—design calculations, dynamic analysis, and life assessment—are provided in Section 3. Detailed analysis results are contained in a separate document.

Sections 4 through 7 cover the acceptance test procedures; installation, transportation, and lifting; startup, operation, and shutdown procedures; and maintenance. Acceptance tests of the system must be performed to validate the design prior to utilization of the SRP in a waste tank at Hanford. Installation procedures have been provided. The SRP has a number of dynamic modes within the normal operating range of the active element. Therefore, preliminary startup, operation, and shutdown procedures have been established. These procedures will require modification based on the as-built condition. Preliminary maintenance guidelines are given along with transportation and lifting considerations. The SRP has been designed to be lifted using a single-point lifting system with a strongback.

Table 1

SONIC RETRIEVAL PROBE REQUIREMENTS

Requirements	Sonic Retrieval Probe
Attach to 12-inch, 150-pound flange riser	Confinement only
Maximum insertion diameter, inches	11
Include lifting lugs for installing and handling	Yes
Imbalance per active element section, oz-in	200
Maximum total probe weight, lb	10,000
Active section weight, lb	2200
Operating frequency range, Hz	30 (1800 rpm) to 70 (4200 rpm)
Time to accelerate to 1800 rpm	5 sec
Vibration isolation from riser, oz-in	<26
Total operation design life, hours	500
Duty cycle	100 starts/stops
Radiation dose, cumulative 10 years	3×10^7 R
Handling shock load, g	10
Flammable gas service (Group B)	Pertains to motor only
Barrier requirements between tank environment and drive motor	One Class 1, Division 2 Group B, separation to nonclassified
Lower end of probe	Flat type
Instrumentation in or on probe	None
Analysis using Finite Element (FEA)	Vibration
Test acceptance criteria	Yes

Section 4 of the SOW contains a number of codes and standards that are generic and not applicable to this program. SwRI designed the probe to "industry standards" for this program. These codes and standards are identified in this document, and their relationships to those given in the SOW are contained in Section 8. References are found in Section 9.

Lastly, Appendix A consists of the drawings developed during this program. Appendix B is the motor specification for the SRP.

There are two supporting documents which exist apart from this final design package. The first is the supporting analysis document that contains details of the analysis performed to arrive at this design. The final design package contains only summaries of the results. The second is the AutoCad™ drawings files. The files were generated using Revision 13 C-3 of the AutoCad™ program. These files contain details of the design not given in this report. All drawings were done to scale so they can be directly used to obtain detailed information of the design.

2. FINAL DESIGN

For the purpose of this document, the design of the SRP consists of five basic units:

- Active Section with Speed Augmenter (Section 2.1)
- Intermediate Section(s) (Section 2.2)
- Upper Section (Section 2.3)
- Support, Isolation, and Seals (Section 2.4)
- Drive Motor/Controller (Section 2.5)

The active section is a direct adaptation of the design developed in the original Sonic Probe program (SwRI, 1994). The active element is slightly over 10 feet long and includes nine active sections and the speed augmenter. One of the critical design elements was the selection of the bearings and lubrication system for the eccentric mass shaft. SKF NUP-311 ECM cylindrical roller bearings were selected based on their load-carrying ability. To achieve the specified service life, they are lubricated with an oil system to reduce the operating temperature, a controlling factor on bearing life. Each individual section has a short shaft, which is connected to its neighbors through a coupler, KSD-270. This coupler transmits torque with little bending, axial, or side loads. In this way, the loads on each segment can be isolated from the adjacent sections.

The second critical design element was the speed augmenter. It was designed to ensure that the drive shaft rpm (<20 Hz, <1200 rpm) is acceptable and the required frequencies can be obtained at the active section (30 to 70 Hz, 1800 to 4200 rpm). The speed augmenter is a chain-driven system with three stages to achieve the required speed increase. Again, an oil system is incorporated into the speed augmenter design to ensure adequate life. Design of the attachment flange to the intermediate sections was based on strength and allowances to break the seal weld and remove the attachment bolts at the interface to the lower intermediate section. This ensured that the active section could be serviced and transported as a separate item.

The intermediate column of the mixer pump design (LPI, 1996) was used as a basis for the intermediate section of the SRP. A standard intermediate section is 8 feet long and consists of a stainless steel torque tube and drive shaft. The drive shaft is supported by bearings located 9 inches from the ends of the torque tube. The drive shaft is also 8 feet long, but is offset to one end of the torque tube to facilitate installation of the couplers between sections. The length of the intermediate section was based on ensuring that the lateral bending mode of the shaft was at least 1.5 times the maximum operating speed of this shaft (>30 Hz = 1.5 x 20 Hz or >1800 rpm). Different length configurations of the SRP are obtained by using unique 4- and 6-foot sections, which can be inserted into the string as necessary. Again, the design of the flanges makes allowances to break the seal weld and remove the attachment bolts so that the sections can be serviced and transported as separate items.

The design of the upper section with seals is a direct adaptation of the 8-foot intermediate section. A steel radiation shield is provided as part of the upper section near the lower bearing. An inflatable bladder is provided immediately above the lower radiation shield to seal the region and provide a soft cushion to ensure the SRP does not bang into the walls of the riser. The shaft of the upper sections is 104.53 inches long to allow for direct interface with the motor. Allowances are made at the interface to the riser to seal the system and ensure that radiation and waste products are not released from the tank through this path. The interior of the SRP structure is pressurized with a nitrogen cover gas, supplied by an external source. This pressurization further prevents ingress of waste from the tank into the interior of the SRP.

The major structural support and isolation for the SRP is to the concrete slab above the tank rather than to the riser. The probe and motor are designed to "float" on the concrete slab and are connected to the 12-inch riser only by a bellows, to maintain confinement as required to plug the riser. The design of the support structure allows for variations in the height of the concrete slab, as well as limited height adjustments of the entire SRP in 6-inch increments. This, combined with the 4- and 6-foot intermediate sections, allows for an overall variation in length from 50.5 to 58 feet using five 8-foot-long standard intermediate sections. If the total number of intermediate sections varies, the length range can be even greater. The support structure is also designed to allow removal of the motor from the SRP for independent servicing. With only slight modifications to the design, the seals on the upper section and motor shaft can be accessed for servicing. The springs and isolation dampers were selected based on responses of the SRP due to operational loads. Adjustments may be made during the acceptance testing.

The motor specified is a commercially available system of the appropriate grade and class for the operating environment. It is a vector-controlled motor system to obtain accurate speed control as well as provide the required torque. Modifications to the motor shaft are required to interface to the upper section coupler and allow for manual rotation of the motor during installation.

The design is intended to allow the SRP to be transportable and fit any double-shell tank at Hanford. The SRP is also designed to be easily decontaminated for reuse in different tanks.

The design of the SRP has been developed to a final design stage supported by design calculations and analysis. Detailed shop and fabrication drawings can be produced by a competent design engineering firm from the design presented in this document. Drawings of the critical elements are provided in this report to be used as a basis for the initial cost estimate and can be used as a bid package. As shown in Table 2, the primary elements of the SRP include the following:

Table 2

OVERVIEW OF ASSEMBLY DRAWINGS

Element	Source	Drawing Number(s)
SRP Top Assembly	From previous design and mixer pump combined	H-6-14340
Active Section Assembly	From previous design	H-6-14348
Intermediate Section Assembly	Based on mixer pump	H-6-14345
Upper Section Assembly	Based on mixer pump	H-6-14346
Support, Isolation, and Seals Assembly	Based on previous design	H-6-14347
Drive/Motor	Commercially available system	See attached Motor Specification, Appendix B

The basis for the design of the SRP was the set of requirements given in Table 1. The source of the design was the original design of the Sonic Probe (SwRI, 1994) and the radioactive waste mobilization mixer pump design (LPI, 1996). Consideration of the requirements listed below was made during the design process:

- Functional Requirements
- Strength Requirements
- Lateral and Rotational Dynamics
- Life Requirements.

The sonic probe has been designed using commercially available parts where possible. These parts include roller bearings for supporting the eccentric weights and drive shaft, drive motor, couplings for the active and intermediate sections, isolator supports, steel for constructing the sonic probe, grease, lubricants, etc. Critical parts are given in this document for cost estimation purposes. All the specified components were carefully selected to ensure that they can withstand the operational loads as well as the radiation and thermal environments surrounding the SRP.

Steel parts used in the fabrication of the SRP will be supplied under the designation and standard practices of American Iron and Steel Institute (AISI) and the standards of Society of Automotive Engineers (SAE) and ASTM, where applicable. Materials certifications will be required of all materials used to allow for Quality Assurance (QA) control.

During the design development, assembly of the SRP itself was a major consideration. The SRP presented in this design can be assembled and disassembled for maintenance and repair as necessary. Examples of the consideration given to probe assembly are evidenced in the design of the individual eccentric mass segments and the modular nature of the intermediate sections. The nine eccentric mass segments are assembled and connected by couplings, followed by the two main halves of the SRP being bolted together. The completed subassembly is then installed in a steel tube to isolate it from the waste in the tank. The intermediate sections are all identical and can be manufactured as a subassembly. These subassemblies can then be connected in a string to build up the desired length of the probe. Depending on the depth of the tank, the number of intermediate sections can be varied to place the active element at the proper depth in the waste.The upper section is a special design to fit within the constraints of the 12-inch riser.

Another consideration of the design was installation, transportation, and storage of the SRP. Lifting lugs are provided on the support structure to allow for insertion and removal from the tank riser using a crane. A decontamination system, supplied by WHC, will wash the SRP as it is removed from the tank to allow for safe handling of the equipment. Allowances are made for removal of the motor from the SRP when the SRP is mounted on the tank. This was done to allow for independent servicing of the motor. The joints between the intermediate sections and the intermediate and active sections are designed so they can be mated and decoupled in the field. This will allow for independent servicing of the various elements as well as storage and transportation as segments. In addition, the SRP can be stored and transported as a unit in the horizontal position. Details of the transportation and lifting considerations are given in Section 5.

2.1 Active Element

The heart of the SRP is the active vibrating element, which is an eccentric mass internal rotary vibrator, as shown in Drawing H-6-14348. The drawings are found in Appendix A. The active element is a direct adaptation of the active element developed in the original design of the Sonic Probe (SwRI, 1994). Design of the active element is similar to a concrete vibrator in which an eccentric mass is spun within a rigid housing. The spinning mass causes the rigid element to produce compressive sound waves that propagate radially in the surrounding fluid. A life of 500 hours and an operating speed of 30 to 70 Hz were the key elements in the design of the active element.

The overall length of the active element is approximately 10 feet, including the speed augmenter and attachment adapter. It is constructed from a series of nine imbalance steel weights (Figure 2) rotating about a common axis concentric with the vertical axis of the SRP. Each of the sections is designed to have a 200 oz-inch imbalance. The eccentric mass (26.14 lbs) is made up of an imbalance weight, shaft, and coupler. The imbalance weight is 16.65 pounds with a cg offset of 0.789. The imbalance weight will be made of AISI-SAE 4130 steel to ensure adequate life.

Details of the configuration of the eccentric mass sections are found in Drawing H-6-14349. Drawing H-6-14348 shows the lowest section and how the bottom of the SRP is sealed. Drawing H-6-14349 is a typical eccentric mass section that is repeated sufficient times to get the required length. Each of the nine sections has a short shaft (2.1654-inch OD) that is supported by two cylindrical roller bearings. The ends of the shaft are stepped down to interface to the couplings (KSD-270), which transmit the full torque but limited bending moments, axial, and lateral loads. By isolating the individual sections, the loads on the individual bearings and the overall assembly can be reduced.

The assembly of an eccentric mass, with its shaft and support bearings, is contained in a heavy-walled (1.188-inch-thick) cylinder. The heavy-walled cylinder is fabricated from AISI 1026 steel round mechanical tubing (11-inch OD and 1.5-inch wall). The nine eccentric mass assemblies are interconnected by couplings, and the individual half-shell heavy-walled cylinders bolted together. This interconnected assembly of nine eccentric masses is then contained within another steel tube with an OD of 11 inches and a wall thickness of 0.25 inch. The thin-walled tube pipe will be made of Type 316L austenitic stainless steel. This material was chosen because of its corrosion resistance.

Because of the unique nature of the active element, the design is based on standard engineering practice and manufacturer's design procedures rather than an existing procedure. The mechanical design of the active element was performed by SwRI using standard methods and practices of mechanical engineering. Hand calculations, spread sheets, Finite Element Analysis (FEA), and vendor-supplied information were used to complete the design. Off-the-shelf components were used to minimize design and fabrication costs and time where possible. Table 3 identifies the drawings that give details of the design of the active element.

Table 3

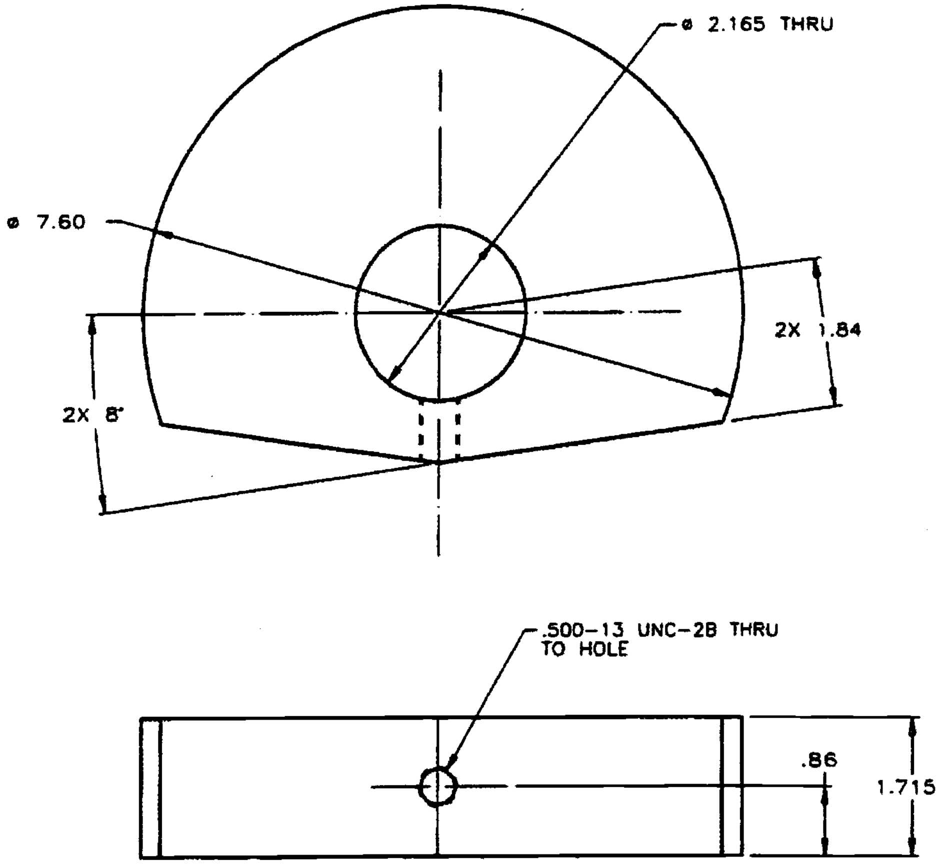
DETAIL DRAWINGS OF ACTIVE ELEMENT OF THE SONIC RETRIEVAL PROBE

Description	Drawing(s)
Active Element Overview	H-6-14348
Details of Imbalance Weight Geometry	Figure 2
Details of Typical Eccentric Mass Assembly	H-6-14349
Details of Speed Augmenter	H-6-14350

The bearings were selected based on a system life above the required 500 hours. Vendor-supplied equations and constants, implemented in spreadsheets, were used to determine bearing life. The key variables which control bearing life include time distributions at speed, type of bearings, number of bearings, and load life factors. The key factors in bearing selection are listed below:

> *Life*—the number of revolutions (or hours) that the bearing runs before the first evidence of fatigue develops in the material of either the race or in the bearing.
>
> *Rating life* (L_{xh})—for a group of apparently identical bearings is the number of hours that (100 - X)% of a group will complete or exceed before the first evidence of fatigue develops.
>
> *Basic load rating*—is that constant stationary radial load which a group of apparently identical ball bearings with stationary outer rings can endure for a rating life of 1 million revolutions of the inner rings. Based on a 500-hour design life and operation at 4200 rpm, the total number of cycles expected on the active element is 126 million. This large number was taken into consideration in the selection of the bearings.

The eccentric mass bearings are SKF NUP-311 ECM, which have a design life of L_{2h} greater than 1000 hours at 4200 rpm. There are a total of eighteen bearings, two each for each of the nine assemblies. The bearings are cylindrical roller bearings with a 55-mm (2.1654-inch) bore, a 120-mm (4.7244-inch) OD, and a depth of 29 mm (1.1417 inches). For oil lubrication, the basic load rating as supplied by SKF is 31,000 lb_f per bearing with a speed rating of 5,600 rpm. The load on a single bearing produced by the eccentric mass operating at 70 Hz is 3,400 lb_f. This is less than 11 percent of the basic load rating at operating conditions (3,400/31,000). Therefore,



ECCENTRIC MASS

SCALE 1/1

MAT'L AISI-SAE 4130

Figure 2. Details of Imbalance Weight Geometry

the bearings will have an acceptable life. The bearing will be a light press fit to the line-bored bearing mount (OD) and slip fit between the bore and shaft. The lower bearing will be a slip fit on both the inner and for the upper bearing outer bearing races, with a key on the outer race to ensure it does not orbit. Using supplied bearing data, approximately 5 horsepower is consumed by overcoming bearing friction in the active element.

The KSD-190 couplers were originally chosen because of their size and torsional stiffness. During the dynamic analysis of the SRP, it was determined that a torsional mode of the active element occurred at 70.5 Hz. This is too close to the upper end of the operating speed (70 Hz); therefore, the coupling was changed to a KSD-270. This increased the coupling stiffness by approximately 60 percent.

Modifications to the original speed augmenter design (SwRI, 1994) were made to ensure that the drive shaft rpm was acceptable and the required frequencies can be obtained at the active section [30 to 70 Hz (1800 to 4200 rpm)]. To meet the operating frequency range specified in the SOW, the speed of the drive motor is increased by a factor of 3.8 times by the speed augmenter. This was accomplished by using three chain-driven stacks (Drawing H-6-14350). The three stacks are necessary because of the required speed factor and limited volume. Chain drive was selected because of the load-carrying capabilities. The efficiency of the speed augmenter in the active section was calculated to be 94 percent.

A 3/8-inch HV chain was selected for the design. For the various stages, the chain width was selected to keep the load under the maximum allowed. This should result in an acceptable chain and sprocket life. Table 4 shows the sprocket sizes and teeth used.

Table 4

DETAILS OF SPEED AUGMENTER DESIGN

Stage	Driver Gear Diameter/ Number of Teeth	Driven Gear Diameter/ Number of Teeth	Chair Width (in.)
One	3.827/32	2.278/19	5.0
Two	3.348/28	2.278/19	3.5
Three	3.468/29	2.278/19	2.5

An additional consideration in the design of the speed augmenter was the selection of the appropriate bearings based on size constraints and loads. The upper stage is heavily loaded and requires the use of an NUP 2306 ECM bearing. Based on the design loads, this bearing exceeds the 500-hour design requirement and is considered to be the limiting factor in the design. The other bearings are not as heavily loaded and use the following bearings: NUP 2307 ECM, NUP 2305 ECM, and 6408. The 6408 seals will have to be replaced by a secondary supplier to get radiation-resistant seals.

The assembly of the active section is done by building up the center core of the probe first. The interior of the active section contains split machined segments formed from commercial thick-wall tubing stock. Two thick-wall tubes will be cut axially to make a single active section. These split segments are keyed together and held together by bolts. Each individual eccentric mass rotating element is assembled into the lower segment half, starting from the lowermost element and working toward the top. As each element is completed, it is joined to the element above it by means of a flex coupling. The upper end of the active section contains the speed augmenter. It is joined to the upper active element using the same coupling. The upper segment half is then bolted onto the lower segment half. The inside machined surface of these split sections hold the bearing supports, which are made from bar stock and lined bared to ensure proper alignment. The bearing supports will be welded into the split lower segment. After fabrication of the nine assemblies of the active section is complete and the upper adapter attached, the thin-walled exterior tube is slipped over the assembled inner section and seal welded shut. The disassembly process for the active section of the SRP is the reverse of the assembly process.

2.2 Intermediate Section

It was determined that the drive shaft and intermediate section drawings for the LPI/ADMP (LPI, 1996) are applicable to what was needed for an SRP driven by a shaft. Therefore, this portion of the mixer pump design was used as a basis for the intermediate section of the SRP. Modifications were made to accommodate installation in a 12-inch riser, increasing the length to 8 feet per section, and selection of bearings and lubrication system design to achieve the required life. The ability for remote separation of the intermediate sections provided by the LPI/ADMP design was also used as a basis for the design of those elements of the SRP. For the preliminary design, a total of five intermediate sections will be utilized in the SRP. Table 5 lists the drawings giving details of the intermediate section.

Table 5

DETAIL DRAWINGS OF INTERMEDIATE SECTION OF THE SONIC RETRIEVAL PROBE

Description	Drawing(s)
Intermediate Section Overview	H-6-14345
Details of the Intermediate Section Shaft	H-6-14345 (Sheet 2)

The overall length of each intermediate section is 8 feet. The main structure of the section is a 6-inch-diameter Schedule 80 pipe (Drawing H-6-14345). This pipe will be made of Type 316L stainless steel. Flanges are welded to each end for connection to adjacent sections. Power is transmitted through a single shaft (Drawing H-6-14345, Sheet 2) that is supported by two bearings (SKF 6212 single row deep groove ball bearings). All 6212 bearing seals will have to be replaced by a secondary supplier to obtain radiation-resistant seals. They have a design life of L_{2h} greater than 1000 hours at the operating load and 1109 rpm. The bearings have a 60-mm (2.3662-inch) bore, a 110-mm (4.3307-inch) OD, and a depth of 22 mm (0.8661 inch). For grease lubrication, the basic load rating is 10,700 lb_f per bearing at a speed rating of 6000 rpm. The estimated load on the worst bearing is 250 lb_f. This is roughly 2 percent of the basic load rating at operating conditions (250/10,700). Therefore, the bearings are anticipated to have an acceptable life. The bearings will be press fit to the bored bearing mount (OD) and slip fit between the bore and shaft. The bearing mounts are located approximately 9 inches from ether end of the pipe section. This allows for fabrication by welding of the bearing support on the ID of the pipe. This also put the centers of the bearings 78 inches apart. Chevron radiation-approved grease or a functional equivalent will be used to lubricate the bearings. Using supplied bearing data, approximately 6 horsepower is consumed by overcoming bearing friction in all the intermediate sections.

The basic diameter of the drive shaft is 2.5 inches with steps to accommodate the bearings. This shaft size was selected based on the required torque transmitted and the lateral bending modes of the shaft based on an assumption of simply supported end conditions. Details of the shaft are given in Drawing H-6-14345, Sheet 2. The spline geometry was based on that given in the LPI/ADMP (LPI, 1996). Calculations have been made to verify its design. The shaft on the LPI/ADMP was made of Type 17-4PH precipitation hardened steel. Similar material will be used for the SRP

The mechanical design of the intermediate section was performed by SwRI using standard methods and practices of mechanical engineering. Hand calculations, spread sheets, FEA, and vendor-supplied information were used to complete the preliminary design. Off-the-shelf components were used to minimize design and fabrication costs and times where possible.

The assembly of the intermediate section is done by first welding the flanges and braces on the ends of the pipe. The bearing supports are then welded in place and bored to accept the bearings. Note that the shaft is offset by 3 inches to one end to facilitate the installation of the flexible coupler (modified Gam/Jakob KSS-700). The intermediate section is then ready for connection to the adjacent sections through the bolted flanges. The shafts are coupled through a spline connection in the flexible couplers. It should be noted that various numbers of intermediate sections can be used to accommodate a variety of tanks. For this preliminary design, the number was set to five for a total length of 40 feet. According to the data available to SwRI, four 8-foot sections and one 6-foot section should put the SRP within 6 inches of the bottom of the tank. The disassembly process for the intermediate of the SRP is the reverse of the assembly process.

2.3 Upper Section

The basic design of the upper section with seals was based on the LPI/ADMP (LPI, 1996). The decontamination system will be provided by WHC. Modifications were made as necessary to fit within the 12-inch riser and achieve the desired life. These were parallel changes made to the intermediate section. The major differences between the upper and intermediate sections are the addition of the radiation shield, the addition of the boot retainer, and the extension of the drive shaft.

The radiation shield is two 3-inch-thick steel donuts welded to the ID and OD of the torque tube just above the lower bearing (Drawing H-6-14346). A clearance is allowed around the shaft for rotation. A 1/2-inch gap is provided between the shield and the riser wall to ensure that the SRP does not bang into the riser. To further ensure this does not happen, a boot retainer is placed immediately above the radiation shield. The boot will act as a soft stop for motion of the SRP as well as provide a seal between the SRP torque tube and the wall of the riser.

The overall length of the shaft has been extended to allow for direct interface to the motor shaft (Drawing H-6-14346, Sheet 2). The shaft on the LPI/ADMP was made of Type 17-4PH precipitation hardened steel. Similar material will be used for the SRP.

The mechanical design of the upper section was performed by SwRI using standard methods and practices of mechanical engineering. Hand calculations, spread sheets, FEA, and vendor-supplied information were used to complete the preliminary design. Off-the-shelf components were used to minimize design and fabrication costs and times where possible. Table 6 lists the drawings giving details of the upper section.

Table 6

DETAIL DRAWINGS OF UPPER SECTION OF THE SONIC RETRIEVAL PROBE

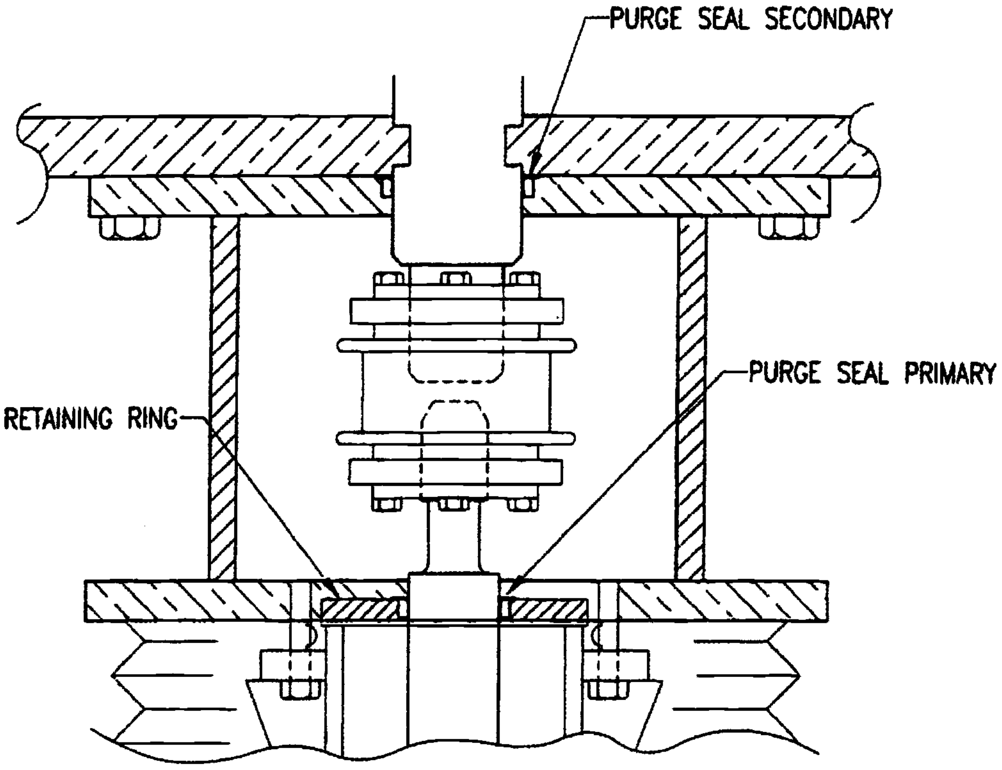
Description	Drawing(s)
Upper Section Overview	H-6-14346
Details of the Upper Section Shaft	H-6-14346 (Sheet 2)

2.4 Upper Support, Isolation, and Seals

The interface requirements for the SRP to the tank are given in Table 1. Based on these requirements, the support structure will interface directly to a 12-inch flange with a configuration similar to Riser No. 25 on WHC Drawings H-2-37772, H-2-37773, H-2-37776, and H-2-37792. A bellows system is provided at the interface between the upper section interface plate and the top of the riser, along with the shaft seal of the SRP to seal the riser (Figure 3). A second seal is provided at the interface of the motor shaft and the motor support plate. These seals will provide an effective seal with the shaft operating at its design speed.

The entire SRP assembly rests on a concrete slab on top of the tank and penetrates into the tank through a 150-lb, 12-inch flange (Drawing H-6-14347). This is to minimize transmission of energy to the tank structure through the riser structure. The probe and motor are designed to "float" on the concrete slab, and are connected to the 12-inch riser by a bellows used to maintain confinement as required to plug the riser and the centering device. The support structure centering mechanism is provided to position the SRP directly over the center of the riser. Bolting the support structure to the concrete slab will ensure that it does not move on the concrete slab during operation (Drawing H-6-14347, Sheet 2).

The support structure rests on four 18 by 18 inch support pads bolted to the concrete slab.It is assumed that the slab has sufficient strength to support the nominal 1200-psi loading. Standard



PART NO. BAL SEAL U-R317-H13-417-SPL-316

Figure 3. Purge Seals Details

square structural tubing is used for the vertical members of the support. The outer tube is connected to the base plate through a height adjustment device. This will allow for accommodation in the heights at the support points. An inner square structural tube allows for the height of the SRP to be adjusted from 0 to 18 inches in 6-inch increments. The upper portions of the four square tubes are welded to a steel plate. This portion of the support structure, along with the centering device, is placed on the concrete slab and aligned with the riser. The four support pads are bolted to the concrete slab. The heights of the legs are adjusted until the plate is level to ensure that the SRP can be installed properly.

The remainder of the support structure is attached to the SRP prior to installation in the tank. Two 1-inch-thick steel plates are welded to the ends of a short section (9 inches) of 12-inch Schedule 80 pipe. This structure is designed to support the entire weight of the SRP, including the 10g drop loading. The upper section interface plate, which supports the upper end of the bellows and contains the shaft seal, is then bolted to the upper section flange. An interface plate is then bolted to the upper plate. The isolation system consists of 24 spring and bolt combinations that run between this large interface plate and a secondary support plate.

The isolation system given in this design is similar to that used on the design of the Sonic Probe (SwRI, 1996). The basis for this design is selection of the springs to provide isolation at the running speeds of the SRP. For this design, the running speed of the motor is assumed to be up to 1100 rpm and between 1800 and 4200 rpm for the active sections. No dampers are specified because of the inherent damping of the structure and that of the boot retainer. If during the acceptance testing dampers are determined to be necessary, they can be added. An alternative approach would be to use a design similar to that proposed by WHC. This design consists of a series of bladders captured between metal surfaces and was not developed in any detail.

The motor is mounted to an interface plate and can be installed on the support structure prior to or after installation of the SRP in the tank (Drawing H-6-14347). Alignment dowels are provided in this plate to ensure proper positioning of the motor with respect to the SRP drive shaft. In addition, allowances are made for manual adjustment of the motor shaft position to interface with the coupler.

The mechanical design of the support, isolation, and seals was performed by SwRI using standard methods and practices of mechanical engineering. Hand calculations, spread sheets, FEA, and vendor-supplied information were used to complete the final design. Off-the-shelf components were used to minimize design and fabrication costs and times where possible. Table 7 lists the drawings that give details of the support structure.

Table 7

DETAIL DRAWINGS OF SUPPORT, ISOLATION, AND SEALS OF THE SONIC RETRIEVAL PROBE

Description	Drawing(s)
Support, Isolation, and Seals Overview	H-6-14347
Purge Seals Details	Figure 3
Support Structure Details	H-6-14347 (Sheet 2)

2.5 Drive Motor Specification and Source List

The active element is powered by an AC electric induction motor located on top of the waste tank that is controlled by a variable-frequency/speed drive remote to the tank. A copy of the motor specification is found in Appendix B. The motor specified is a commercially available system of the appropriate grade and class for the operating environment. The 125-hp electric motor is mounted on top of the probe with a vibration isolation support frame/probe interface. The critical speed of the drive shaft for the SRP is lower than the LPI/ADMP design due to the smaller diameter riser size, but is still above the 1100-rpm operating speed. The drive shaft of the motor will have to be modified to accommodate interface to the SRP. This requires shortening of the shaft, reduction of the shaft OD to accommodate the coupler, and machining of flats for a spanner wrench to adjust the position of the motor during installation.

Based on initial contacts with vendor, the major concern is the requirement for a specified grade and class. In most cases, motor of this size are nonspark-producing, but have not been explicitly qualified for the specified grade and class.

2.6 Commercial Parts Specification and Source List

The commercial parts established for this preliminary design are given in Table 8. Additional elements will be added to this list as the design proceeds.

Table 8

COMMERCIAL PARTS ESTABLISHED FOR PRELIMINARY DESIGN OF SONIC RETRIEVAL PROBE

Item	Manufacturer	Identification	Number Required
Active Element Bearings	SKF	NUP-311 ECM	18
Bearing Grease	Chevron	NRR-159	Gallon
Active Element Couplers	GAM/JAKOB	KSD-270	9
Active Element Speed Augmenter Chain 1	Morse	3/8" x 3" & 2"	1 (40 links)
Active Element Speed Augmenter Chain 2	Morse	3/8" x 2" & 1.5"	1 (52 links)
Active Element Speed Augmenter Chain 3	Morse	3/8" x 1.5" & 1"	1 (42 links)
Active Element Speed Augmenter Sprocket 1A	Morse	3/8" 32 teeth	1
Active Element Speed Augmenter Sprocket 1B	Morse	3/8" 19 teeth	1
Active Element Speed Augmenter Sprocket 2A	Morse	3/8" 28 teeth	1
Active Element Speed Augmenter Sprocket 2B	Morse	3/8" 19 teeth	1
Active Element Speed Augmenter Sprocket 3A	Morse	3/8" 29 teeth	1
Active Element Speed Augmenter Sprocket 3B	Morse	3/8" 19 teeth	1
Speed Augmenter Lubricant	Chevron	NRR-360	3 Gallons
Active Element Thick-Walled Pipe 20'	Ryerson	1026	1
Active Element Thin-Walled Tube 0.25"	TBD	Type 316 SS	1
Active Element Miscellaneous Hardware	TBD	NA	TBD
Intermediate Section Bearings	SKF	6212-RS2	10
Upper Section Bearings	SKF	6212-RS2	2
Intermediate Section Couplers	GAM/JAKOB	KSS-700	6
Intermediate Section Couplers	GAM/JAKOB	KSS-1150	1
Intermediate Section Pipe 6" Schedule 80	TBD	Type 316 SS	5
Upper Section Pipe 6" Schedule 80	TBD	Type 316 SS	1
Upper Section Bellows	TBD	Type 316 SS	1
Intermediate and Upper Section Miscellaneous Hardware	TBD	NA	TBD
Support/Isolator Miscellaneous Hardware	TBD	NA	TBD
Drive Motor/Controller	Magnetek	445TC	1
Speed Augmenter Bearings	SKF	NUP 2307 ECM	2
Speed Augmenter Bearings	SKF	NUP 2306 ECM	3
Speed Augmenter Bearings	SKF	NUP 2305 ECM	2
Speed Augmenter Bearings	SKF	6824-RS2	1

3. SUMMARY OF ANALYSIS

Some results of the analysis task have already been reported in the previous sections during discussion of specific hardware components. The analysis ranged from a definition of structural loading to life assessment of the bearings and structure. The design of the SRP was analyzed by a combination of basic strengths of materials and finite element analysis (FEA) techniques, which evaluate structural responses to a number of loading conditions. Based on these responses, stresses in the critical structural elements were calculated and compared to allowable values. The initial sizing of the structural components and selection of components was accomplished using classical methods of analysis. Additionally, detailed structural analysis was performed using FEA methods, implemented in the computer programs Images 3-D™ (Celestial Software, 1994), ABAQUS™ (Hibbitt, Karlsson & Sorensen, Inc., 1995), and ANSYS™ (ANSYS, 1995). Only limited results are presented in this report; detailed results are contained in the supporting analysis report.

The following conclusions were made based on the analysis presented in this report. The actual frequencies specified may change due to changes in the couplers in the active section and the results of the acceptance testing.

(1) A strongback is required for a single point lift of the SRP at the motor support lifting eyes.

(2) The SRP has sufficient strength to withstand the 10-g vertical drop load based on stress in the upper section, stress in the speed augmenter housing, bearing on the concrete slab, and stress in the support legs.

(3) The dynamic response of the system requires that caution be exercised during startup and shutdown to ensure that time at resonances is limited. In addition, run conditions may be limited based on the results of the acceptance testing.

(3a) Startup will require rapid acceleration up to the active section initial frequency of 25 Hz to 40 Hz to transition through the first torsion resonances of the pipe and shaft.

(3b) Operation of the preliminary design (KSD-190 couplers) is limited to 60 Hz because the third torsion resonance of the shaft is at 70.5 Hz. This can be increased to the required 70 Hz by increasing coupling stiffness (approximately 60 percent) of the active section coupler (KSD-270 couplers).

(3c) Rapid acceleration to the operating frequency of 70 Hz is required to reduce response at the second torsion resonance of the shaft.

(3d) Shutdown procedures will be the reverse of the startup procedures, except that more time will be required to ensure adequate cooldown.

(4) Stresses in the rotating mass, speed augmenter housing, intermediate section flanges, and critical upper section torsion tubes are below the fatigue limit of the materials at operating conditions.

(5) Bearing life in the active element and the intermediate and upper sections is greater than the 500-hour design life.

(6) Life of the speed augmenter bearings, chains, and sprockets is greater than the 500-hour design life.

3.1 Load Definition

The loads on the SRP were divided into two major cases: (1) construction, handling, and installation and (2) operation. The first is considered an equivalent static loading condition. Construction and handling loads are addressed in the use of good engineering practice for the design of the various structural elements. The installation loads include those encountered during lifting of the SRP from a horizontal position to the vertical position for installation in the tank. In addition, a 10-g drop load is specified to account for problems that may be encountered during installation. For this specific load, the SRP does not have to be functional after the drop, just remain intact so that it can be removed. For all other loading, the SRP must remain operational following the application of the load.

An initial consideration is the installation of the SRP into the tank. Based on the assumptions of a uniform beam subjected to a single point lift at the motor support plate, it is necessary to use a strongback for this operation to limit stress levels in the torque tube. This is discussed in detail in Section 5.

Installation loads also include a 10-g vertical accident condition. For this case, the SRP is assumed to fall during installation, resulting in an equivalent 10-g static load. The resulting vertical load on the concrete slab above the tank is ten times the weight of the SRP and the suspended portion of the support structure (8,500 pounds). Loading on the riser itself will be minimized because of the design of the support structure. To ensure that the SRP does not separate and damage the integrity of the tank, it must be shown that the resultant stresses in the probe are below the ultimate strength of the material.

The operational load case is the most difficult to define because of the influence of fluid on the dynamic response of the SRP. The three-dimensional motion of the SRP active section during normal operation has not been defined in detail because of the inherent complexities. A simplified 2-D response model was used during the analysis. Normal operational load considered in the design included two different load cases: (1) steady state operation in water and (2) startup and shutdown in water. It is likely that the waste material in the tanks will have physical characteristics that will further limit the response of the SRP during normal operation. Therefore, the water case is considered the bounding analysis.

Response to the steady state operation conditions was based on dynamic analysis at a discrete active element operating frequency near the upper end of the operational range of the SRP. During inservice operation, the SRP will not be run at resonances, so these conditions can be considered worst-case responses. Two separate operational speeds need to be considered. In most cases, the specified operational speed is that of the active section. The operational speed of the drive shaft will be 26 percent of that of the active section.

The startup and shutdown load cases in water are transient events. The active element will begin to spin up to the initial speed after the electric motor is commanded to start. The rate of increase in speed is dependent on the characteristics of the electric motor and the resistance of the rotating elements of the active section and shafts to changes in speed. For the SRP, the electric motor has sufficient power to drive the elements, and the controlling factor will be the drive signal applied to the electric motor. As indicated in Section 6, the pump rate will be approximately 10 Hz/sec. An important consideration in the selection of the vector control motor was its accurate speed control and full torque capabilities throughout its operating range.

The response characteristic of the SRP will be controlled, in part, by the fluid in which the system operates. The equations of motion of the combined structural and fluid system can be defined in terms of:

$$(m_{structure} + m_{fluid})\ddot{x} + (c_{structure} + c_{fluid})\,\dot{x} + k_{structure}\,x = f(t)$$

where:

$m_{structure}$ – mass of structure
m_{fluid} – mass of displaced fluid
$c_{structure}$ – damping of structural system
c_{fluid} – damping of fluid
$k_{structure}$ – stiffness of the fluid
$f(t)$ – forcing function

The mass and stiffness values associated with the structural elements are derived directly in the FEA process. The damping of the structure was defined in terms of modal damping. For a uniform slender beam, the modal damping is small; <0.5 percent is typical. Because of the bolted flanges connecting the various sections together, the actual damping of the SRP may be higher than this value. Verification of the modal damping characteristics will be made during the acceptance testing.

Typically, structural motion in a fluid is affected by the added mass of the fluid and the effective damping of the fluid on the structural response. The effective stiffness of the fluid can be ignored because of its limited resistance to shearing. For this case—a high-density small-diameter active section—the added mass of the fluid is insignificant. The value of the effective damping is difficult to quantify. Calculation of the damping of a moving structure in a stationary fluid was based on the procedures defined in (Blevins, 1990). The calculation for the original sonic probe was given in Appendix D.2.2 (SwRI, 1994) and was used as a basis for this analysis. A basic assumption for the formulation is that the structure is under harmonic motion. For water, the empirically derived damping values vary from 0.16 percent (at 0.1 Hz) to 0.01 percent (at 70 Hz). The effective damper, c_{fluid}, is calculated as a product of the modal mass, frequency, and damping. Therefore, it will increase with operating frequency and varies from 0.01 to 0.31 lbsec/inch over the frequency range of 0.1 to 70 Hz.

Steady state operation in water is a dynamic load case with the active section driving the system. Some input will also come from the rotation of the drive shaft, but this will be minimal because of the small amount of imbalance present. The excitation is within the frequency range of 50 to 70 Hz with a total offset load of 1800 in-oz (nine sections at 200 in-oz each). For a 2-D model, the excitation is given by:

$$f(t) = F_0 \sin(\omega_n t)$$

where $F_0 = (\textit{offset load})(\omega_n^2)$.

Therefore, the magnitude of the forcing friction varies from 0.1 pound at 0.1 Hz to 56,400 pounds at 70 Hz. Above 14 Hz, the lateral component of excitation is greater than the total weight of the active section.

3.2 Design Calculations

The basic design calculations were used to initially size the various components of the system bearings, shaft sizes, spline configuration, speed augmenter (gears, chains, bearings, and support structure), and basic structural strength of the intermediate pipe section. Note that a large number of components used in this design were based on the original design for the Sonic Probe (SwRI, 1994) and the design of the LPI/ADMP (Lawrence Pump Inc., 1996). Design calculations for those components were checked during this design process. Discussion of the results is given in the Section 2. Details are also contained in the supporting analysis report.

A detailed FEA was performed to verify the integrity of the rotating mass,. It should be noted that during steady state operation, the mass itself is loaded, but the load can be considered static with respect to its reference coordinate system. Therefore, it is not necessary to consider fatigue of the mass. The resulting loads on the shaft and bearing supports are cyclic, and fatigue is a controlling factor. An ABAQUS™ (Hibbitt, Karlsson & Sorensen, Inc., 1995) solid model of the mass was developed and loaded proportional to the 4200 rpm operating condition of the active section. The maximum Von-Mises stress in the mass is less than 5,000 psi. Assuming a worst-case stress concentration factor of 3 for the pin hole used to fix the weight to the shaft, the highest stress is less than 15,000 psi. Therefore, use of a material such as AISI-SAE 4130 (Boyer, 1985) will provide an adequate safety margin.

The maximum axial stress in the upper section of the SRP was calculated to be 5,900 psi for the 10-g vertical accident condition. This value is below the yield strength of the material and the allowable strength (0.7 x tensile strength). Therefore, the upper section will not separate under the assumed loading condition. There is sufficient margin to eliminate any requirement for a redundant system to carry the axial load during this accident condition. The resultant axial load on the concrete slab was 87,500 pounds. This related to an effective loading on the support pads of 68 psi. This is considered acceptable based on allowables for the compressive strength of concrete, and it is likely that the controlling factor will be the design of the footings for the slab.

For this loading condition, the second critical component on the SRP was the structural support of the speed augmenter. The maximum axial stress was calculated to be 870 psi. Therefore, the active section will remain attached to the intermediate sections during this accident condition.

Details of the design calculations for stress in the intermediate section during handling are contained in Section 5. Along with the information provided in this section, these represent the worst-case loading and control the design. Information on other design calculations are contained in the supporting analysis report.

3.3 Dynamic Analysis

Because of the physical restraints imposed on the design, there are both lateral and torsion resonances within the normal operation range of the active element (30 to 70 Hz), as well as the operational range of the drive shaft and motor (7.5 to 18.5 Hz). Note that because of the designed imbalance for the active element, resonances associated with the operating frequencies of active element are critical. Those resonances associated with local response of the intermediate section need to be considered, but are not controlling. Operation of the SRP at any of the resonances for a period of time will damage the probe. Therefore, operational procedures must be established to ensure that transition through them is rapid (10 Hz/sec), and steady state operations are not within 15 percent at any critical resonance. The excess horsepower available in the motor will allow for this rapid transition from one operating frequency to another. Therefore, the number of cycles during which the SRP is at any given resonance will be minimized. If one takes into account the reduction factor due to the rapid transition through the frequency range (SwRI, 1994), the sonic probe can be shown to survive. Because of the damping of the structure and fluid combination, the buildup in amplitude will be minimized.

Note that measurement of the as-built resonances during the acceptance testing is critical in defining the limitations of the operational frequency range. During normal operation in the tank, no instrumentation is available to measure response of the SRP, although accelerometers on the motor support are recommended (see Section 4).

Dynamic FEA analysis was used to determine the basic resonances of the shaft and pipe support to identify those frequencies at which the SRP must not be run during operation. Preliminary strength of materials analysis of the lateral dynamics of the sonic probe was based on the procedures given in Blevins (Blevins, 1979). This was a simplified model based on the effective stiffness of six intermediate sections with a lumped mass representing the active element. The first resonance was calculated to be 0.22 Hz. The resonances are similar to the earlier design (SwRI, 1994); therefore, some confidence in the strength of the new design was established.

A number of beam element FEA models were developed to quantify the dynamic characteristics of the SRP using both Images 3-D and ANSYS. The first was a model of a single intermediate section. The torsion tube section and the shaft physical properties were used in the model. Additional masses were used to represent the weight of the flanges, bearing supports, and coupling. Support conditions for this model were assumed to be a cantilever beam. FEA gives a first lateral bending resonance of the pipe and shaft at 16.7 Hz. The first bending resonance of the shaft on the bearings was at 34.3 Hz, while the first torsion resonance of the shaft was at 217 Hz. The corresponding first torsion resonance of the pipe was at 253 Hz. Although the first lateral bending resonance is within the operating range, it is not considered important because of the influence of the other intermediate sections and the active element in the overall SRP response. The important considerations are the local lateral bending and torsion resonances of the shaft. These are above the operating frequency range of the SRP shaft (<18.5 Hz).

After these initial results were verified by parallel analysis, a detailed model of the entire SRP was developed. The FEM included details of the individual active sections, the speed augmenter, the five intermediate sections, the upper section, the support structure, and the motor. A number of runs were made with different support spring stiffness and variations in the stiffness of the polymer boot seal. This were done to develop bounds on the results..The identification of resonances for the condition with normal support isolation springs and normal stiffness for the polymer boot seal is given in Table 9. Note that the analysis represents the design using the KSD-190 couplings in the active section. Subsequent analysis with the increased torsional stiffness, using KSD-270 couplings, was performed, and results are given in the supporting analysis report.

The important resonances are those below 80.5 Hz, because they can be excited by the active section. This represents the operating range of the active section, 70 Hz, plus a margin of 15 percent to account for as-built conditions and separation of resonances from the operating conditions. Based on these initial results, holes in the operating frequencies will have to be established to ensure that no operations are at resonances. The lowest resonances are the lateral bending resonances of the entire assembly. Both the operating speeds of the active and shaft sections

Table 9

RESONANCES FOR THE SRP WITH NOMINAL SUPPORT AND POLYMER BOOT STIFFNESS

Resonance	Frequency (Hz)	Description
1	0.24	1st Bending (Assy)
2	2.14	2nd Bending (Assy)
3	6.10	3rd Bending (Assy)
4	11.37	4th Bending (Assy)
5	11.78	Axial of Support Springs
6	**13.70**	**1st Shaft Torsion**
7	17.13	5th Bending (Assy)
8	**19.83**	**1st Pipe Torsion**
9	23.77	Shaft and Pipe Bending
10	30.76	Shaft and Pipe Bending
11	31.68	Axial of Intermediate Section Couplers
12	32.80	Axial of Intermediate Section Couplers
14	34.13	Shaft Bending
14	34.39	Axial of Intermediate Section Couplers
15	34.65	Shaft Bending
16	36.61	Shaft Bending
17	36.83	Axial of Intermediate Section Couplers
18	36.91	Shaft Bending
19	37.57	Shaft Bending
20	39.35	Axial of Intermediate Section Couplers
21	**39.58**	**2nd Shaft Torsion Active Section**
22	39.80	Shaft and Pipe Bending
23	41.13	Axial of Intermediate Section Couplers
25	47.83	Shaft and Pipe Bending
26	57.28	Axial of SRP
27	**70.50**	**3rd Shaft Torsion Active Section**
28	71.88	Shaft and Pipe Bending
30	82.88	Shaft and Pipe Bending
31	95.07	Shaft and Pipe Bending
32	98.09	4th Shaft Torsion Active Section

will excite these resonances, making transition time critical. The first axial resonance of the spring supports is at 11.78 Hz. Driving force at this resonance is minimal; therefore, the axial resonances are not considered critical. There are a number of axial resonances that represent local responses due to the lack of axial stiffness in the couplers. The actual conditions will be higher because of the assumptions made in modeling of the shaft restraints in the bearings. Shaft torsion, 13.70 Hz, and torque tube torsion, 19.83 Hz, define the lower range for the initial operating frequency. The initial startup must rapidly drive the active section above these two resonances.

There are a number of intermediate shaft resonances between 34 and 38 Hz. Because of the variations in end conditions, the resonances of the individual sections have been separated slightly. It is recommended that operation in this frequency range be limited. The second shaft torsion resonance is at 39.58 Hz. Transition from the initial frequency to the operating frequency must be rapid to ensure that dynamic response of the resonance does not develop. The final resonance of real concern is the third shaft torsion resonance at 70.5 Hz. This is at the upper extreme of the operating range. To ensure that this resonance does not affect the performance of the SRP, the torsion stiffness of the couplers in the active section was increased by 60 percent by changing from the KSD-190 to the KSD-270 couplers. This increase will also affect the other torsion resonances to some extent. Therefore, the performance of acceptance testing is required to identify the as-built condition.

The resonance analysis results were used as a basis for subsequent modeling of the dynamic loading of the SRP. As indicated earlier, the two conditions analyzed were startup and shutdown and operation at the maximum active element speed. For this analysis, it was assumed that the torsional stiffness of the couplers was increased by 60 percent to drive the third torsional resonance of the shaft out of the operating range. Based on these assumptions, the structural response of the SRP was calculated, and stress in the critical areas and riser loads determined. During startup and shutdown, the assumed acceleration rate was 10 Hz/sec. The resulting build-up in dynamic response of the SRP at resonances was calculated by the FEA code. Because of the high number of cycles during normal operation, to ensure adequate performance, the stress in the members, including stress concentrations, for all conditions must be below the fatigue limit of the material. In all cases, the resulting stresses were below the fatigue limits of the materials. Details are contained in the supporting analysis document.

The controlling factor on the overall response of the system during operation in the waste is the physical properties of the waste material. Under normal operating conditions, it is anticipated that the actual motion of the active element as it precesses will be very much smaller than that calculated for water.

3.4 Design Verification

Design verification is the process of determining if the calculated stresses in the various members are below the allowable stresses based on material properties. The following materials were used in the design of the SRP with material properties based on accepted standards, as given in the supporting analysis document. Type 316L austenitic stainless steel was used in all materials exposed to the internal environment of the tank. This material has sufficient strength, is corrosion resistant, and is weldable. All elements that are welded to these external elements are also fabricated of this Type 316L stainless steel. The shafts are Type 17-4PH precipitation-hardened steel because of its strength and the fact that it was used in the LPI/ADMP design. AISI-SAE 4130 steel is used for the eccentric mass and all other interior elements of the SRP. The thick-walled pipe used to fabricate the active section is AISI 1026. The materials used in the construction of the support structure are ASTM A500 and A283. These materials were selected because of availability, strength, and machinability. Because they are exposed to the environment, they will be protected as necessary. Details of the materials used are contained in Section 2.

The material allowables are based on the information supplied in Section 5.0 of (Strehlow, 1994) and ANSI/AISC N690-1984. For austenitic stainless steel, the allowable stresses are given:

Tension	$F_{tension} \leq 0.60\ F_{yield}$ on the gross area
Shear	$F_{shear} \leq 0.4\ F_{yield}$ on the net area
Compression	Not applicable except on support legs
Bending	$F_{bending} \leq 0.66\ F_{yield}$

all of which are based on the yield strength of the material. The allowable stresses calculated based on these formulation are then multiplied by the appropriate stress limit coefficient. The stress limit coefficient for operational and external loads are:

Normal	1.0
Extreme	1.6

For the SRP, normal loads include live and dead loads due to normal operation as defined in Table Q1.5.7.1 of ANSI/AISC N690-1984. For this case, the extreme load is the 10-g vertical drop. The stress limit coefficient in shear is limited to 1.4 for the extreme classes of operational and external loads.

The second check required is an allowable based on the ultimate strength of the material as defined in (Strehlow, 1994). The allowable stresses based on ultimate strength are:

Tension	$F_{tension} \leq 0.70\ F_{ultimate}$ on the gross area
Shear	Not given
Compression	Not applicable except to support legs
Bending	$F_{bending} \leq 0.70\ F_{ultimate}$ times Z/S

For bending, Z is the plastic section modulus and S is the elastic section modulus. For a circular tube, the value of Z/S is 1.27; for a circular bar, the value of Z/S is 1.70 (Beedle, 1958). Details of the allowables for the materials used in the construction of the SRP are contained in the supporting analysis documentation.

The fatigue evaluation for this design is limited to determination of the stresses during normal operating conditions. For this condition, the stresses calculated during the analysis are associated with the global response of the structure. Based on stress concentrations, these should be multiplied by a factor of 2 to 3 to develop a better understanding of the fatigue characteristics of the SRP. Acceptable fatigue life is assumed based on verification that the stress levels are below the fatigue limits of the materials.

4. ACCEPTANCE TEST PROCEDURES

Prior to operation of the SRP, a functional check must be performed to ensure the structural integrity and operational characteristics of the probe. The following tests are to be performed in a tank of water with a 12-inch riser and concrete slab simulating installed conditions:

- Operational testing in water
- Operational life

During the operational testing, instrumentation will be installed on the exterior of the SRP to characterize the response. Thermocouples will be attached to at least three locations on the exterior of the probe. The primary emphasis will be to measure the outer wall temperature in the location of the active element bearing, the speed augmenter, and the intermediate section bearings. It will be possible to estimate the temperature at the bearings based on a thermal model of the system. This will allow verification of the thermal environment values used in the life calculation for the bearings.

Accelerometers will also be installed on the exterior of the SRP to measure the dynamic response of the SRP. Radial and tangential accelerometers will be installed at a minimum of three locations on the active element and a minimum of three locations throughout the height of the intermediate and upper sections. They will be used to characterize the lateral and torsional response of the SRP under a variety of operating conditions. In addition, several vertical accelerometers will be used to measure the axial response of the system distributed throughout the length of the SRP.

As indicated in Section 6, it is recommended that external triaxial accelerometers be installed on the motor support plate to identify SRP response when installed in a specific tank. The measured response of these accelerometers must be full characterized during this series of tests to ensure that the appropriate information can be identified. The primary concern is to ensure that torsion and lateral bending modes can be identified. The torsional and axial response will be affected by changes in probe length, but not waste properties.

Strain measurements will be made on the surface of the SRP at critical locations. The critical locations are defined as the support pipe between the upper section and the motor support plate (to define loading on the riser), a flange near the top of the SRP, and in the speed augmenter. Rosette strain gauge configurations are recommended.

The operational conditions of the electric motor will also be measured. Note that it is required that the SRP operate in only the counterclockwise direction, and this should be verified at the start of the acceptance testing program.

Data acquisition will include thermal time histories at all thermocouple locations. It will be necessary to extrapolate the temperatures to the bearing locations following the testing. Time histories will also be required for the strain gauges. These will then be resolved into the principal strains at the critical locations.

It will be necessary to perform several weeks of dynamic testing to obtain all the required information necessary to ensure safe operation of the SRP in the tanks. Data acquisition will require both phase and amplitude information to define modes of the system. A state-of-the-art modal testing data acquisition and analysis package is recommended for the dynamic testing.

The dynamic testing will consist of 10 to 20 startups and shutdowns from 0 to the initial frequency. For this current design, the initial frequency is estimated to be 25 Hz. The initial runs need to be made rapidly (10 Hz/sec) to define the critical frequencies in this range. As the frequencies are defined, the range can be adjusted and the transition time changed to allow for acquisition of the required data. It is important to identify the modal damping as well as the frequencies. The next set of tests will be 10 to 20 transitions from 25 Hz up to the maximum operating frequency. Note that care should be taken in slowly stepping up to the highest frequency. Again, the early runs should be made with rapid transitions (10 Hz/sec) to ensure that the SRP is not damaged at resonance frequencies. Later runs can be made at slower transitions to obtain better data. Care should be taken to not run at system resonance during any of this testing.

The final test will be a 24-hour test at the highest operating speed that is safe to run within the 70-Hz limit.

5. INSTALLATION, TRANSPORTATION, AND LIFTING CONSIDERATIONS

5.1 Preinstallation

The motor can be installed before or after installation of the SRP into the tank or test stand. The following steps are required.

- Make sure that the isolation damper has been properly attached between the main support plate and the motor support plate.

- Make sure that lifting lugs on the motor support plate are in good condition and properly installed.

- A strongback must be attached the length of the probe (a minimum beam shape of a W 12 x 99 or W 10 x 100 is required; refer to American Institute of Steel Construction standard). This same strongback could also be used for shipping.

- Make sure that all shipping materials other than the strongback have been removed.

- Make sure that the SRP support stand is properly installed and leveled.

CAUTION: All cranes, hoists, lifting straps, chains, pins, shackles, hooks, and other apparatus shall be rated or tested for the working load. The SRP with motor attached and ready to install in the tank is 8500 pounds. The estimated weight of the strongback is 6500 pounds. A 10-ton or higher rated crane should be used when lifting the SRP. A constant tension shall be maintained on the crane hook at all times. Lift smoothly and slowly while avoiding twisting. If necessary, protect the motor and SRP from cables and chains. Lift the SRP only from the two designated lifting lugs. The SRP support stand has an approximate weight of 2500 pounds and should be handled accordingly.

SPECIAL NOTES: The main support plate cannot be used to support the weight of the probe in the horizontal position without damaging the isolation damper; therefore, the weight of the probe should always be on the motor support plate in the horizontal position. DO NOT use the motor lifting lug positions for the entire SRP. All bolts should be torqued to ASME standards based on grade and size, except the isolation damper spring retaining bolts. The spring-retaining bolts are set to the free length of the springs and locked.

5.2 Lifting the SRP

The SRP will be lifted by the two lifting lugs on the motor support plate only (lugs shown in Drawing H-6-14347). The lifting strap must have a yoke arrangement which allows the cables to straddle the motor during the lifting procedure. All straps and retaining devices holding the SRP to the shipping or transportation cradle will be removed. Clear the surrounding area to provide sufficient space to access, lift, and move the SRP. While lifting the SRP clear of the cradle, keep the crane cable vertical. Once the SRP is clear of the cradle, it can be moved to its destination.

5.3 Lifting the Support Stand

The support stand does not have any specific lifting restraints or lifting lugs. The weight of the total support stand is approximately 2500 pounds. The support stand will have to be lowered level to and straight down over the 12-inch riser. The support stand will be put in place in two parts, the lower support stand first, followed by the upper support stand. The weight of the upper support stand is approximately 2100 pounds.

Order of installation with motor attached:

(1) Bolt on flange adapter and upper radiation shield to 12-inch riser.

(2) Mount lower support stand to 12-inch riser and bolt to concrete slab.

(3) Mount bellows to upper radiation shield.

(4) Position upper support stand at desired height and attach to lower support stand. The support stand must be leveled to within 0.010 inch per foot before the SRP can be installed onto the stand.

(5) Lift SRP to the vertical position and remove the strongback.

(6) Lower SRP onto support stand and bolt in place.

(7) Attach bellows to upper coupling housing.

(8) Pressurize internal cavity of SRP with nitrogen to desired pressure (not to exceed 150 psi).

(9) Make electrical connections to motor. All electrical connections should be checked before power is applied.

(10) Verify counterclockwise motor rotation before probe is operated. Reversing the motor direction will damage the internal probe mechanism.run up.

(11) Pressurize boot retainer to predetermined pressure (10 to 100 psi).

Additional steps for motor installation:

(12) Check probe shaft runout with respect to the register fit in the motor support plate. The total indicated reading (TIR) must be less than 0.006 inch. There should be no change from the last setting if the probe was not released from the motor support plate. A method for checking and aligning shafts is given below.

(13) Check motor shaft runout with respect to the motor adapter plate. The total TIR must be less than 0.006 inch. There should be no change from the last setting if the motor was not released from the motor adapter plate. A method for checking and aligning shafts is given below.

NOTE: The pins in the motor adapter plate will allow for proper alignment between the motor and probe for installation provided that the alignment criteria have been met. If these criteria are not met, it is very likely that the coupling between the motor and probe will experience premature failure.

(14) Mount KSS-1150 coupling to motor shaft.

(15) Lift motor by its lifting lugs over the probe.

(16) Orient the splines on the coupling attached to the motor shaft with respect to the probe splines using the pin points for a reference.

(17) Lower the probe so that the alignment pins are engaged just past the taper on the pins into the motor support plate.

(18) Place the spanner wrench onto the motor shaft in the machined slot provided. As the motor is slowly lowered, it may be necessary to rock the shaft back and forth gently to get the splines to mate properly. Once the splines have been aligned, remove the spanner wrench and lower the motor until the motor adaptor plate contacts the motor support plate.

(19) Bolt motor adapter plate to motor support plate.

(20) Pressurize internal cavity of SRP with nitrogen to desired pressure (not to exceed 150 psi).

(21) Make electrical connections to motor. All electrical connections should be double checked before power is applied.

(22) Verify counterclockwise motor rotation before probe run up. Reversing the motor direction will damage the internal probe mechanism.

(23) Pressurize boot retainer to predetermined pressure.

5.4 Shaft Alignment and Checkout Instructions

(1) Alignment of vertical equipment is best performed when the equipment is in the vertical orientation when measurements are made.

(2) Check the alignment between the registered fit in the plate and the shaft.

(3) Mount a dial indicator on the shaft and set it to read off the registered fit rim facing the shaft.

(4) Turn the shaft one full revolution and note the TIR. If the TIR is greater than the allowed specified for that shaft, then adjustment is necessary. Loosen the bolts that hold the registered fit (bolts holding the plate) with respect to the shaft, and move the plate by 1/2 the total indicator reading in the direction away from the lowest reading.

(5) Tighten the bolts and recheck the TIR. If the TIR is still above the acceptable reading, then repeat steps (4) and (5) until acceptable results are achieved.

6. STARTUP, OPERATION, AND SHUTDOWN

Before the SRP is started for the first time, the resonances should have been determined by tests in the bending, axial, and torsional resonances. This will determine the basic safe operational ranges for the SRP. These values will shift, depending on the depth and type of material the SRP is immersed in and the total length of the SRP. Acceleration or deceleration should be swift at each identified resonance so that the SRP is not excited for any length of time. This will ensure that operation does not damage the SRP. Ramp rates should be on the order of 10 Hz per second.

Startup will consist of reaching two operating frequencies, each with its discrete ramp sequence. The first ramp sequence will be to an initial frequency in the 25- to 40-Hz range. This will allow the oil and grease to move into the bearings and warm up before high-frequency operation. The acceleration to the initial frequency should take approximately 5 seconds, and the SRP will remain at the initial frequency for approximately 5 minutes. This fast acceleration will prevent the SRP from excessively exciting any one resonance and prevent damage to the SRP or tank. Because the resonance varies with the operating conditions, an external set of accelerometers should be installed on the motor support plate to monitor bending, axial, and torsional motion. If the standard predetermined safe frequency is no longer acceptable, the accelerometers will detect this condition and immediately initiate system shutdown. At this point, new safe frequency conditions must be determined for this set of conditions on the SRP. Once this has been done, a new startup can begin.

Once the SRP has warmed up for approximately 5 minutes at the initial frequency, it can be accelerated to the operational frequency (approximately 70 Hz). Again, it must be accelerated quickly to this frequency. The accelerometers should continually monitor SRP operation at the operating frequency. As discussed above, the acceptable operating range will change as the level and condition of the fluid in which the SRP operates and changes in SRP length. The accelerometers will be used for emergency shutdown in case there is sufficient change in the conditions or the SRP operating frequency is approaching an identical resonance. The SRP has been designed for continuous operation and it can be run until the fluid level becomes too low for safe operation or failure of an internal part occurs due to design life. The SRP should exceed 500 hours of operation if the operational guidelines have been followed. The SRP is designed for 100 start/stop cycles, if short runs are desired.

Shutdown operations are the reverse of startup except that a longer time is required for an adequate cooldown period at the initial frequency. A 15-minute cooldown is recommended before shutting off the SRP. This time period will increase the life of the grease-packed bearings. This time period is not required in emergency situations where structural damage to the SRP is imminent or in other safety-related conditions.

The accelerometers discussed above have multiple uses. First, they will help with safety of operation. The accelerometers will monitor shifts in resonances and shut the system down if the resonances occur in the standard operating range. Also, they may be indicate if a bearing is starting to fail before catastrophic failure of the bearing occurs. Early indications of failure should decrease the cost for repair. Second, the accelerometers could be used to change operating conditions away from shifting resonances during operation. The resonant condition will result in increased accelerometer output. A log of the accelerating and decelerating curves should be maintained to track resonance values. It is recommend by SwRI that this instrumentation be incorporated before final operation of the SRP.

Motor operating conditions must be tracked. Motor operating speed must be tracked with the motor controller. This information allows determination of the life of the SRP at actual operating conditions. Also, the current (torque and hp) to run the motor at speed must be tracked. A large deviation from the normal operating conditions could signify bearing or coupling problems.

The accelerometers and motor operating conditions should be sufficient information to keep track of the SRP operation history.

7. MAINTENANCE

There is no standard maintenance required for the SRP. The following items are identified based on good maintenance practices.

- Maintenance requirements for the motor will be supplied by the manufacturer.

- Check all flange mounting bolt torque values prior to installation of the SRP into the tank.

- Perform a visual inspection using 10X magnification of the seal welds at the flange locations prior to installation of the SRP into the tank.

- Manually turn the shaft at the SRP prior to installation of the motor to ensure free running.

- Periodically check the torques on the bolts of the support structure and motor mounting plates.

- Inspect the isolation springs for damage or corrosion.

All other maintenance options require complete rebuilds of the affected element.

8. DESIGN CODES AND STANDARDS

In Table 1 of the SOW, a number of codes and standards are identified as applicable to the SRP design. It was determined that a number of the categories and associated codes and standards are not applicable to the design of the SRP. Rather than perform a detailed review of all the codes and standards, an alternative approach was taken.

The design of the SRP was based on a number of procedures including manufacturing procedures and standard engineering practice. These procedures have been demonstrated to provide acceptable design for mechanical systems. Table 10 identifies the design practices used and reflects the requirements given in the SOW.

Table 10

APPLICABLE DESIGN CODES AND STANDARDS

Category/Application	SOW Requirements	SRP Design Procedures	Comments
Structural	UBC; ACI 318; AISC; UCEL-15910; AWS-D1.1	Strength of materials and FEA to define stresses for comparison to Strehlow, 1994, allowables	Support structure and SRP
Process Equipment–Vessels and Tanks	ASME VIII; API; AWWA-D100; UL-58, UL-142	Specification of appropriate corrosion-resistant steel	SRP within tank
Process Equipment–Piping and Valves	UBC; ASME VIII; ASME B-16.xx, B-31.1, B-31.3, B-31.9; AWWA; Hydraulic Institute Standards	Use of commercially available tubing and fitting with acceptable pressure ratings	Nitrogen purge only
Process Equipment–Pumps	API; ANSI/ASME 373.1M, 2M; ASME VIII; Hydraulic Institute Standards; AWWA, AFMBA	Standard engineering practice to allow for shipping, storage, and operation	Oil pumps for bearing and speed augmenter are specialty designs
Process Equipment–Heat Exchangers	ASME VIII; TEMA; ASHRAE	NA	
Process Equipment–Ducts and Fans	ASHRAE; SMACNA	NA	
Process Equipment–Pre and HEPA Filters	SAHRAE-52.68; ASME/ ANSI-509, 510; MIL-F-51068C	NA	
Mechanical Handling–Cranes	CMAA; ANSI B30.xx; ASME NOG-1	Standard engineering practice as defined in Section 5	Applicable to handling in installation in tank
Mechanical Handling–Other Equipment	ANSI 16.xx; AISC; ANSI N14.6	NA	
Electrical	NEC, NEXC, IES Lighting Handbook; IEEE-57	Motor/Controller Manufacturers Specifications	
Instruments and Controls	ISA; ANS-8.2, N42.18, N13.1	NA	Motor mount accelerometer recommended but not required
Fire Protection	NFPA	Standard engineering practice Group B specifications for motor	
Chemical and Toxicological Hazards	OSHA, AICHE Safety Standards; API Safety Standards; ACGHI Requirements; NEPA	NA	
All Applicable Equipment	OSHA; UL; Local and State Standards; AWS; NEMA; ASTM; ANSI; NEPA	Not used	

9. REFERENCES

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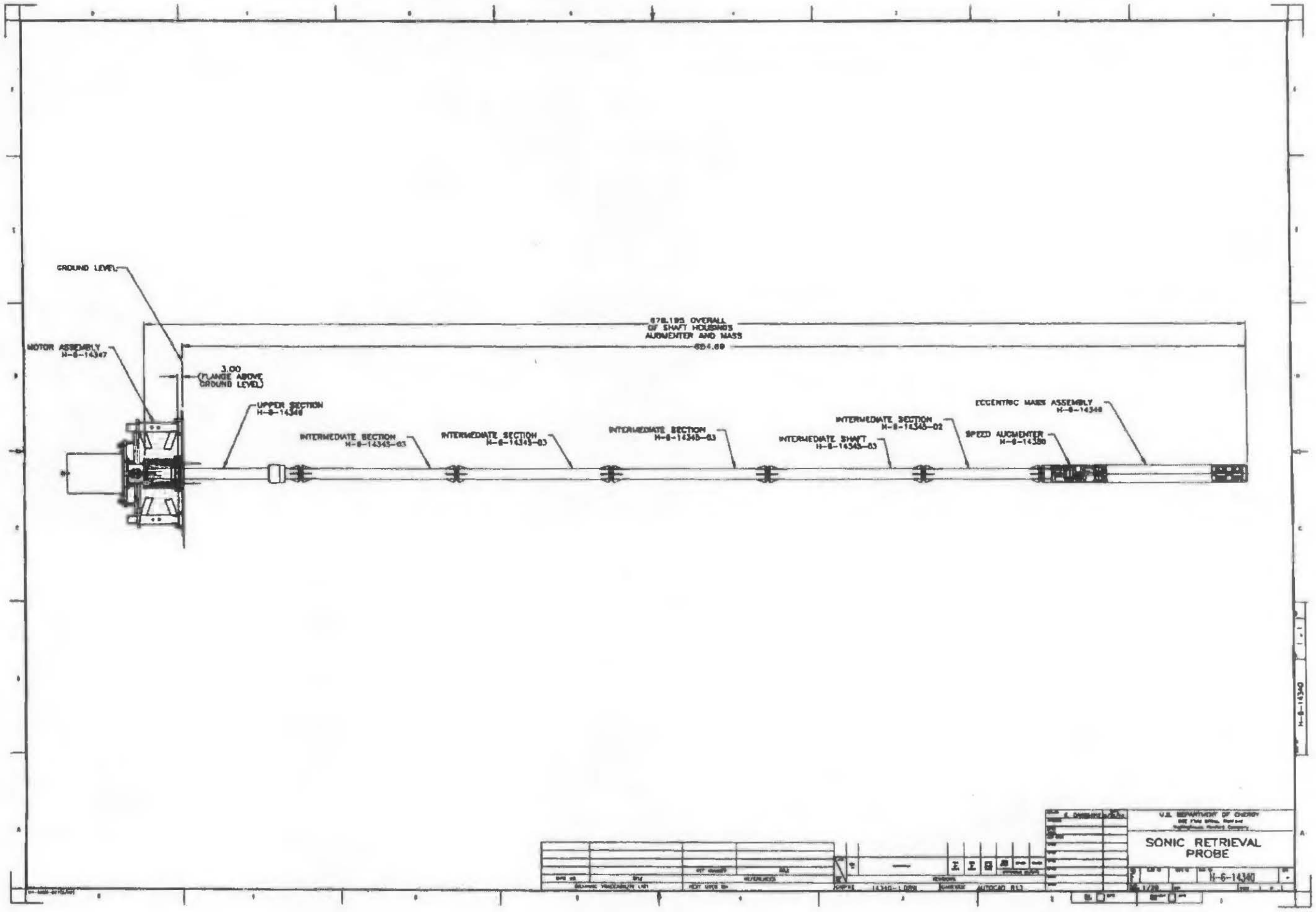
Appendix A

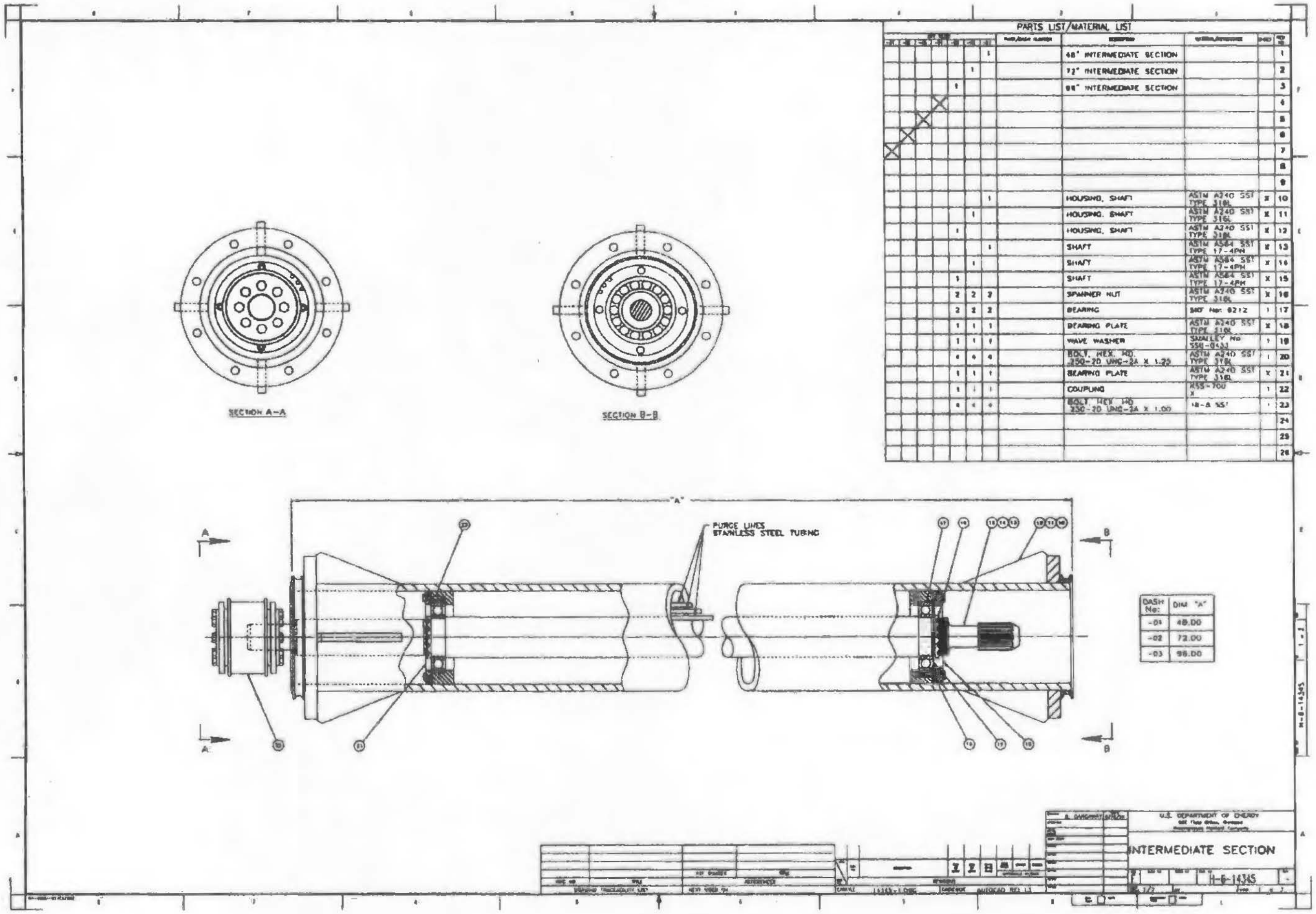
REDUCED DRAWINGS

Appendix A

LIST OF DRAWINGS

H-6-14340	Sonic Retrieval Probe
H-6-14345	Intermediate Section (2 sheets)
H-6-14346	Upper Section (2 sheets)
H-6-14347	Motor Assembly (2 sheets)
H-6-14348	Eccentric Mass Assembly
H-6-14349	Eccentric Mass Segment
H-6-14350	Speed Augmenter


GROUND LEVEL
878.195 OVERALL OF SHAFT HOUSINGS AUGMENTER AND MASS
854.69
MOTOR ASSEMBLY H-6-14347
3.00 (FLANGE ABOVE GROUND LEVEL)
UPPER SECTION H-6-14346
INTERMEDIATE SECTION H-6-14345-03
INTERMEDIATE SECTION H-6-14345-03
INTERMEDIATE SECTION H-6-14345-03
INTERMEDIATE SHAFT H-6-14345-03
INTERMEDIATE SECTION H-6-14345-02
SPEED AUGMENTER H-6-14380
ECCENTRIC MASS ASSEMBLY H-6-14348
U.S. DEPARTMENT OF ENERGY
SONIC RETRIEVAL PROBE
H-6-14340
1/20
AUTOCAD R13
14340-1.DWG



PARTS LIST/MATERIAL LIST

						1		48" INTERMEDIATE SECTION			1
					1			72" INTERMEDIATE SECTION			2
				1				98" INTERMEDIATE SECTION			3
			X								4
		X									5
	X										6
X											7
											8
											9
						1		HOUSING, SHAFT	ASTM A240 SST TYPE 316L	X	10
					1			HOUSING, SHAFT	ASTM A240 SST TYPE 316L	X	11
				1				HOUSING, SHAFT	ASTM A240 SST TYPE 316L	X	12
						1		SHAFT	ASTM A564 SST TYPE 17-4PH	X	13
					1			SHAFT	ASTM A564 SST TYPE 17-4PH	X	14
				1				SHAFT	ASTM A564 SST TYPE 17-4PH	X	15
				2	2	2		SPANNER NUT	ASTM A240 SST TYPE 316L	X	16
				2	2	2		BEARING	SKF No. 6212	1	17
				1	1	1		BEARING PLATE	ASTM A240 SST TYPE 316L	X	18
				1	1	1		WAVE WASHER	SMALLEY No SSB-0433	1	19
				4	4	4		BOLT, HEX. HD. .250-20 UNC-2A X 1.25	ASTM A240 SST TYPE 316L	1	20
				1	1	1		BEARING PLATE	ASTM A240 SST TYPE 316L	X	21
				1	1	1		COUPLING	KSS-700 X	1	22
				4	4	4		BOLT, HEX. HD. .250-20 UNC-2A X 1.00	18-8 SST	1	23
											24
											25
											26

DASH No:	DIM "A"
-01	48.00
-02	72.00
-03	98.00

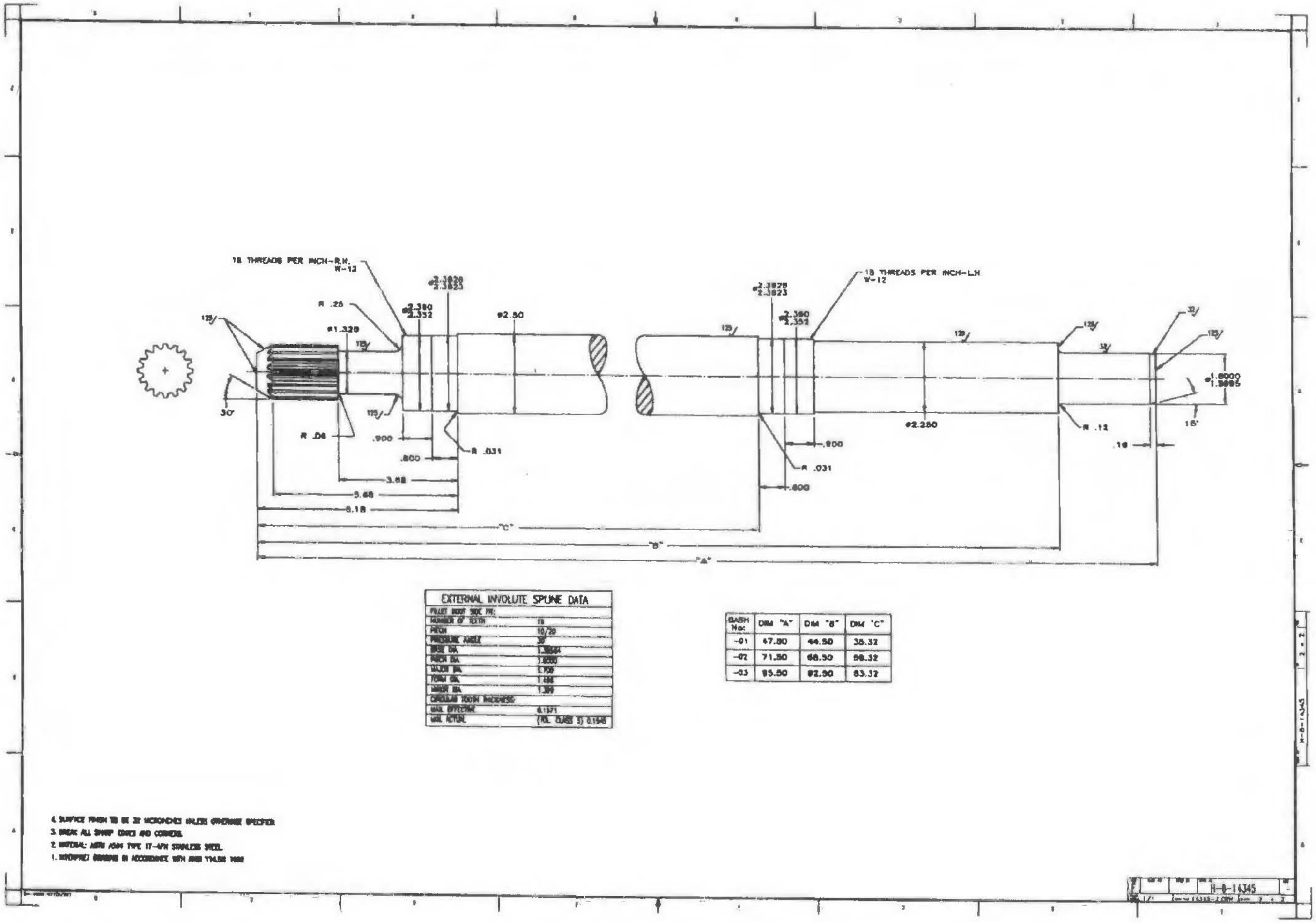
U.S. DEPARTMENT OF ENERGY

INTERMEDIATE SECTION

H-6-14345

14345-1.DWG

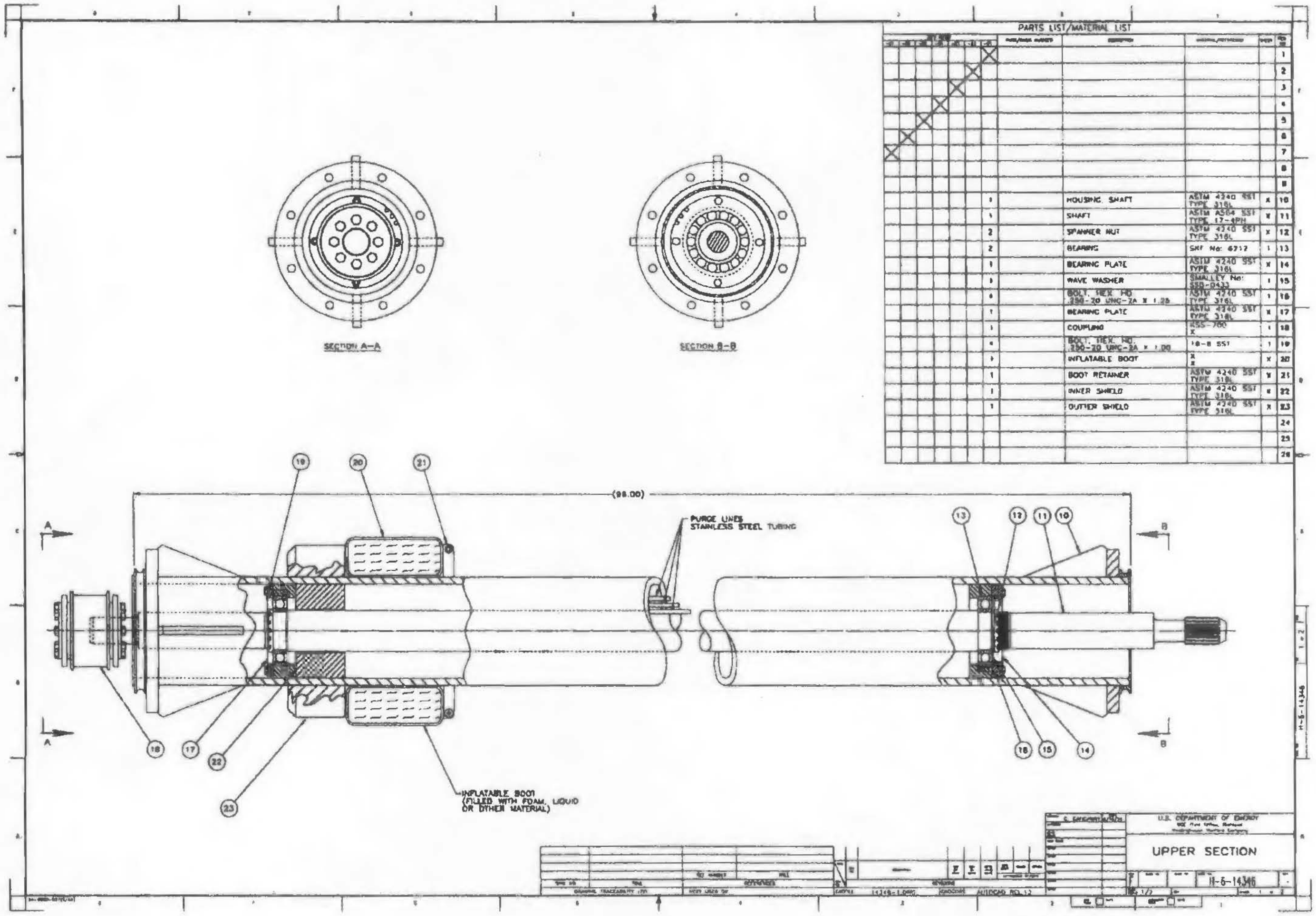
AUTOCAD REL 13



EXTERNAL INVOLUTE SPLINE DATA	
FILLET ROOT SIDE FIT	
NUMBER OF TEETH	18
PITCH	10/20
PRESSURE ANGLE	30°
BASE DIA	1.55884
PITCH DIA	1.8000
MAJOR DIA	1.900
FORM DIA	[illegible]
MINOR DIA	[illegible]
CIRCULAR TOOTH THICKNESS	
MAX. EFFECTIVE	0.1571
MIN. ACTUAL	(TOL. CLASS 5) 0.1548

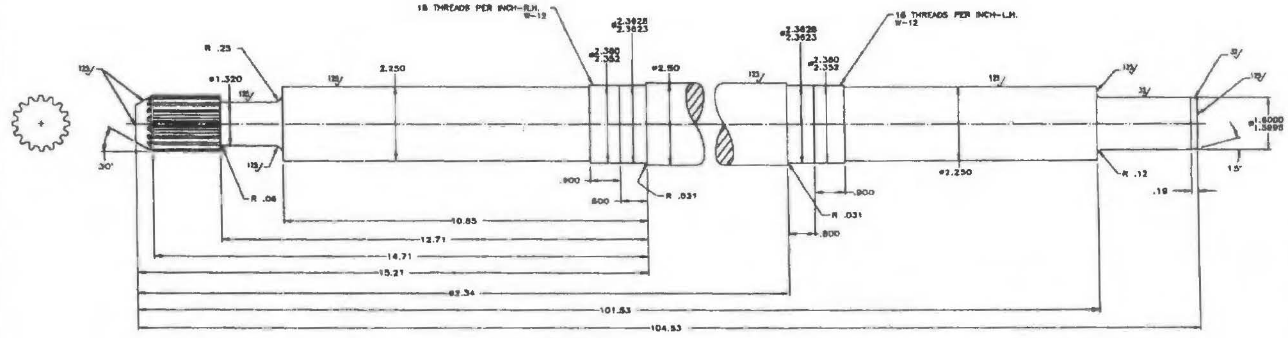
DASH No.	DIM "A"	DIM "B"	DIM "C"
-01	47.50	44.50	35.32
-02	71.50	68.50	59.32
-03	95.50	92.50	83.32

4. SURFACE FINISH TO BE 32 MICROINCHES UNLESS OTHERWISE SPECIFIED.
3. BREAK ALL SHARP EDGES AND CORNERS.
2. MATERIAL: ASTM A564 TYPE 17-4PH STAINLESS STEEL.
1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M 1982



PARTS LIST/MATERIAL LIST

				1
				2
				3
				4
				5
				6
				7
				8
				9
1	HOUSING, SHAFT	ASTM 4240 SST TYPE 316L	X	10
1	SHAFT	ASTM A564 SST TYPE 17-4PH	X	11
2	SPANNER NUT	ASTM 4240 SST TYPE 316L	X	12
2	BEARING	SKF No: 6712	1	13
1	BEARING PLATE	ASTM 4240 SST TYPE 316L	X	14
1	WAVE WASHER	SMALLEY No: SSB-0433	1	15
4	BOLT, HEX HD. .250-20 UNC-2A X 1.25	ASTM 4240 SST TYPE 316L	1	16
1	BEARING PLATE	ASTM 4240 SST TYPE 316L	X	17
1	COUPLING	KSS-700 X	1	18
4	BOLT, HEX HD. .250-20 UNC-2A X 1.00	18-8 SST	1	19
1	INFLATABLE BOOT	X X	X	20
1	BOOT RETAINER	ASTM 4240 SST TYPE 316L	X	21
1	INNER SHIELD	ASTM 4240 SST TYPE 316L	X	22
1	OUTTER SHIELD	ASTM 4240 SST TYPE 316L	X	23
				24
				25
				26



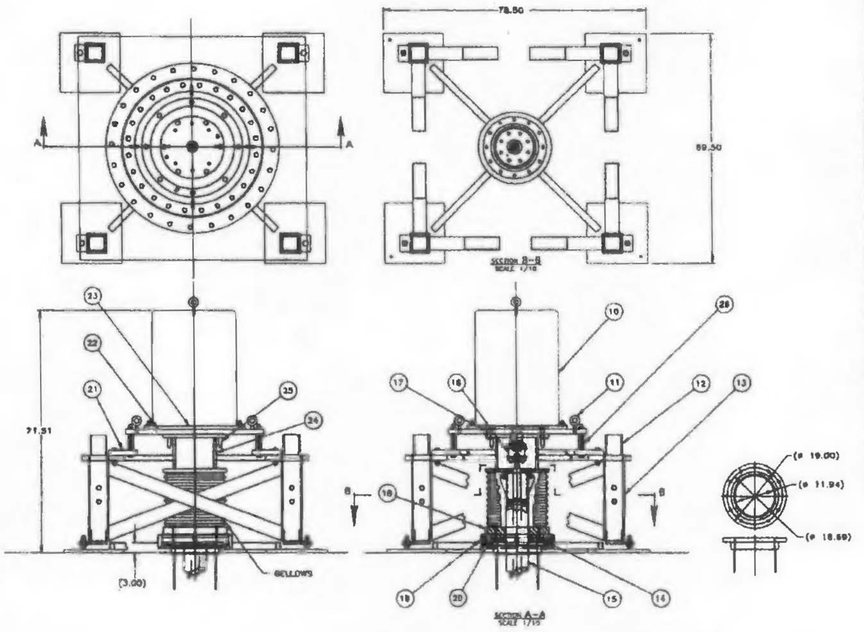
EXTERNAL INVOLUTE SPLINE DATA	
FILLET ROOT SIDE FIT:	
NUMBER OF TEETH	16
PITCH	10/20
PRESSURE ANGLE	30°
BASE DIA.	1.38564
PITCH DIA.	1.6000
MAJOR DIA.	1.700
FORM DIA.	1.496
MINOR DIA.	1.396
CIRCULAR TOOTH THICKNESS:	
MAX. EFFECTIVE	0.1571
MIN. ACTUAL	(TOL. CLASS 5) 0.1545

4. SURFACE FINISH TO BE 32 MICROINCHES UNLESS OTHERWISE SPECIFIED.
3. BREAK ALL SHARP EDGES AND CORNERS.
2. MATERIAL: ASTM A564 TYPE 17-4PH STAINLESS STEEL.
1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M 1982

F H-6-14346
1/1

GENERAL NOTES :

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M (82). DIMENSIONS ARE IN INCHES. TOLERANCE ON DECIMALS , .X = ±.1, .XX = ±.03, .XXX = ±.005, ANGLES ±1°. DIMENSIONING AND TOLERANCING IN FRACTIONS ARE GENERAL DIMENSIONS.
2. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
3. MACHINED SURFACE TO BE $\sqrt{}^{125}$
4. ALL NON-STAINLESS STEEL PARTS TO PAINTED WITH EPOXY PAINT



PARTS LIST/MATERIAL LIST

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X		XXXXXXXX	XXXXXXXX	X	1
					2
					3
					4
					5
					6
					7
					8
					9
1		MOTOR	MAGNETEK 4451C	1	10
5		EYE-BOLT	McMASTER-CARR No. 3013T68	1	11
4		LEG	ASTM A500 GRADE B	X	12
1		STAND	ASTM A283 GRADE C	X	13
X		BOLT, HEX. HD. .500-13 UNC-2A X 4.00	18-8 SST	1	14
1	H-6-14346	MOTOR SHAFT		X	15
1		COUPLING	KSS No. KSS-1150	1	16
X		BOLT, HEX. HD .875-9 UNC-2A X 2.50	18-8 SST	1	17
1		GUARD, RADIATION	ASTM A283 GRADE C	X	18
1		RING, ALIGNMENT	ASTM A283 GRADE C	X	19
1		PLATE, ADAPTER	ASTM A283 GRADE C	X	20
1		PLATE, MOUNTING	ASTM A283 GRADE C	X	21
1		PLATE, MOTOR	ASTM A283 GRADE C	X	22
1		ADAPTER, MOTOR	ASTM A283 GRADE C	X	23
1		EXTENSION, PROBE	ASTM A240 SST TYPE 316L	X	24
2		PIN, ALIGNMENT	ASTM A240 SST TYPE 316L	X	25
24		COMPRESSION SPRING	SPEC CV-2000-6000-365		26
					27
					28
					29
					30
					31
					32
					33
					34
					35
					36
					37
					38
					39
					40

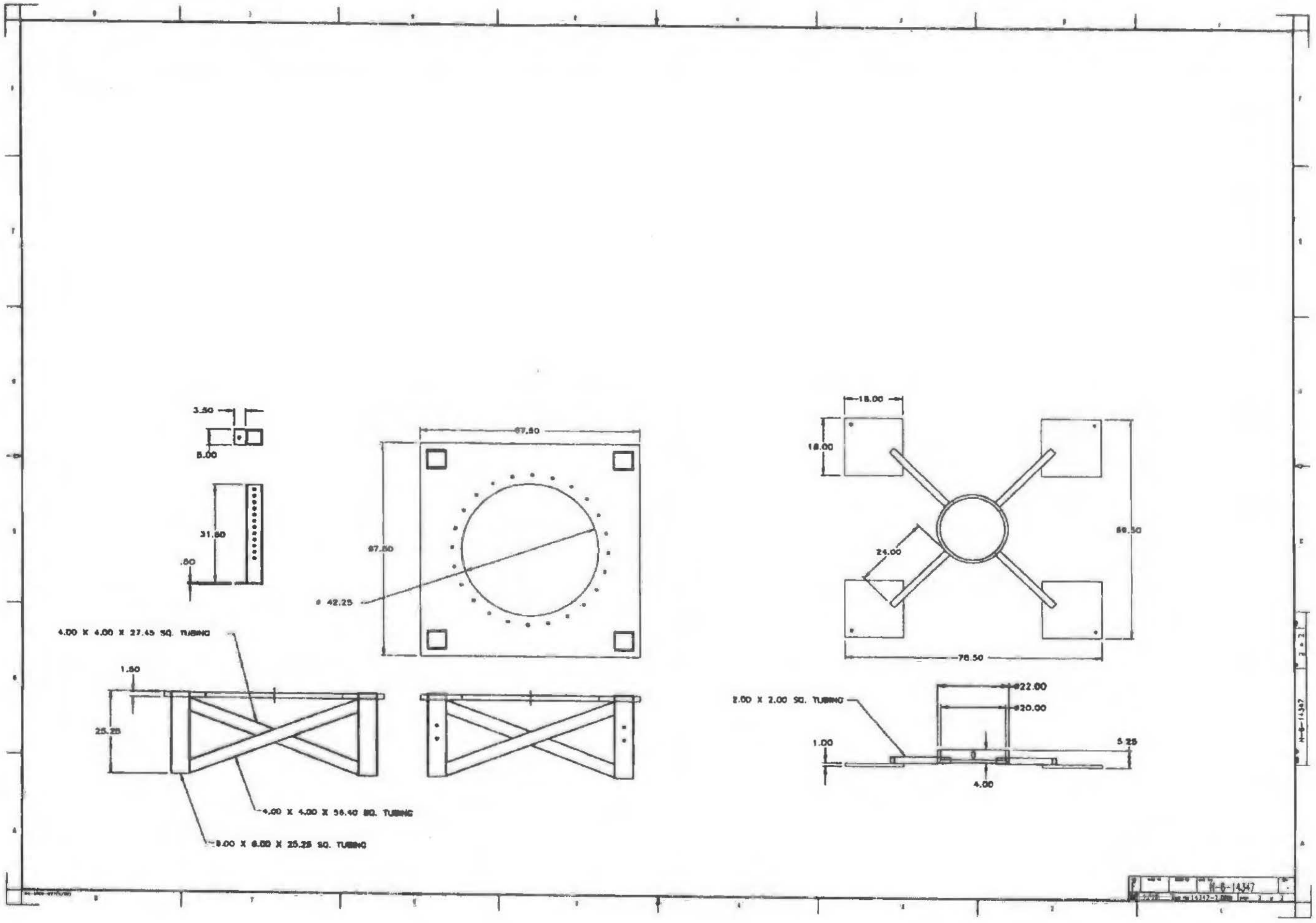
U.S. DEPARTMENT OF ENERGY

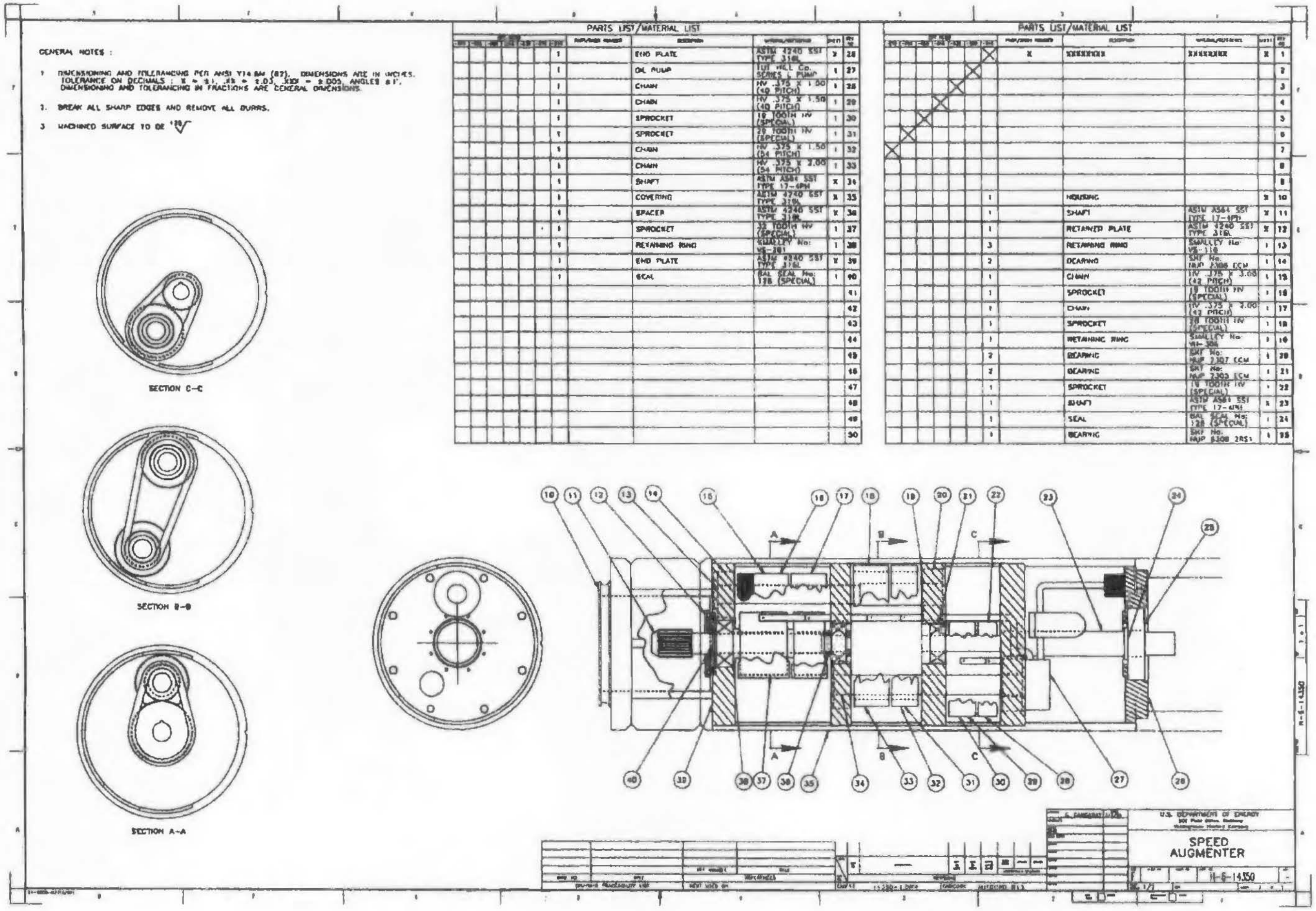
MOTOR ASSEMBLY

H-6-14347

SCALE 1/10

AUTOCAD R13


3.50
5.00
31.50
.50
97.50
97.50
⌀ 42.25
4.00 X 4.00 X 27.45 SQ. TUBING
1.50
25.25
4.00 X 4.00 X 56.40 SQ. TUBING
8.00 X 8.00 X 25.25 SQ. TUBING
18.00
18.00
24.00
69.50
76.50
2.00 X 2.00 SQ. TUBING
⌀22.00
⌀20.00
1.00
5.25
4.00
H-6-14347
2 of 2



GENERAL NOTES :

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M (82). DIMENSIONS ARE IN INCHES. TOLERANCE ON DECIMALS : .X = ±.1, .XX = ±.03, .XXX = ±.005, ANGLES ±1°. DIMENSIONING AND TOLERANCING IN FRACTIONS ARE GENERAL DIMENSIONS.
2. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
3. MACHINED SURFACE TO BE $^{125}\surd$

PARTS LIST/MATERIAL LIST

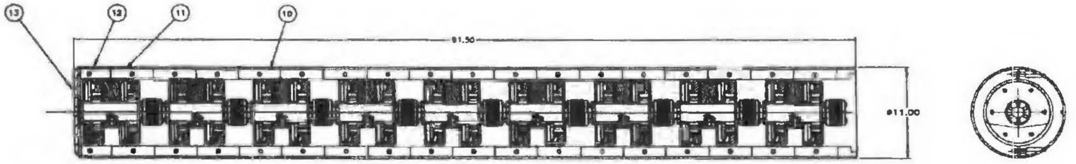
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	X	XXXXXXXX	XXXXXXXX	X	1
					2
					3
					4
					5
					6
					7
					8
					9
1		HOUSING		X	10
1		SHAFT	ASTM A564 SST TYPE 17-4PH	X	11
1		RETAINER PLATE	ASTM 4240 SST TYPE 316L	X	12
3		RETAINING RING	SMALLEY No: VS-118	1	13
2		BEARING	SKF No. NUP 2306 ECM	1	14
1		CHAIN	HV .375 X 3.00 (42 PITCH)	1	15
1		SPROCKET	19 TOOTH HV (SPECIAL)	1	16
1		CHAIN	HV .375 X 2.00 (42 PITCH)	1	17
1		SPROCKET	28 TOOTH HV (SPECIAL)	1	18
1		RETAINING RING	SMALLEY No: WH-306	1	19
2		BEARING	SKF No: NUP 2307 ECM	1	20
2		BEARING	SKF No: NUP 2303 ECM	1	21
1		SPROCKET	19 TOOTH HV (SPECIAL)	1	22
1		SHAFT	ASTM A564 SST TYPE 17-4PH	X	23
1		SEAL	BAL SEAL No: 128 (SPECIAL)	1	24
1		BEARING	SKF No. NUP 6308 2RS1	1	25
1		END PLATE	ASTM 4240 SST TYPE 316L	X	26
1		OIL PUMP	TUTHILL Co. SERIES L PUMP	1	27
1		CHAIN	HV .375 X 1.00 (40 PITCH)	1	28
1		CHAIN	HV .375 X 1.50 (40 PITCH)	1	29
1		SPROCKET	19 TOOTH HV (SPECIAL)	1	30
1		SPROCKET	29 TOOTH HV (SPECIAL)	1	31
1		CHAIN	HV .375 X 1.50 (54 PITCH)	1	32
1		CHAIN	HV .375 X 2.00 (54 PITCH)	1	33
1		SHAFT	ASTM A564 SST TYPE 17-4PH	X	34
1		COVER RING	ASTM 4240 SST TYPE 316L	X	35
1		SPACER	ASTM 4240 SST TYPE 316L	X	36
1		SPROCKET	32 TOOTH HV (SPECIAL)	1	37
1		RETAINING RING	SMALLEY No: VS-281	1	38
1		END PLATE	ASTM 4240 SST TYPE 316L	X	39
1		SEAL	BAL SEAL No: 128 (SPECIAL)	1	40
					41
					42
					43
					44
					45
					46
					47
					48
					49
					50

GENERAL NOTES :

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M (82). DIMENSIONS ARE IN INCHES. TOLERANCE ON DECIMALS : .X = ±.1, .XX = ±.03, .XXX = ±.005, ANGLES ±1°. DIMENSIONING AND TOLERANCING IN FRACTIONS ARE GENERAL DIMENSIONS.
2. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
3. MACHINED SURFACE TO BE $\overset{125}{\surd}$

PARTS LIST/MATERIAL LIST

	X	XXXXXXXXX	XXXXXXXXX	X	1
					2
					3
					4
					5
					6
					7
					8
					9
8	H-6-14349-1	INTERMEDIATE SEGMENT		1	10
1	H-6-14349-2	END SEGMENT		1	11
1		OUTER COVERING	ASTM 4240 SST TYPE 316L	X	12
1		END CAP	ASTM 4240 SST TYPE 316L	X	13
					14
					15
					16
					17
					18
					19
					20
					21
					22
					23
					24
					25



U.S. DEPARTMENT OF ENERGY

ECCENTRIC MASS ASSEMBLY

F

H-6-14348

1/4

14348-1.DRW

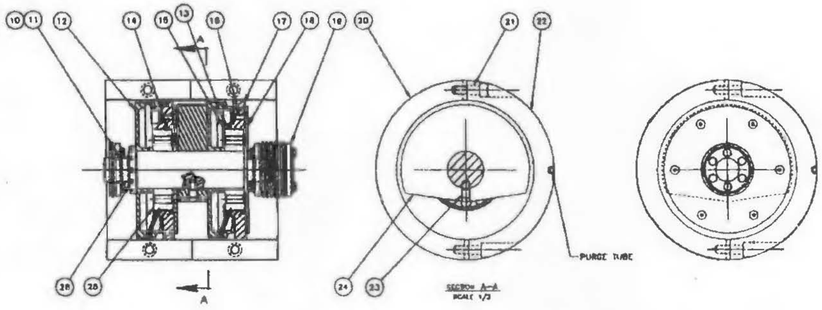
AUTOCAD R13

GENERAL NOTES :

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M (82). DIMENSIONS ARE IN INCHES TOLERANCE ON DECIMALS : X = ±1, .XX = ±.03, .XXX = ±.005, ANGLES ±1°. DIMENSIONING AND TOLERANCING IN FRACTIONS ARE GENERAL DIMENSIONS.
2. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
3. MACHINED SURFACE TO BE 125√

PARTS LIST/MATERIAL LIST

						6		INTERMEDIATE SEGMENT			1
					1			END SEGMENT			2
											3
											4
											5
											6
											7
											8
											9
						1		SHAFT	ASTM A564 SST TYPE 17-4PH	X	10
					1			SHAFT	ASTM A564 SST TYPE 17-4PH	X	11
					2	2		OIL CUP	ATSM 4240 SST TYPE 316L	X	12
					6	6		SCREW, FLT. HD. CAP .138-32 UNC-2A X .38	18-8 SST	X	13
					1	1		KEY	ATSM 4240 SST TYPE 316L	X	14
					1	1		KEEPER, BEARING	ATSM 4240 SST TYPE 316L	X	15
					12	12		SCREW, FLT. HD. CAP .250-20 UNC-2A X .75	18-8 SST	X	16
					2	2		FLANGE, BEARING	ATSM 4240 SST TYPE 316L	1	17
					2	2		PLATE, KEEPER	ASTM A240 SST TYPE 316L	X	18
					1	1		COUPLING	KSD KSD-100	1	19
					2	2		HOUSING	ATSM SST TYPE 1026	1	20
					4	4		SCREW, SOC. HD. CAP .500-13 UNC-2A X 1.50	18-8 SST	X	21
					2	2		HOUSING	ATSM SST TYPE 1026	1	22
					1	1		LOCKING PIN	ATSM 4240 SST TYPE 316L	1	23
					1	1		ECCENTRIC MASS	ASTM CHS TYPE 4130		24
					2	2		BEARING	SKF No. 6217		25
					1	1		RETAINING NUT	ATSM 4240 SST TYPE 316L		26
											27
											28
											29
											30



SECTION A-A
SCALE 1/2

U.S. DEPARTMENT OF ENERGY

ECCENTRIC MASS SEGMENT

H-6-14349

DRAWING TRACEABILITY LIST

NEXT USED ON

REVISIONS

AUTOCAD R13

Appendix B

MOTOR SPECIFICATIONS FOR THE SONIC RETRIEVAL PROBE

MOTOR SPECIFICATIONS FOR THE SONIC RETRIEVAL PROBE

for

WESTINGHOUSE HANFORD CORPORATION
P.O. Box 1970
Richland, WA 99352

Southwest Research Institute Project
17-6356-171

Prepared
by:
John C. Simonis
Wiede K. Cutshall

2 July 1996

Southwest Research Institute
P.O. Drawer 28510
San Antonio, TX 78228-0510

Motor Specifications for the Sonic Retrieval Probe

I. **General:** The following constitutes the specifications for an electric motor to drive the eccentric weights in the Sonic Retrieval Probe. Based on preliminary interaction with motor vendors, a 125 Hp, vector-controlled motor would be adequate to power the Sonic Retrieval Probe.

II. **Design Submittal Requirements:**

A. Dimension Print.

B. Motor Weight and Center of Gravity.

C. Wiring Diagram.

D. Parts List.

E. Estimated Design Life: 1000 hours total operating life spread over a five (5) year period without maintenance. However, the total design life must be considered as continuous operation for 1000 hours.

F. Basis for Design Life: Design life analysis is to be based on bearing life, seals, lubrication, insulation system, and cable life.

G. *Preferred* Electrical Code Specification: Class 1, Division 2, Group B for Hydrogen. *Required*: Totally enclosed blower cooled motor with no internal arc producing devices.

H. Driven Inertia: 8 slug•ft^2.

I. Operating Environment:
  1. Temperature: 120°F to -30°F.
  2. Humidity: up to 100% condensing, exposed to the environment.
  3. Barometric pressure: sea level to 1000 ft.

J. Electrical Requirements:
  1. Motor: 460 ± 10% VAC, 3 Phase, 60 Hz.
  2. Blower Motor: 230/460 ± 10% VAC, 3 Phase, 60 Hz; or 115/230± 10% VAC, 1 Phase, 60 Hz.
  3. Speed/Rotation Indicator: Integral to the motor.

K. Operational Requirements for Motor and Controller:
  1. Torque: 90 ft•lb.
  2. Operating speed: continuously variable 0 to 1200 (nominal) RPM.
  3. Speed resolution: <0.2%.
  4. Speed regulation: <0.2%.

5. Power factor: 1.15.
6. Adjustable acceleration rate: >2 Hz/sec.
7. Adjustable deceleration rate: >2 Hz/sec.
8. Skip frequencies: three (3) selectable, adjustable bands.
9. Overload capacity: >150% for 60 sec (200% peak).
10. Starting torque: >150%.
11. Efficiency: > 95%.
12. Power loss ride-through: 2 sec.
13. Inertia ride-through.
14. Selectable auto restart after momentary power loss.
15. Programmable auto restart: to 10.
16. Mounting: NEMA "C" face Type 6.
17. Motor restricted to shaft motion in clockwise (defined looking at shaft-end of motor) direction only.

L. Operation Requirements for Controller:
   1. Alpha numeric operator key pad with a minimum of 2 lines by 16 characters.
   2. Control logic: 24 v.
   3. Timer function.
   4. Communication port: RS232.
   5. Speed reference: remote on motor.
   6. Set point: PID control.
   7. Signal follower: bias and gain.
   8. Analog monitor output: ± 10 VDC proportional to output parameters.
   9. Auto tune: motor characteristics.
   10. Flash ROM: programmable via RS 232 port.
   11. Encoder response: >300 kHz
   12. Stall torque: to 150% at zero speed for 60 seconds (1 minute) and 100% continuous.
   13. Hour meter.

III. Fabrication, Inspection, and Test Plan for Prototype Unit:

A. Motor housing, end brackets, fan cover and conduit boxes shall be produced from a suitable metal alloy; castings shall be machined and 100% visually inspected.

B. All other motor components (*e.g.*, stator, rotor, shaft etc.) shall be manufactured according to the requirements of the application.

C. Inspection shall be performed on all components for 100% reliability.

D. All components not manufactured by the supplier of the motor and controller shall be subjected to the same quality requirements as imposed on the motor and controller system supplier.

E. Assembled motor and controller shall be inspected in accordance with manufacturer supplied documents.

F. Motor shall be tested by the manufacturer to verify advertised performance specifications.

G. Motor shall be balanced in accordance with ISO 1940, quality grade 2.5. The imbalance shall not exceed 0.0003 inch-pound per pound of rotor weight.

H. Noise level from the motor measured at 3 feet shall not exceed 87 dBA when the motor is operating at full speed and torque.

IV. Shipping and Handling:

A. Quotes are not to include shipping costs, but shall state shipping origin of motor and controller.

B. The lifting lug(s) strength shall be adequate to lift the motor and assume a shock loading of 1.5g.

C. Any and all maintenance requirements for up to a two year storage period (prior to initial use, or during lifetime) shall be specified. Motor may be stored either horizontally or vertically.

V. Installation:

A. The supplier of the motor and controller shall provide a list of spare parts that may require replacement including dust seals, output bearings, input bearings, and blower motor.

B. The supplier of the motor and controller shall provide two (2) copies of the operation manuals.

C. The supplier of the motor and controller shall provide four (4) hours of training for personnel responsible for maintaining and operating the motor.

ATTACHMENT 2

15-TF-0008

White Paper on the Preferred Strategy for Managing Hazards Associated with Retained Flammable Gas in Double-Shell Tanks

White Paper on the Preferred Strategy for Managing Hazards Associated With Retained Flammable Gas in Double-Shell Tanks

T. G. Goetz January 2015

1.0 Introduction

The purpose of this white paper is to provide a recommendation to the U.S. Department of Energy, Office of River Protection (ORP) on the preferred strategy for managing hazards associated with retained flammable gas in double-shell tanks (DSTs). This white paper supplements RPP-RPT-58280, *Options for Reducing the Inventory of Retained Flammable Gas in Hanford Double-Shell Tanks*, which identified five strategies (selected from an original list of 30 options) considered to be most practical for reducing retained flammable gas hazards. RPP-RPT-58280 does not, however, rank the five preferred options nor does it evaluate the range of deployment strategies (from full deployment to maintaining the current control posture) versus the relative risks of retained flammable gas hazards. This task is achieved in this white paper.

2.0 Retained Gas Hazards and Controls

A high-level overview of the types of retained flammable gas hazards, the controls applied to prevent these hazards, and remaining risks after controls are applied is provided below.

2.1 Overview of Retained Gas Hazards

Some DSTs retain significant volumes of gas, a significant portion of which is hydrogen. Retained gas hazards in DSTs are manifested as gas release events (GRE), which are large gas releases characterized by a sudden onset, a sharp increase in gas release rate above steady-state rates, and a short duration. A GRE may occur spontaneously, or be induced by operations-related disturbances of the waste or natural phenomena such as seismic events. Flammable gas hazards from large GREs, where the flammable gas concentration in the headspace increases to ≥ 100% of the lower flammability limit (LFL) in a short period of time, cannot be prevented by active ventilation systems, although active ventilation does reduce the duration of the hazard (i.e., the time when the flammable gas concentration is ≥ 100% of the LFL).

RPP-13033, *Tank Farms Documented Safety Analysis* (DSA), categorizes GRE phenomena as either spontaneous or induced as summarized below.

- Spontaneous GREs are caused by a phenomenon called "buoyant displacement" and can occur in saltcake waste tanks with a deep layer of supernatant when a portion or "gob" of the settled solids accumulates sufficient gas to become buoyant with respect to the liquid above it, breaks away, and rises through the liquid. Tanks that are conservatively estimated to contain sufficient retained gas to reach 100% of the LFL if all of the retained gas is released from a spontaneous buoyant displacement GRE (BDGRE) are categorized as Waste Group A tanks. Five DSTs (241-AN-103, 241-AN-104, 241-AN-105, 241-AW-101, and 241-SY-103) are categorized as Waste Group A tanks.

- Induced GREs are caused by waste-disturbing activities which are qualitatively categorized according to the amount of waste that may be disturbed and the magnitude of the associated retained gas releases. Local waste-disturbing activities (e.g., sampling, lancing, ball rheometer) affect limited volumes of waste, do not have the potential for initiating large retained gas releases (observed releases were < 25% of the LFL), and thus will not be discussed further. Global waste-disturbing operations affect the entire (or the majority of the) waste volume and have the potential to release a large fraction of the retained gas. Tanks that are conservatively estimated to contain sufficient retained gas to reach 100% of the LFL if all of the retained gas is released into the tank headspace, but (unlike the Waste Group A tanks) have no potential spontaneous BDGRE flammable gas hazard, are categorized as Waste Group B tanks. The only authorized operations (i.e., operations that are encompassed within the existing safety basis) with the potential to induce a significant GRE in DSTs are waste transfers, large water additions, and chemical additions. Apart from these operations, a seismic event could also cause a significant induced gas release.

Note that the consequences of a flammable gas deflagration in a DST headspace (significant facility worker hazard that does not exceed guidelines for the 100-m worker) are equivalent regardless of whether the initiating event is a spontaneous or induced GRE. Further note that a flammable gas detonation in a DST headspace is not a credible hazard (i.e., the frequency is "beyond extremely unlikely") for either GRE mechanism, so only flammable gas deflagrations are considered in this white paper.

2.2 Controls

Controls associated with spontaneous and induced GREs are described below. Because there is no practical way to mitigate these consequences, the applied controls focus on preventing flammable gas deflagrations.

2.2.1 Controls for Spontaneous GREs

Based on the operational history of the five Waste Group A DSTs, a spontaneous GRE of sufficient size to cause the tank headspace to reach 100% of the LFL is not expected. This conclusion is supported by Standard Hydrogen Monitoring Systems data collected from 1994 to 2001, which indicates that the hydrogen concentration from spontaneous BDGREs only exceeded 25% of the LFL twice (in DST 241-AN-105) with the maximum concentration being 47% of the LFL. Consistent with this historical behavior, a BDGRE that occurred in DST 241-AN-105 in March 2013 was conservatively estimated to have resulted in a peak flammable gas concentration of 32% of the LFL, although actual measurements taken during that time showed concentrations of < 10% of the LFL (see RPP-CALC-54951, *Best Estimate Headspace Flammability in Tank 241-AN-105 During the March 16, 2013 Buoyant Displacement Gas Release Event*). The control strategies described below are aimed at ensuring that future spontaneous GREs remain within this historical range.

To avoid creating the potential for larger spontaneous GREs than those historically observed and to prevent creating new Waste Group A tanks, the *River Protection Project Authorization Agreement between the U.S. Department of Energy, Office of River Protection and Washington River Protection Solutions LLC* (letter 14-NSD-0008):

- Prohibits waste additions to the five Waste Group A DSTs without prior ORP approval
- Prohibits creation of additional Waste Group A tanks without prior ORP approval

In addition, per the tank farms DSA:

- Large water additions (>10,000 gal in DSTs 241-AN-103, 241-AN-104, 241-AW-101, and 241-SY-103; and >5,000 gal in DST 241-AN-105) to the Waste Group A DSTs are not authorized
- Chemical additions to the Waste Group A DSTs are not authorized

Although no safety-significant structures, systems, and components (SSCs) or specific administrative controls (SAC) are required for the prevention or mitigation of spontaneous GREs in DSTs, as an important contributor to defense-in-depth, ignition controls are required at all times in the tank headspace and connected enclosed spaces directly above the five Waste Group A DSTs. (See HNF-SD-WM-TSR-006, *Tank Farms Technical Safety Requirements* (TSR), Administrative Control (AC) 5.9.2, "Ignition Controls.").

Furthermore, per Defense-in-Depth Feature #30 in tank farms DSA Table 3.3.2.3.2-2, "Other Defense-In-Depth Features (Non-Safety SSCs and Non-TSR Administrative Features)," waste surface level monitoring and trending provides an additional layer of protection against a DST headspace deflagration due to a spontaneous GRE by evaluating DST waste surface level data for adverse trends or deviations that may be indicative of unanticipated gas retention or GRE behavior.

2.2.2 Induced GREs

Induced GREs are discussed in relation to the initiator, which may be an operational activity or a seismic event.

2.2.2.1 Controls for Operationally Induced GREs

Based on evaluations of induced GREs and the authorized tank farm operations described in tank farms DSA Chapter 2, there are only two DST operations that could potentially induce a GRE where the flammable gas concentration reaches or exceeds 100% of the LFL. These operations are waste transfers that uncover solids in Waste Group B DSTs and water additions, chemical additions, and waste transfers into Waste Group B DSTs.

To prevent these induced GRE hazards, a TSR control (SAC 5.8.1, "DST Induced Gas Release Event Evaluation") requires evaluations of waste transfers from DSTs and water additions, chemical additions, and waste transfers into DSTs to determine whether restrictions or controls are required to prevent an induced GRE flammable gas deflagration. As part of these evaluations:

- Prior to waste transfers from DSTs, engineering performs an evaluation to determine if an induced gas release due to uncovering solids can produce a flammable gas concentration of ≥ 100% of the LFL in the sending DST headspace, assuming zero ventilation. If the waste transfer could uncover solids in the sending DST and the flammable gas concentration produced by the induced GRE could be ≥ 100% of the LFL, then the volume of liquid waste transferred from the sending DST is limited to a volume that prevents achieving 100% of the LFL in the tank headspace. Otherwise no other actions are required.
- Prior to water additions, chemical additions, and waste transfers into DSTs that exceed specified volumes, engineering performs an evaluation to determine if an induced gas

release due to dissolution of soluble settled solids would be sufficient to achieve a flammable gas concentration ≥ 100% of the LFL in the receiving DST headspace, assuming zero ventilation. If the evaluation indicates that flammable gas concentration could be ≥ 100% of the LFL then Limiting Condition for Operation (LCO) 3.4, "DST Induced Gas Release Event Flammable Gas Controls," is applicable. Otherwise no other actions are required.

LCO 3.4 ensures that DST primary tank ventilation systems are operable and operating to prevent flammable gas hazards from induced GREs during water additions, chemical additions, and waste transfers into DSTs.

2.2.2.2 Controls for Seismically Induced GREs

A seismic event could also cause a significant retained gas release and provide the ignition source for a flammable gas accident. Based on an estimated gas release fraction in a DST of 50% from a design basis seismic event and assuming a bounding (95th percentile) methodology, there currently are seven DSTs (241-AN-103, 241-AN-104, 241-AN-105, 241-AP-105, 241-AP-108, 241-AW-103, and 241-SY-101) with sufficient quantities of retained flammable gas to reach 100% of the LFL in the tank headspace if 50% of the retained gas is suddenly released. If a more realistic (50th percentile) methodology is used then only two DSTs (241-AN-103 and 241-AN-105) retain sufficient flammable gas to reach 100% of the LFL in the tank headspace if 50% of the retained gas inventory is suddenly released.

As will be described in more detail later in this report, within the current regulatory demands there are no practical controls to prevent seismically induced GRE flammable gas hazards. Although it does not prevent a potential flammable gas deflagration, a TSR Control (AC 5.9.6) requires evacuating personnel from DST tank farms following a detected seismic event and provides some risk reduction to facility workers.

3.0 Risk Profile After Application of Existing Controls

3.1 Risk Profile for Spontaneous GREs

As described previously, spontaneous GREs from the Waste Group A tanks will continue to occur in the future but based on past behavior the resultant flammable gas concentrations should be < 100% of the LFL. The existing controls prevent activities in Waste Group A tanks that are deemed most likely to create the potential for larger spontaneous GREs than those historically observed, and also prevent creation of new Waste Group A tanks without explicit approval from ORP. Given that the Waste Group A tanks are largely being maintained in a static condition the probability of a flammable gas deflagration caused by a spontaneous GRE is low. Thus, the Waste Group A tanks will not be considered further except for those Waste Group A tanks that are vulnerable to seismically induced GREs.

3.2 Risk Profile for Operationally Induced GREs

The currently authorized operations that may induce a GRE (i.e., waste transfers that uncover solids in Waste Group B DSTs and water additions, chemical additions, and waste transfers into Waste Group B DSTs) are evaluated via SAC 5.8.1 (with zero ventilation assumed) and actions (i.e., limiting the volume of liquid waste transferred from the sending DST or applying LCO 3.4) are taken to prevent induced GREs. In light of this robust set of TSR controls, operationally induced GREs will not be considered further.

3.3 Risk Profile for Seismically Induced GREs

Given the absence of existing controls to prevent seismically induced GRE flammable gas hazards, the frequency of such hazards is equivalent to the frequency of the initiating earthquake. Per the tank farms DSA, an earthquake of sufficient magnitude to release a significant fraction of gases retained in DST waste and cause a flammable gas concentration exceeding the LFL in the tank headspace is qualitatively determined to be at least "unlikely" ($> 10^{-4}$ to $< 10^{-2}$ per year). Thus, tanks vulnerable to seismically induced GREs will be evaluated against the retained gas inventory reduction strategies.

4.0 Risks versus Retained Gas Inventory Reduction Strategies

Before evaluating the risks versus retained gas inventory reduction strategies, it important to identify current mission drivers, which also involve risk reduction (environmental rather than nuclear safety). The two key mission objectives which must be considered as part of the overall evaluation are:

- SST retrievals (part of the Tri-Party Agreement and legally mandated by the Consent Decree) including Evaporator campaigns as a supporting space management activity
- Pump-out of the DST-AY-102 primary tank (to be conducted per the Settlement Agreement with the State of Washington)

Note: Resolution of vapor issues is an emergent high-profile mission objective that is also likely to command significant resources.

After evaluating 30 potential options, RPP-RPT-58280 identified the following five retained gas inventory reduction strategies as the most practical to apply:

- Mixer Pump
- Pulsed Air Mixer
- Pulse Jet Mixer
- Sonic Agitation
- Existing Technologies and Waste Management Techniques

Three of these options (Pulsed Air Mixer, Pulse Jet Mixer, and Sonic Agitation), are qualitatively dismissed from further consideration. These technologies have never been deployed in tank farms and have more uncertainties than the other two options (Mixer Pump and Existing Technologies and Waste Management Techniques), both of which have been used to reduce and remediate retained flammable gas hazards in DST 242-SY-101. These two options are considered below

4.1 Mixer Pumps

As noted in RPP-RPT-58280, mixer pumps are a robust technology with broad industry acceptance and previous application in the Hanford Tank Farms. It is important to note however, that deployment of mixer pumps involves:

- Significant infrastructure upgrades to the affected tank(s).
- Long term maintenance costs due to the intermittent operation of the mixer pump(s) that would be required for the foreseeable future

- The possibility that the mixer pump itself may unintentionally trigger a larger than anticipated gas release (this risk is considered manageable but may entail deployment of additional instrumentation and control equipment (e.g., safety-significant real-time flammable gas monitoring and pump control logic) and/or modeling and testing

Based on past experience, design, procurement, installation, and testing of mixer pumps is a labor intensive, multi-year evolution that will divert significant resources from the key mission objectives of SST retrievals and the pump-out of the DST 241-AY-102 primary tank.

4.2 Existing Technologies and Waste Management Techniques

RPP-RPT-58280 considers the following waste management processes could be employed to reduce the retained flammable gas hazards.

- Strategic intra-tank farm transfers (i.e., movement/redistribution of waste from tank to tank)
- Transfer waste to new tanks, if constructed
- Dilution, using buffered water

Given the speculative nature of the second option – construction of new tanks is not within the current contract and is not being actively pursued by ORP – it will not be considered further.

With respect to intra-tank farm transfers and dilution, RPP-RPT-58280 observes that utilizing the limited DST space to dilute existing waste or spread waste solids among more tanks would curtail SST retrievals. Note that the ability to conduct the scheduled Evaporator campaigns would also be affected.

4.3 Recommendation

The final recommendation considers the following:

- A subset of DSTs (currently seven [based on bounding methodology] or two [based on the more realistic methodology]) may experience flammable gas concentrations that are ≥ 100% of the LFL in a seismic event.
- The frequency of the initiating seismic event is "unlikely" and the estimated consequences of a potential flammable gas deflagration in a DST represent a significant facility worker hazard (but not a significant hazard to the 100-m worker)
- This event would normally require TSR level controls (safety-significant SSCs and/or SACs), but given the existing waste configurations and mission imperatives no practical controls are available
- The available retained gas inventory reduction strategies are either labor intensive, multi-year evolutions with an associated long-term maintenance burden (mixer pumps) or large consumers of available DST space with detrimental impacts on mission objectives that need that space (strategic intra-tank farm transfers and/or dilution)

Given the negative impacts on the current mission (i.e., legally mandated SST retrievals and/or pump-out of the DST 241-AY-102 primary tank are likely to be delayed) which also involve risk reduction, it is recommended that the current posture of risk acceptance based on the existing controls (with no deployment of the retained gas inventory reduction strategies) be maintained.

5.0 References

HNF-SD-WM-TSR-006, Tank Farms Technical Safety Requirements, Rev. 7-V, Washington River Protection Solutions LLC, Richland, Washington.

RPP-13033, Tank Farms Documented Safety Analysis, Rev. 5-H, Washington River Protection Solutions LLC, Richland, Washington.

RPP-CALC-54951, *Best Estimate Headspace Flammability in Tank 241-AN-105 During the March 16, 2013 Buoyant Displacement Gas Release Event*, Rev. 1, Washington River Protection Solutions LLC, Richland, Washington.