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ENGINEERING CHANGE NOTICE

Page 1 of 2

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Process Control Plan for Single-Shell Tank Saltcake Dissolution Proof-of-Concept

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RPP-7715
Revision 2

PROCESS CONTROL PLAN FOR SINGLE-SHELL TANK SALTCAKE DISSOLUTION PROOF-OF-CONCEPT

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LIST OF TERMS

approx.	approximate
atm	atmosphere
CHG	CH2M HILL Hanford Group, Inc.
cm^2/sec	square centimeter pr second
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ft	feet
ft^2	square feet
ft^3	cubic feet
g	grams
g/cc	grams per cubic centimeters
g/L	grams per liter
g/mL	grams per milliliter
gal	gallons
gal/day	gallons per day
gpm	gallons per minute
hr	hours
ILL	interstitial liquid level
in.	inch
ISOE	Interim Stabilization Operations Engineer
kgal	kilogallons
kL	kiloliters
LFL	lower flammability limit
LOW	liquid observation well
LDMM	liquid detection, monitoring, and mitigation
M or *M*	moles per liter
MBD	material balance discrepancy
MeV	million electron volts
mm	millimeters
n/a	not applicable
NOC	Notice of Construction
ORP	U.S. Department of Energy, Office of River Protection
Pa	Pascals
PNNL	Pacific Northwest National Laboratory

ppm	parts per million (by volume in the gas phase, by mass in solids and liquids)
RCRA	*Resource Conservation and Recovery Act*
REDOX	Reduction Oxidation
SHMS	Standard Hydrogen Monitoring System
SpG	specific gravity
SST	single-shell tank
TMACS	Temperature Monitoring and Control System
TMS	Topographical Mapping System
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
VOC	volatile organic compound
vol %	volume percent
WDOH	Washington State Department of Health
wt%	weight percent
%	percent
°C	degrees Celsius
°F	degrees Fahrenheit
µCi/g	microcuries per gram

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1.0 INTRODUCTION

This document describes the process controls for the tank 241-U-107 (U-107) saltcake dissolution proof-of-concept operations. Saltcake dissolution is defined as a method by which water-soluble salts will be retrieved from the Hanford Site radioactive waste tanks utilizing dissolution as the mobilizing mechanism. The proof-of-concept operations will monitor the retrieval process and transfer at least 100 kgal of fluid from tank U-107 to the double-shell tank (DST) system during the performance period. Tank U-107 has been identified as posing the highest long-term risk to the Columbia River of all single shell tanks (SSTs). This is because of the high content of mobile, long-lived radionuclides mostly in the saltcake waste in the tank. To meet current contractual and consent decree commitments, tank U-107 is being prepared for interim stabilization in August 2001. It is currently scheduled for saltcake retrieval in 2023, near the end of the SST retrieval campaign because of a lack of infrastructure in U-Farm. The proof-of-concept test will install a system to dissolve and retrieve a portion of the saltcake as part of, and operating in parallel with, the standard interim stabilization system to be installed on tank U-107. This proof-of-concept should provide key information on spray nozzle selection and effective spray patterns, leak detection, monitoring, and mitigation (LDMM) and in-tank saltcake solubility data that will help in the design of a full-tank retrieval demonstration system.

1.1 BACKGROUND

The near-term strategy for retrieval of wastes from the SSTs has shifted from maximizing the number of SSTs emptied of waste to minimizing the inventory of contaminants of concern in the SSTs. The contaminants of concern are defined as long-lived radionuclides that could potentially reach the groundwater and the Columbia River (CHG 2000b).

The near-term strategy also calls for the development and demonstration of retrieval methods, including saltcake dissolution, for future use as the waste immobilization systems become operable. To that end, CH2M HILL Hanford Group (CHG), the U.S. Department of Energy (DOE), and the State of Washington Department of Ecology (Ecology) negotiated the M-45-03C milestone of the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1997), which reads

> "Complete full-scale saltcake waste retrieval technology demonstration at single-shell tank S-112. Waste shall be retrieved to the DST system to the limits of the technology (or technologies) selected. Selected saltcake retrieval technology (or technologies) must seek to improve upon the past-practice sluicing baseline in the areas of expected retrieval efficiency, leak loss potential, and suitability for use in potentially leaking tanks. This demonstration shall also include the installation and implementation of full-scale LDMM technologies. The parties recognize and agree that this action is for demonstration and initial waste retrieval purposes. Completion of this demonstration shall be by written approval of DOE and Ecology. Goals of this demonstration shall include the retrieval to safe storage of approximately 550 curies of mobile, long-lived radioisotopes and 99% of tank contents by volume (per DOE Best Basis Inventory (BBI) data, 8/01/2000)."

The M-45-03C milestone has a completion date of September 30, 2005. CHG has selected saltcake dissolution as the retrieval method to be demonstrated in tank S-112 and to satisfy the M-45-03C milestone (CHG 2000b).

Saltcake dissolution retrieval has not been demonstrated in a Hanford Site waste tank. As such, there are technical uncertainties associated with its implementation and the performance expectations. The many technical uncertainties are associated with the following questions:

- Can dissolution be controlled to allow the waste surface to recede uniformly without excessive surface run-off; the formation of deep ditches, caverns, or mounds; damage to suspended hardware due to attached waste masses or shifting waste; or the development of regions of waste that cannot be efficiently retrieved by the method itself?

- Will dissolution rates be sufficient to adequately saturate the brine with dissolved solids?

- Will seepage rates of the brine through the porous solid waste be sufficient to allow timely retrieval?

- Will LDMM techniques that do not require long shutdown periods for monitoring a quiescent and stagnant liquid surface be proven effective?

- Will it be possible to show that the risks and uncertainties associated with the full-scale demonstration of the saltcake dissolution retrieval method (M-45-03/S-112 Demonstration) are tenable? This would be demonstrated by the early identification of issues impacting overall system design, equipment and component selection, process control strategy, operating activities, and transfer rheology.

- Will it be possible to demonstrate the cost-effectiveness of the full-scale tank S-112 demonstration project?

To address these uncertainties, and possibly identify other issues that have not been envisioned, proof-of-concept operations are planned for tank U-107. The saltcake dissolution proof-of-concept operations in tank U-107 has been made a Superstretch Performance Based Incentive agreement between DOE and CHG, with specific deliverables and schedule.

1.2 TANK SELECTION

Tank U-107 was selected for the proof-of-concept operations because it contains suitable waste (i.e., saltcake) and interim stabilization activities are scheduled in tank U-107 at a time that will complement the proof-of-concept operational activities. The brine produced by saltcake dissolution is to be removed with saltwell pumping equipment. Cost efficiencies will be realized by conducting the proof-of-concept operations concurrent with the scheduled interim stabilization of the tank. Coordinating the installation of saltwell pumping equipment with the

installation of the saltcake dissolution water distribution system will further improve cost efficiencies.

Tank U-107 is the highest-risk tank based on mobile, long-lived radionuclides (specifically technetium-99) (CHG 2000b). Yet the lack of basic infrastructure in U-Farm deterred early retrieval when the M-45-03 milestones were negotiated. Using the interim stabilization system for partial retrieval by saltcake dissolution, therefore, reduces the risk of the mobile long-lived radionuclides earlier than provided in the baseline SST retrieval schedule.

1.3 OBJECTIVES

The primary objective of the proof-of-concept operations is to reduce technical risks and uncertainty associated with the full-scale deployment of the saltcake dissolution method in tank S-112. Included as technical uncertainties are all the issues and potential effects of the dissolution system and LDMM investigations that cannot be reliably predicted beforehand.

Secondary objectives include the reduction of risks associated with the waste in tank U-107, the development of equipment, plans, and procedures that can be extended to the retrieval of tank S-112, and the test deployment of a waste surface topography mapping system.

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2.0 PROCESS PERFORMANCE AND EVALUATION CRITERIA

The primary objective of the proof-of-concept operations is to reduce technical risks and uncertainty associated with the full-scale deployment of the saltcake dissolution method in tank S-112. Additional objectives include development of equipment, plans, and procedures that can be extended to the retrieval of tank S-112 by saltcake dissolution; the test deployment of a waste surface topography mapping system that could be useful for all retrieval methods; and reduction of environmental risks associated with the waste in tank U-107.

The U.S. Department of Energy, Office of River Protection (ORP) Performance-Based Incentive requires that at least 100,000 gallons of brine be transferred to the DST system and that a sample of the process fluid be taken and analyzed. The goal of reducing the technical risk requires specific knowledge be gained in the process, regardless of the actual volume of brine pumped. Therefore, the saltcake dissolution proof-of-concept operations will be considered fully successful when sufficient water has been added to the surface of tank U-107 over several areas and data have been collected to determine:

- The volume of waste dissolved per unit volume of water added;
- The overall qualitative behavior of saltcake in response to surface water addition;
- The effectiveness of the LDMM developmental strategy and approach;
- The cause(s) of adverse behavior such as dilute liquid in the saltwell screen, excessively non-uniform dissolution, excessive runoff, or solids accumulation in the saltwell screen; and
- That no unmanageable safety concerns exist with the full-scale demonstration in tank S-112.

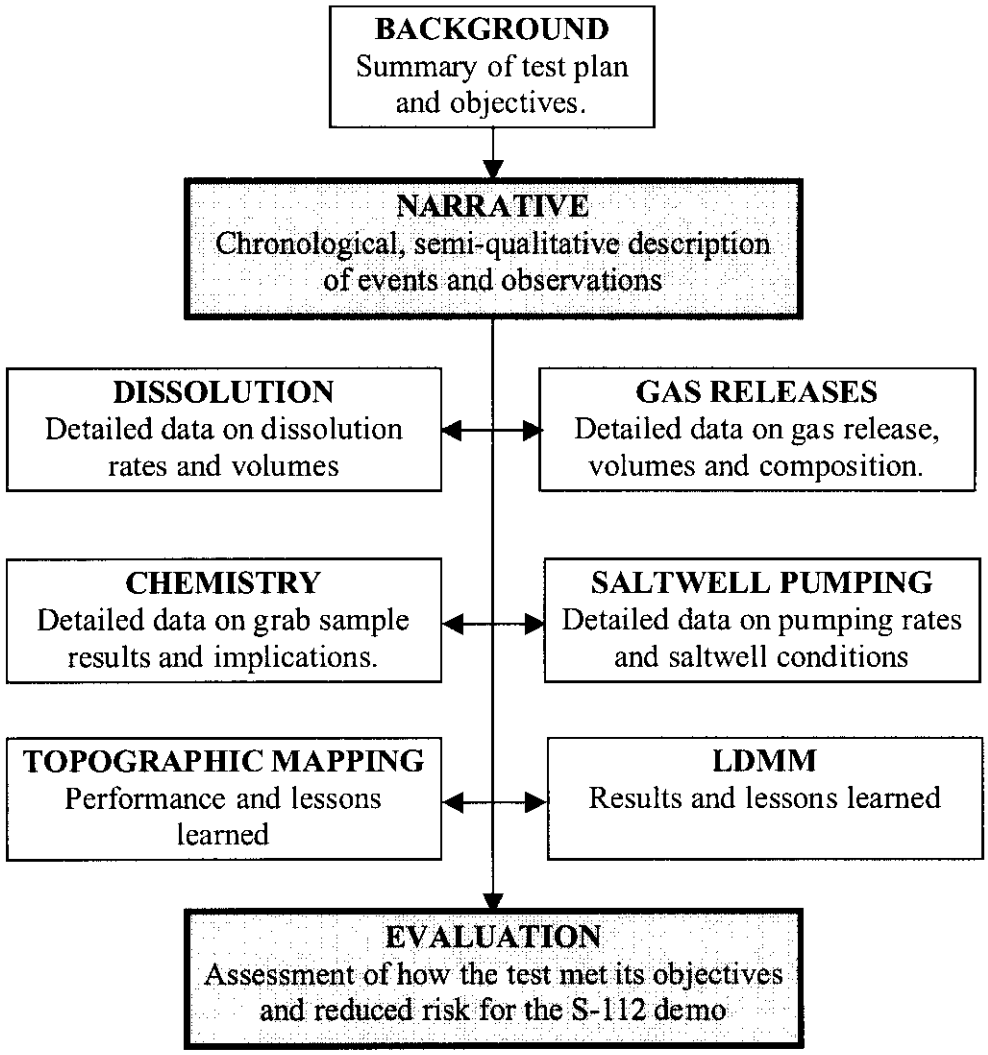
The operation can alternatively be deemed successful if it shows that the saltcake dissolution retrieval method is fundamentally unworkable or impractical for reasons that cannot be alleviated by adjusting the process. The final report, outlined in Section 2.1, will embody the results and the evaluation of the technology. Section 2.2 briefly discusses the perceived technical risks and how they will be addressed by the tank U-107 proof-of-concept demonstration.

There exists quantitative evidence upon which to base reasonable expectation for positive results from the dissolution proof-of-concept. Appendix A represents one such example. This analysis considers only diffusion as the driving force for salt dissolution and, therefore, may conservatively be considered an upper bound for time scales involved with the process once a length scale is specified. The conclusion of Appendix A is that dissolution of the salts should be fairly rapid, with significant dissolution occurring on the order of hours, if not minutes, from the time of water application.

2.1 FOCUS OF THE FINAL REPORT

The final report is the vehicle for reducing the technical risk and evaluating the basic feasibility of the saltcake dissolution retrieval method. The report will be arranged by topic in a broadly hierarchical fashion. The two focal points of the report are the narrative of the operation, where the actual events will be described as they occurred, and the evaluation, which will assess how the test met its objectives. The narrative will set the context and background for the detailed data analysis sections, which in turn support the final evaluation. A preliminary identification of the major sections and their relationships are illustrated in Figure 2-1. The information discussed in each of the preliminary sections is summarized below.

Figure 2-1. Layout of the Final Report



2.1.1 Background

The background gives a summary of the test plan and objectives as well as a brief discussion of the tank conditions and waste properties. The water addition system and saltwell pumping system is also briefly summarized in somewhat less detail than in the Process Control Plan (PCP).

2.1.2 Narrative

The entire process will be described chronologically in this section. The discussion will be mainly qualitative but with high-level summary data given to quantify the outcome of specific tests and events. It could serve as a stand-alone summary for management or the public. In-tank video frames, Topographical Mapping System (TMS) maps and sketches will be used to illustrate the observations. The chronology defined in this section will provide the framework for the detailed discussions in later sections.

2.1.3 Dissolution

The narrative will have described the progress of dissolution qualitatively. This section will synthesize a detailed description of dissolution performance from water flow rates and spray patterns, saltwell specific gravity (SpG) and chemistry, pumping rates, volume changes indicated by TMS maps and video, as well as neutron and gamma logs. An interpretation of the data and observations, based in part on modeling results, will also be included in this section. Actual performance will be compared to the predicted ratios of solids dissolved and brine produced per gallon of water added.

2.1.4 Gas Releases

The hydrogen data from the Meggit Safety System[1] Hydrogen Cells in tank U-107's Standard Hydrogen Monitoring System (SHMS) allows a semi-quantitative description of gas releases during pumping and dissolution. Though tank U-107 waste is estimated to contain a significant volume of trapped gas (PNNL 2001b), only a nominal elevation in hydrogen concentration is expected during dissolution compared to that of saltwell pumping alone. Any headspace grab sample data obtained will also be included as evidence of changes in the released gas composition.

2.1.5 Chemistry

This section will contain the detailed results of saltwell grab sample analyses. Changes in saltwell composition during dissolution will be described and implications evaluated. Dissolution chemistry will be compared with previous dissolution studies (Herting 2001) and with earlier core samples. Evidence for or against any of the postulated chemistry effects (e.g., phosphate re-precipitation, radionuclide scavenging, etc.) will be discussed.

[1] Meggit Safety Systems, Fullerton, California

2.1.6 Saltwell Pumping

The detailed history of pumping rate, dilution flow rate, and saltwell properties (i.e., liquid level and SpG) will be described here. Most important will be the changes in all of these parameters as water is added in different locations and rates. Pumping data both before and after water addition will be used. The effect of dissolution on interstitial liquid draining will be assessed if possible. Of special interest are lessons learned in coordinating water addition and dissolution data collection with interim stabilization operations.

2.1.7 Topographical Mapping

This section will describe the system, the calibration effort, and the data obtained during testing. The system's performance and the value of the data obtained will be evaluated, and lessons learned for future applications will be discussed.

2.1.8 Leak Detection

The tank U-107 test will be the first application of several technologies specifically to leak detection during retrieval by saltcake dissolution. This section will present the results of mass balance calculations including uncertainties and the data on which they are based. The consistency of volume changes deduced from TMS maps, the cumulative volumes of water added and brine removed, and the changes in liquid content as measured by the neutron logs will be assessed. Results from the spectral gamma logs in the external wells will also be presented (negative results are expected). Lessons learned that can improve LDMM in future operations will be described.

2.1.9 Evaluation

The evaluation is the overall conclusion to the document. It will summarize the detailed data in the context of the narrative to assess how well the test objectives were met. Discussions will focus on the most important findings and lessons learned, and how these can be used to reduce technical risk in the tank S-112 saltcake dissolution retrieval demonstration.

2.2 APPLICATION TO TANK S-112 RETRIEVAL DEMONSTRATION

The primary objective of the tank U-107 proof-of-concept demonstration is to reduce technical risks associated with the tank S-112 saltcake dissolution demonstration. The technical risks are primarily associated with the fact that no tank-scale saltcake dissolution tests have been conducted on the Hanford Site wastes, and that currently planned tank S-112 activities are based on best engineering judgment about how the dissolution process will proceed. Understanding the dissolution process and the relative influence of the main parameters will allow the design of the tank S-112 retrieval system to proceed with confidence. This section briefly discusses the perceived technical risks and how they will be addressed by the tank U-107 proof-of-concept demonstration.

2.2.1 Water Distribution

Risk: The technical risk is that inadequate understanding of the effects of water spray patterns and flows may result in an ineffective or over-designed water distribution system. There are many feasible methods to distribute the water, but it is not known whether it is important to distribute the water uniformly over a large area or if a local water addition is more effective. It is suspected that the spray pattern and flow rate have a strong influence on the formation of pools, mounds, ridges, or channels that may impair dissolution. Shadowing of the spray by an obstruction may be a problem. On the other hand, sub-surface water migration, dissolution, and slumping might result in relatively uniform dissolution, regardless of the spray pattern, and there may be considerable latitude in the design.

Issues:

- Effect of spray pattern on dissolution behavior.
- Performance of large-area versus local water application.
- Qualitative indication of effects of shadowing.

Resolution in Tank U-107:

The spray pattern areas, flow rates, and intensities of the planned test series vary considerably. With the exception of a forcible, directed spray, the choices of practical distribution methods should be covered adequately.

Two tests will assess the strategy of applying water to small versus large areas. The "large area test" will apply a commercial irrigation sprinkler to uniformly distribute water over a large area of the waste surface. During this test, the waste surface will be monitored for undesirable features (e.g., pools, waste mounds, channels) and their correlation with the water distribution. By comparison, the "near wall, large volume test" will investigate the effectiveness of putting a large volume of water in a relatively small area of the waste.

Shadowing will be addressed in a limited way by two tests; a small specific "shadowing test", which will direct a spray at a nearby 3 1/2-inch thermocouple tree, and the spray pattern of the "Fury" test will include the same obstruction. Shadowing by large-diameter obstructions will not be tested.

2.2.2 Process Control

Risk: The technical risk is that combining the new and diverse aspects of controlled water addition with the established saltwell pumping operations will result in the impairment of one or both. A major issue is expected to be adjusting the water flow rate and times to maintain the maximum pumping rate of near-saturated brine while keeping the liquid level in the saltwell in the desired range. The combined operation also imposes additional demands on the

infrastructure including water and electrical supply, transfer systems, and operations staff. The plan also calls for first-time operations: making TMS scans and moving the TMS between risers.

Issues:

- Process control of water addition versus pumping rate and water addition.
- Coordination of the infrastructure to perform simultaneous water addition plus saltwell pumping.
- Performing TMS scans.

Resolution in Tank U-107:

The tank S-112 demonstration is expected to use generally similar process control tools and strategies as the tank U-107 proof-of-concept. Therefore, valuable lessons learned in tank U-107 will have direct application to plans and procedures for tank S-112.

However, the tank U-107 proof-of-concept will not provide process control experience during anticipated rapid dissolution of "dry" waste or during slow dissolution of the last three feet or so of waste. Mobilization of insoluble solids, forced penetration of water into saturated waste, or recirculation of saltwell liquor will not be tested in tank U-107.

2.2.3 Process Monitoring

Risk: The technical risk in process monitoring is that monitoring data will be inadequate to control the process or that funds are wasted on unneeded data from costly systems. The two most important goals of process monitoring are maintaining the progress and efficiency of dissolution and leak detection. The dissolution process must be monitored indirectly by measuring waste volume changes and monitoring liquid properties in the saltwell. Several systems are available to do this. The current practice for leak detection is a mass balance inferred from waste volume changes in the tank, which has a high uncertainty.

Issues:

- Usefulness of TMS system for dissolution monitoring and leak detection.
- Use of in-tank video for process control and information.
- Detection of leaks (e.g., efficacy of mass balance).
- Use of saltwell screen grab samples and interpretation of results for dissolution monitoring.
- Adequacy of saltwell pumping data (e.g., dip tube SpG, liquid level, etc.) in representing dissolution effectiveness.

Resolution in Tank U-107:

The primary sources of real-time process monitoring information in tank U-107 are the in-tank video, saltwell pumping and water flows, and dip tube data in the saltwell screen including liquid level and SpG. Periodic TMS scans and saltwell grab samples are expected to provide confirmatory data on the cumulative results of dissolution and will be specifically assessed. The tank U-107 experience will assess whether this integrated system is adequate or excessive for process monitoring. The need to measure additional quantities in-line such as density, water fraction, or radioactivity will also be evaluated.

2.2.4 Dissolution Behavior

Risk: The technical risk is that understanding of dissolution behavior will be insufficient to assess the likelihood and consequences of various process problems or to develop strategies to avoid them. Soluble species dissolve at different rates, and a significant volume of insoluble and lower solubility solids are present in every tank. As dissolution progresses, a layer of less soluble or insoluble solids may accumulate and impair dissolution. The varying dissolution rates of the chemical constituents make it difficult to predict the volume of solids dissolved per unit volume of water added and the volume of brine produced. The complex interplay of physical and chemical phenomena makes it very difficult to predict the kinetics and spatial effects of dissolution.

Issues:

- Phosphate dissolution and re-precipitation in waste and in saltwell screen.
- Initial dissolution behavior as water contacts unsaturated waste.
- Buildup of insolubles as dissolution proceeds.
- Uniformity of dissolution (e.g., Do mounds form because draining and dissolution are slower in regions of low porosity? Is it a problem if they do?).
- Ability to model dissolution kinetics and qualitative waste behavior.
- Ability to predict global dissolution parameters (i.e., How much water produces how much brine?).

Resolution in Tank U-107:

Data from the tank U-107 tests will provide evidence of the most severe dissolution problems if they occur, although small effects may go undetected. The data will qualitatively validate predictions of global dissolution behavior based on laboratory tests. The observed dissolution behavior will also serve as input to future modeling efforts.

The behavior of dissolution of a deep layer of "dry" saltcake will not be examined in the tank U-107 tests nor will the dissolution of the low-hydraulic head period when only a meter or so of waste remains.

2.2.5 Brine Transport

Risk: The technical risks are that the brine created by dissolution, (1) creates large surface features that impair further dissolution as it flows to the saltwell, or (2) does not flow readily to the saltwell, therefore, limiting the rate of water addition. Small-scale experiments give some evidence that dissolution tends not to be uniform. It is possible that the dissolution process will be non-uniform and create steep canyons and ridges. These features are thought to potentially channel the flow such that the water will run off before dissolution is complete. At the other extreme of non-uniform dissolution, dissolution may tend to form pools that drain very slowly into the saltwell only by porous media flow through the saturated waste. The radial migration of dilute brine on top the interstitial liquid level (ILL) is proposed as a mitigating mechanism for these two adverse effects. Otherwise, spray patterns and flows may need to be revised to minimize them.

Issues:

- Behavior and effect of water pooling.
- Effect of runoff of dilute brine on dissolution efficiency and surface topography.
- Migration of water through unsaturated waste on top of the ILL.
- Effects of dissolution on drainage rate.

Resolution in Tank U-107:

The "near saltwell (channeling)" test places a high flow rate in a relatively small area near the saltwell with the expectation of creating channels and observing dilute runoff. Any channels created in this test will remain during the "Fury (Large Volume)" test to follow where 3 kgal of water is added through the "Fury" tank washer. The more intense spray of the Fury may smooth out surface irregularities, if any have been created. If not, the effect of channels or pools on brine runoff will be observed.

The "Near Wall (Large Volume)" test is expected to create at least a temporary pool. Migration of dilute brine over the ILL is expected to occur in this test, which should cause subsurface dissolution and general slumping of the waste surface.

The "Large Area" tests, which places about 16 kgal of water over approximately one-third of the surface area is expected to provide data on how dissolution affects interstitial liquid draining rate. However, the behavior of draining and brine transport during the low-hydraulic head phase when the last three feet or so of waste dissolves will not be tested.

2.2.6 Effects Important to Tank S-112 not tested in Tank U-107

The waste configuration in tank S-112 is much different from that in tank U-107. Approximately the top six feet of tank S-112 is unsaturated waste with very little moisture which overlays about ten feet of liquid-saturated waste. By contrast, tank U-107 has about 13 feet of liquid saturated waste, including up to 24 inches of supernatant. The dissolution testing in tank U-107 will begin after saltwell pumping removes all of the supernatant and creates several inches of unsaturated waste at the surface. Only 100 kgal of brine are planned to be created by dissolution in tank U-107. This will remove somewhat less than two feet of waste.

Therefore, tank U-107 tests will not investigate the behavior of rapid dissolution of the deep "dry" zone in tank S-112. However, little technical risk is associated with this phase of the demonstration, and a full-scale evaluation of the process should not be crucial. The only question concerning this phase is whether it is more efficient to apply water uniformly on the surface of this zone or to attempt to dissolve it locally from the center outward. It would be useful to resolve this issue sooner than later.

More importantly, because of its limited duration and water volume, the tank U-107 proof-of-concept will not provide any experience with the difficult low-hydraulic head phase when roughly three feet of waste remains. The drainage rate of interstitial liquid approaches zero at this stage, and the dense interstitial brine prevents the water from contacting the soluble waste. The preliminary strategy for tank S-112 is to use a more forceful, directed jet to erode the saturated surface and allow the water to penetrate into the saturated waste. It is not known if this technique will be effective. If not, the last 20 to 25 percent of the tank S-112 waste volume may not be retrieved.

All other important effects and methods planned for tank S-112 are adequately covered by tank U-107 tests.

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3.0 PROCESS DESCRIPTION

This section includes a summary of the overall saltcake dissolution operations concept and the saltwell pumping process along with a description of the waste and the actual equipment involved. The saltcake dissolution operations concept is described in Section 3.1, and saltwell pumping is briefly summarized in Section 3.2. Section 3.3 describes the tank and riser allocation, instrumentation, water distribution hardware, and saltwell pumping system. The waste in tank U-107 is described in terms of its extent, physical properties, and chemical composition in Appendix B.

3.1 SALTCAKE DISSOLUTION OPERATIONS

Saltcake dissolution, as defined for the tank U-107 proof-of-concept operations, is a process by which water-soluble waste salts are mobilized by dissolution and removed by saltwell pumping. Nozzles suspended in the tank headspace will be used to introduce water onto the waste surface to initiate dissolution. The resultant brine is then removed from the tank by a conventional saltwell jet pump located in the saltwell screen.

Prior to the start of the saltcake dissolution operations, the supernatant and a portion of the interstitial liquid will be removed by saltwell pumping. The operations will be initiated with the introduction of water to the exposed saltcake waste. This will be done to ensure direct contact of the dissolution water with the saltcake itself[2].

The initial water applied to the waste surface is expected to cause rapid dissolution (see Appendix A), and become saturated with the most soluble sodium salts (e.g., nitrite and nitrate salts and caustic). Because these salts make up the bulk of the saltcake matrix at the surface, the surface of the waste should recede as dissolution occurs. The initial brine produced is expected to seep into the porous saltcake, and percolate downward to the interstitial liquid interface. As more water is added, it may pool and/or run off the surface, depending on whether the brine creation rate exceeds the rate that it can percolate into the saltcake. In either case, dissolution of the most soluble salts is expected to result in a layer of insoluble species (e.g., metal oxides) and the less soluble salts (e.g., phosphates and carbonates) at the surface.

The saltcake dissolution method is intended to be a cost-effective alternative to past-practice sluicing. Aspects of the saltcake dissolution method that are expected to allow it to be cost-effective are as follows:

- Existing saltwell pumping equipment, infrastructure, and expertise will be used to remove the brine produced;

[2] The density of the supernatant and interstitial liquids is about 1.4 times that of water. This density difference would greatly diminish the mixing of added water with the existing waste liquids, and result in very slow dissolution if the supernatant and interstitial liquids near the surface were not removed.

- Water distribution will be accomplished using a relatively simple and inexpensive system of nozzles, which can be reused or disposed of inexpensively; and

- Existing tank farm infrastructure is sufficient to allow retrieval at the anticipated saltcake dissolution rates.

In addition, this saltcake dissolution should use a lower total volume of water to remove the waste and should maintain a lower hydraulic head than past-practice sluicing. These attributes reduce the risk of tank leaks.

3.2 INTERIM STABILIZATION

The Hanford Site has 149 SSTs containing liquid and solid radioactive wastes from the processing of nuclear weapons materials. Of these, 67 are known or suspected to have leaked liquid into the surrounding soil (CHG 2001a). To minimize the amount of material that could potentially leak to the surrounding soil, drainable liquids are to be removed from all SSTs as an aspect of the tank interim stabilization process.

Much of the liquid to be removed from the SSTs resides in the interstitial pores of the waste. Drainable liquids are removed from the SSTs by a method commonly called *saltwell pumping*. In this method, a long cylindrical metal screen (the saltwell screen) is installed as a well casing in the solid waste. In most tanks, the saltwell screen is installed near the center of the tank and extends virtually to the bottom of the tank. A jet pump located inside and at the bottom of the saltwell screen is used to pump liquid out as it drains into the saltwell screen. At the onset of pumping, any supernatant liquids (i.e., free liquid above the solids) drain quickly into the well. Initially the rate of liquid removal is limited by pump capacity; however, as the liquid inventory is depleted, the pumping rate eventually exceeds the rate that liquids drain into the saltwell screen and the liquid level within the saltwell drops. The pumping rate is then reduced to approximately match the liquid drainage rate to prevent the jet pump from running dry.

Because the interstitial liquid migrates relatively slowly through the porous saltcake, the interstitial liquid level near the saltwell decreases much more rapidly than it does far from the saltwell. As a result, the depth of unsaturated waste[3] will be greater near the saltwell (i.e., near the tank center) than far away from the saltwell (i.e., near the tank wall).

A schematic of a typical saltwell pumping system is given in Figure 3-1. The centrifugal pump forces fluid at high pressure down through a pipe to the jet assembly located at the bottom of the saltwell. An eductor inside the jet assembly converts the high pressure, low velocity fluid from the centrifugal pump to low-pressure, high velocity flow. Liquid in the saltwell enters the jet assembly via the foot valve[4] and is flushed with the high velocity fluid up to the suction of the centrifugal pump. A piping "Tee" at the outlet of the centrifugal pump allows a portion of the

[3] In this document, "unsaturated waste" is waste that has been drained of drainable liquid.

[4] The foot valve is a check valve intended to prevent the system from draining into the saltwell when the centrifugal pump is shut off. Without the foot valve, the system might need to be re-primed each time the centrifugal pump was shut off.

liquid to be returned to drive the jet assembly and a portion to be sent to the receiver tank. A diaphragm-operated valve controls the amount of liquid sent to the receiver tank. Usually the diaphragm-operated valve is adjusted automatically to maintain a specified liquid level in the saltwell. Fresh water for priming the system and for flushing the lines (to prevent or remove plugging) is introduced via the "flush line" shown in the figure.

Figure 3-1. Interim Stabilization System

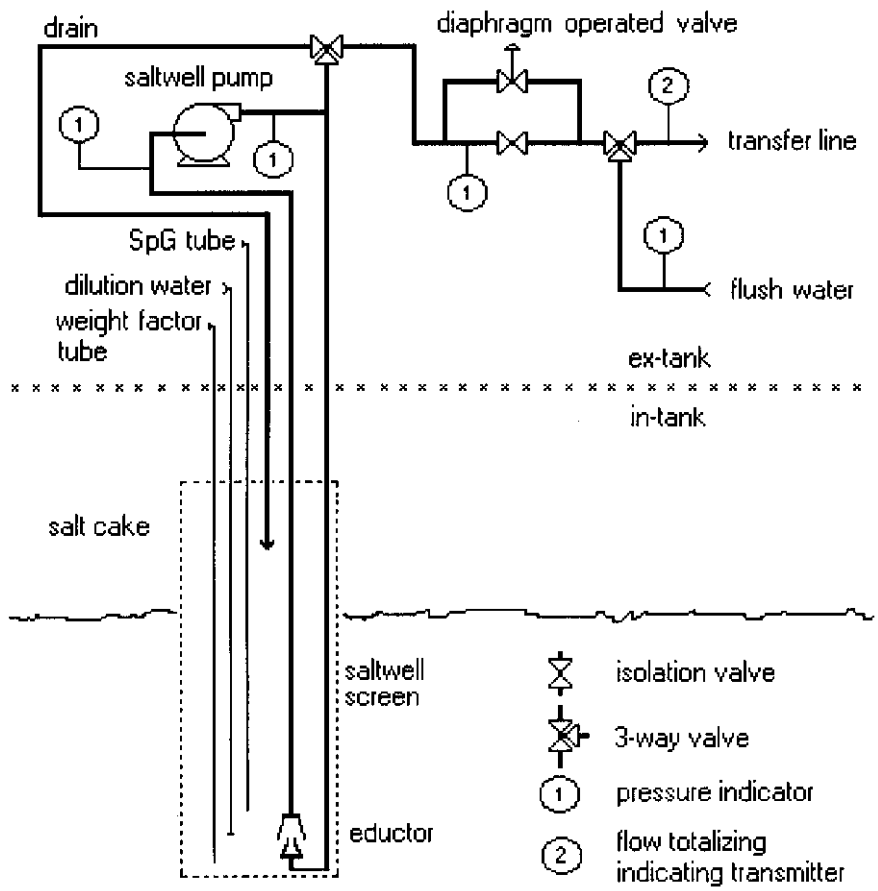
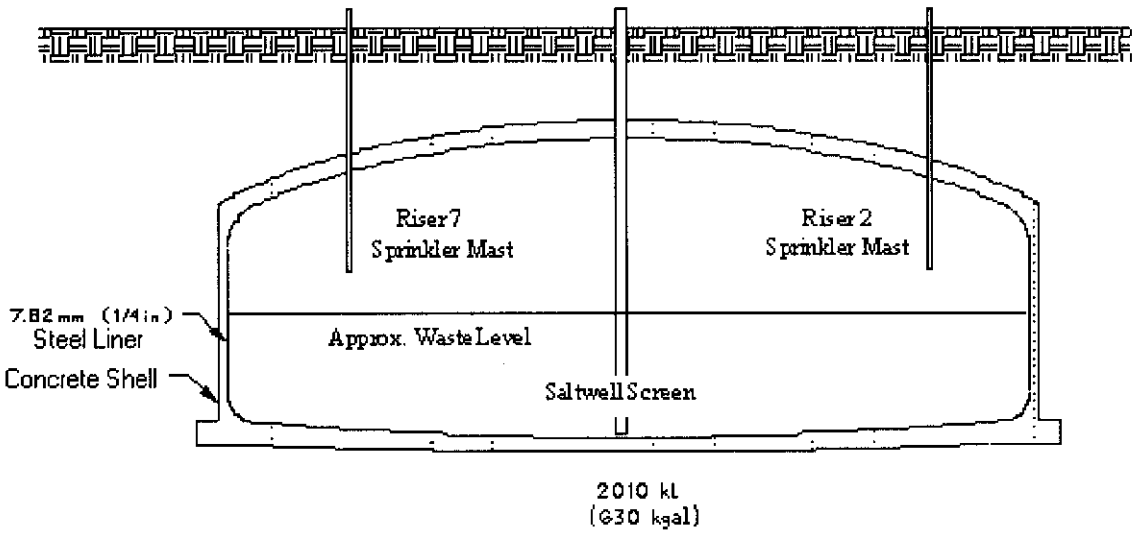


Figure 3-1 also depicts the locations of pressure and flow-metering instrumentation and the three dip tubes used to measure the specific gravity and depth of liquid in the saltwell screen. The dip tubes are open-ended tubes through which air is slowly passed. One dip tube is open to the headspace of the saltwell screen above the liquid, and the weight factor and the specific gravity tubes (labeled "weight factor tube" and "SpG dip tube," respectively, in Figure 3-1) extend to almost the bottom of the saltwell screen. A differential pressure meter connected between the weight factor dip tube and tube in the headspace measures the liquid head pressure in the saltwell screen. A second differential pressure meter connected between the weight factor dip and the specific gravity dip tubes (which differ by precisely a length of 10-in.) is used to determine the specific gravity of the liquid.

3.3 TANK 241-U-107 DESCRIPTION

Tank U-107 is a single-shell tank with a primary steel liner and concrete dome with a nominal operating capacity of 530,000 gallons. The 75-ft diameter tank has a 12-in. dish bottom, a 4-ft radius knuckle, and an operating depth of 18 ft 8 in. (LMHC 1997). A profile view of the tank structure is shown in Figure 3-2. The riser locations and allocations are described in Section 3.3.1, and instrumentation is discussed in Section 3.3.2. The interim stabilization system is described in Section 3.3.3 and the saltcake dissolution water addition system in Section 3.3.4. The Topographical Mapping System is summarized in Section 3.3.5.

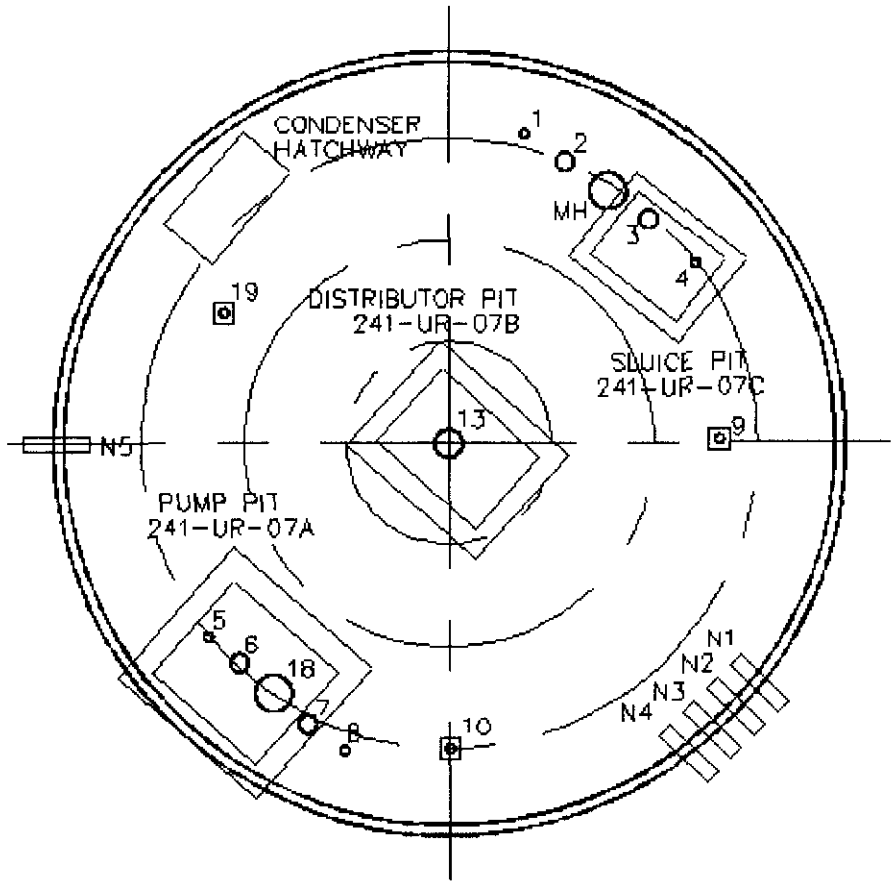
Figure 3-2. Tank 241-U-107 Profile View



3.3.1 Riser Allocation and Location

Most of the risers in tank U-107 are located at about 30-ft from the tank center as shown in the tank plan view in Figure 3-3. Riser sizes and allocations are listed in Table 3-1.

Figure 3-3. Tank 241-U-107 Plan View



3.3.2 Tank Instrumentation

The waste surface level is currently measured by an ENRAF™[5] buoyancy gauge in Riser 8. This instrument was installed in August 1994. The absolute accuracy of any of the waste level instruments depends on the degree of surface irregularity and the uncertainty in the reference position. Combined, these could produce a systematic error of 1 to 8 in. depending on the tank. Sensing level change is generally more important than absolute accuracy. The ENRAF™ records level in 0.01-in. increments and is able to resolve level changes to within ± 0.1 in..

Vertical temperature measurements are taken from a thermocouple tree mounted in Riser 1, with readings monitored and recorded through the Temperature Monitoring and Control System (TMACS). Tank U-107 has eleven thermocouples. The lowest is located at 22 inches above the tank bottom with the next eight spaced 24 inches apart (22 inches, 46 inches, 70 inches, 94 inches, 118 inches, 142 inches, 166 inches, 190 inches, and 214 inches). The last two are located at 262 and 310 inches. Only the first six thermocouples are within the waste. The last

[5] ENRAF is a trademark of the ENRAF Corporation, Houston, Texas

five indicate the headspace temperature. The uncertainty in the temperatures is estimated to be ±1.8 °C (3 °F) (PNNL 1995).

The tank headspace is monitored by a Meggit Safety System™ Hydrogen Cell. It consists of two photochemical cells configured so that one covers a high range (0 to 10 percent by volume) and one a low range (0 to 1 percent by volume) of hydrogen concentrations. The system can also collect a grab sample automatically if a high hydrogen alarm point is reached. Data are recorded by connection to the TMACS and by the onboard chart recorder.

Table 3-1. Tank 241-U-107 Riser Description

Riser No.	Diameter (in.)	Description And Comments
1	4	Temperature Probe
2	12	Spare (Fixed water spray nozzle assembly and TMS)
3	12	Sluice Nozzle
4	4	Recirculation Line Dip Leg
5	4	Recirculation Line Dip Leg
6	12	Sluice Nozzle
7	12	Spare (Impact sprinkler and TMS)
8	4	ENRAF™ level gauge
9	4	Spare (video camera)
10	4	Standard Hydrogen Monitor System / Breather Filter
13	12	Saltwell screen and jet pump
18	42	Sludge Pump
19	4	Liquid Observation Well
N1	3	Inlet Sealed In Diversion Box 241-U-153
N2	3	Inlet Sealed In Diversion Box 241-U-153
N3	3	Inlet Sealed In Diversion Box 241-U-153
N4	3	Spare, Capped
N5	n/a	Overflow

Notes:

TMS = Topographical Mapping System
n/a = not applicable

A liquid observation well (LOW) is located in Riser 19 to monitor the interstitial liquid level. An LOW consists of a hollow tube, capped on the bottom, inserted into a riser from the surface to the bottom of the tank from which the tank contents are monitored with neutron and gamma probes. The neutron probe consists of a neutron source (1.5 Curies of americium-beryllium, AmBe) adjacent to a BF_3 gas tube thermal neutron detector. The AmBe source emits fast, high-energy neutrons at about 4.5 MeV, which are then moderated by the hydrogen of the surrounding moisture and detected by the BF_3. The detector response is a good indicator of the moisture content at the elevation surrounding the LOW. The gamma probe is simply a low efficiency Geiger-Mueller tube that detects naturally occurring gamma radiation penetrating the

LOW from the waste (mostly cesium-137 and cobalt-60, with secondary gamma from strontium-90). The general assumption is that the gamma count is roughly proportional to the liquid content because cesium is generally soluble in water.

3.3.3 Current Interim Stabilization System Instrumentation

Several measurements from the saltwell pumping system are automatically logged during operation. These measurements provide useful process information. They are listed as follows:

(1) Dilution flow rate (water flow into the base of the saltwell);

(2) Transfer flow rate (saltwell liquid plus dilution water out to the double-shell receiver tank 241-SY-102);

(3) Diaphragm operated valve position (valve that sets transfer flow rate);

(4) Specific gravity of liquid in the saltwell (as registered by the dip tubes);

(5) System pressure at pump suction, pump discharge, and transfer line; and

(6) Liquid head pressure in the saltwell (as registered by the dip tubes).

These data are read at a relatively high frequency and are downloaded to a file-server daily. Additional data are recorded on rounds sheets taken periodically as specified by the Authorization Basis. Additionally, the saltwell pumping equipment features an access port on its mounting flange. This allows limited access to the interior of the saltwell screen. This feature provides a potential location for the application of additional instruments and will be used to collect liquid samples from the saltwell screen.

3.3.4 Saltcake Dissolution Water Addition System

The saltcake dissolution system consists of a series of nozzles and sprinklers to add water in several specific patterns. Figure 3-4 shows a schematic diagram of the spray nozzle system in Riser 2 and the sprinkler system in Riser 7. Quick-connect fittings connect the selected line to the plant water supply. The flow is filtered in-line, and the pressure drop across the filter is monitored by means of pressure indicators before and after the filter housing. A solenoid valve downstream of the filter allows the flow to be controlled from the pump, instrumentation, and control (PIC) skid. The solenoid valve serves to shutdown any water addition upon a saltwell pump failure. Downstream of the solenoid valve, the flow rate in the line is monitored with a display-type flow totalizer. The flow rate is measured with a flow element downstream of the totalizer. The flow rate is controlled by means of a pressure regulating valve and is provided with an in-line isolation ball valve. The pressure is monitored upstream of the pressure regulating valve.

Quick-connect fittings allow the line to be connected to one of four spray nozzle tubes penetrating a blind flange in the 12-inch Riser 2. The spray nozzle droplegs extend approximately 200 inches below the flange into the tank headspace. Three of the tubes have spray nozzle fittings on the end, each pointing in a different direction, and the fourth has a fitting

for the Fury™[6] tank washer. The adapter in Riser 7 contains one dropleg to the Nelson™[7] impact sprinkler with a quick-connect fitting to the water supply. Both risers contain an additional flange (not shown) for the topographic mapping system.

The plan and schedule for water addition is described in Section 4.2. An impact sprinkler will be installed in Riser 7 for a large-area pattern. Three fixed nozzles will be installed on an assembly in Riser 2. One will be aimed at the thermocouple tree in Riser 1, another at the waste surface near the tank wall, and the third toward the saltwell screen. A modified version of the Fury™ tank washer will be mounted at the base of the fixed nozzle assembly to spray a circular area approximately 20 ft in radius. The "footprints" of the impact sprinkler and each of the fixed nozzles are shown in Figures 3-5 through 3-8. The Fury™ tank washer is shown in Figure 3-9. The Fury™ tank washer spray pattern along with all others is shown in Figure 3-10.

[6] Fury is a trademark of the Chemdet Corporation, Port Washington, New York.
[7] Nelson is a trademark of the L. R. Nelson Corporation, Peoria, Illinois.

Figure 3-4. Schematic of the Water Distribution System for Tank 241-U-107

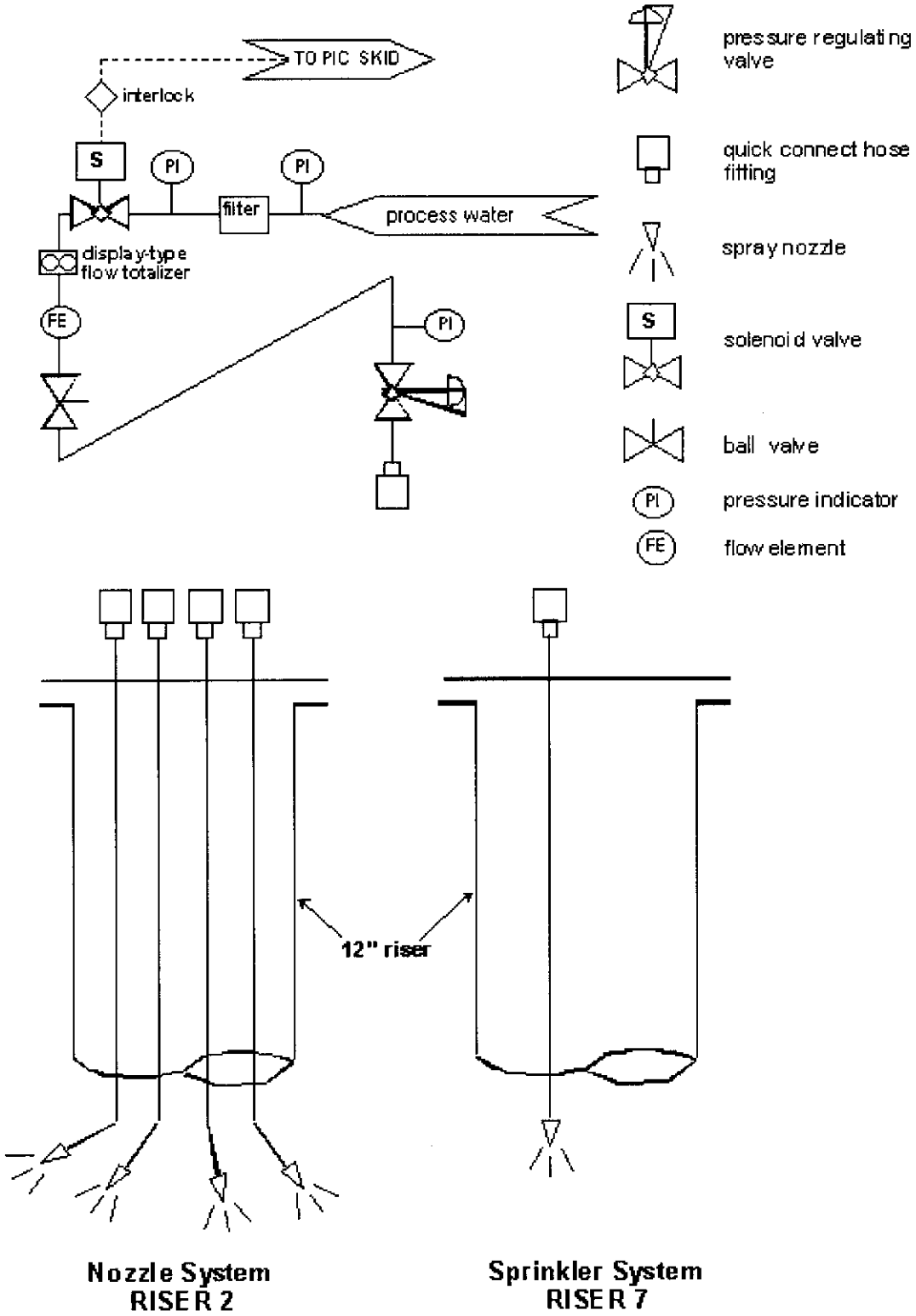
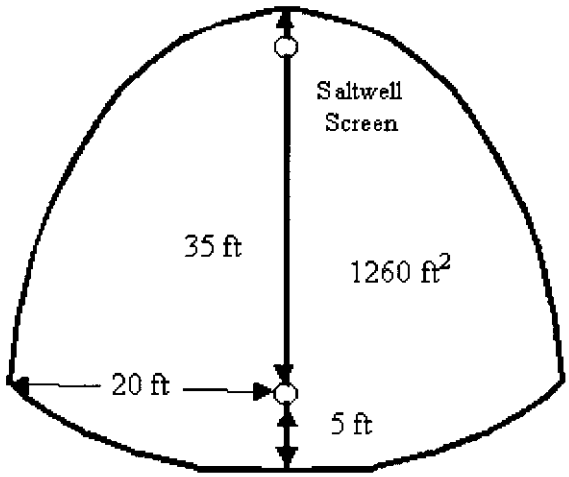
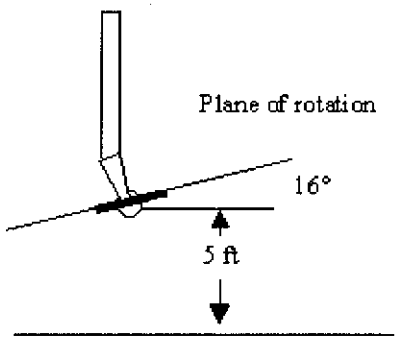


Figure 3-5. Large Area Spray Pattern

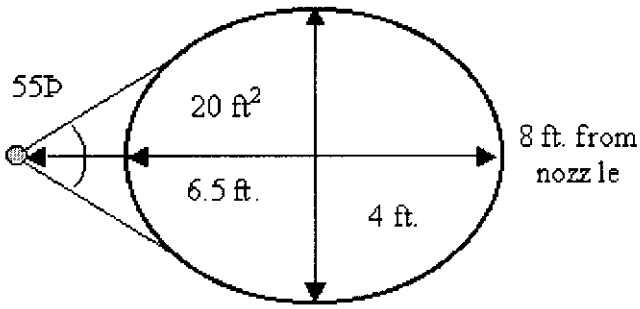


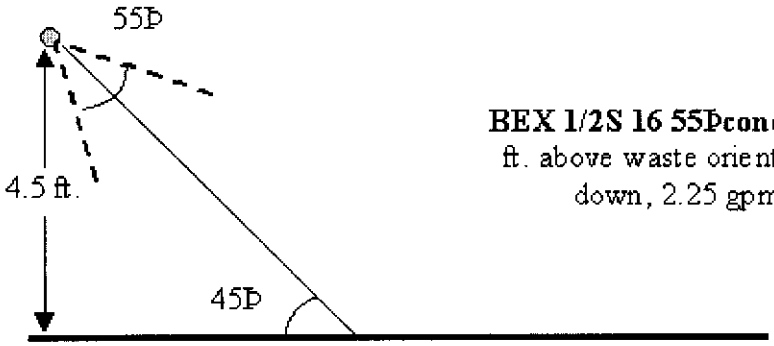


Nelson Impact Sprinkler
5 ft. off waste, 16 degrees off horizontal, 3.25 gpm

Patterns are approximate and not to scale

Figure 3-6. Shadowing Spray Pattern





BEX 1/2S 16 55Þcone set 4.5 ft. above waste oriented 45Þ down, 2.25 gpm.

Patterns are approximate and not to scale

Figure 3-7. Near-Wall Spray Pattern

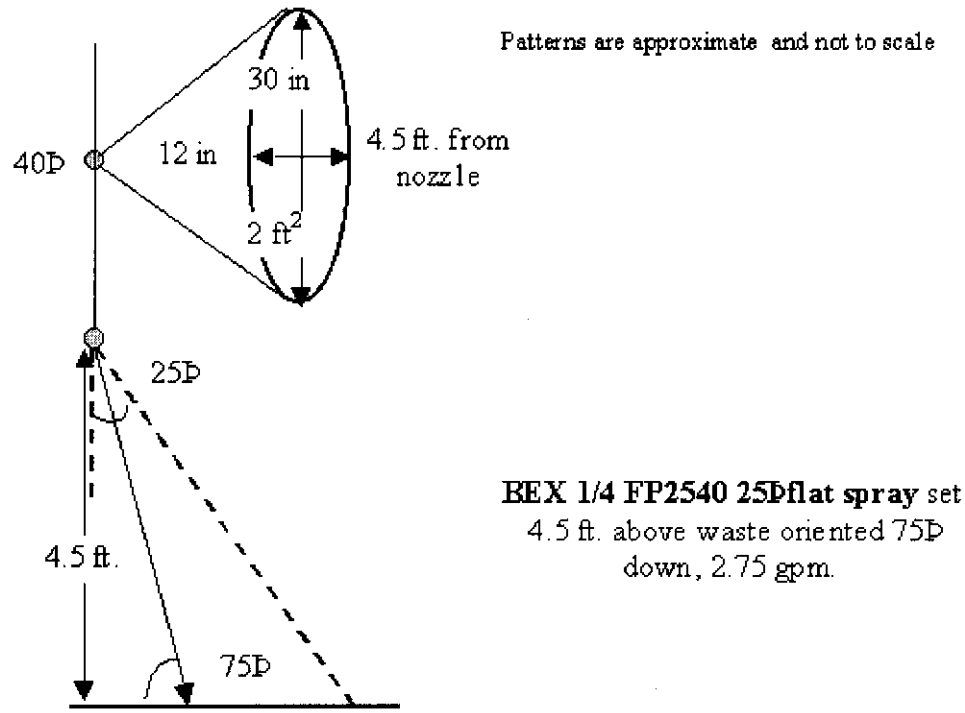


Figure 3-8. Near-Saltwell Spray Pattern

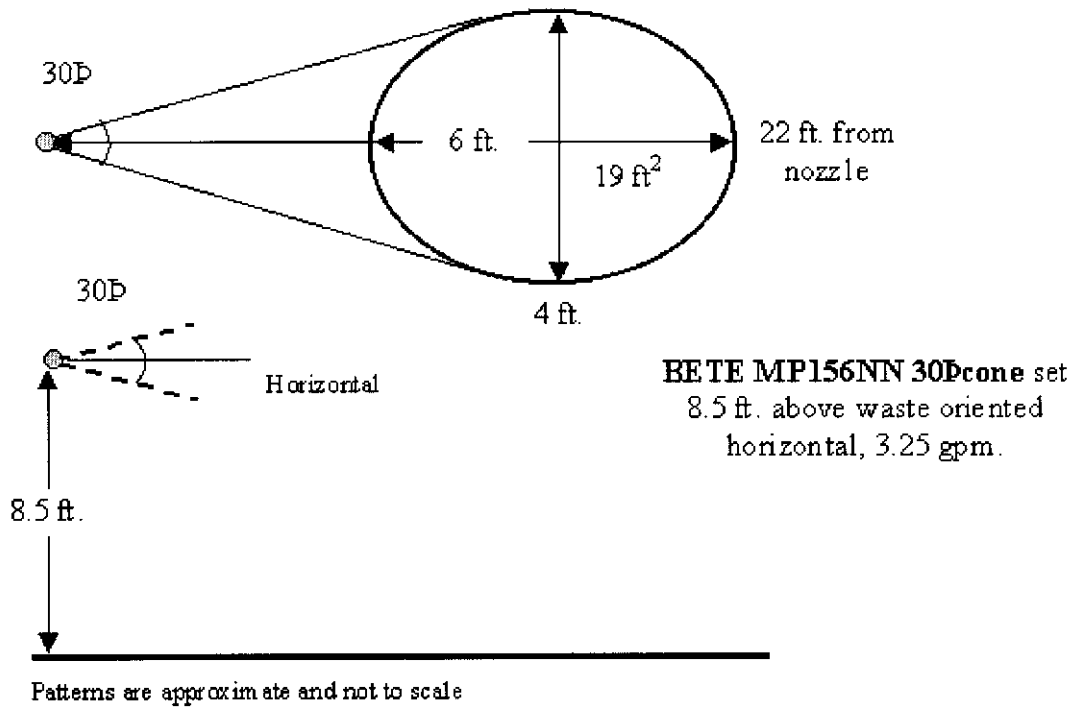
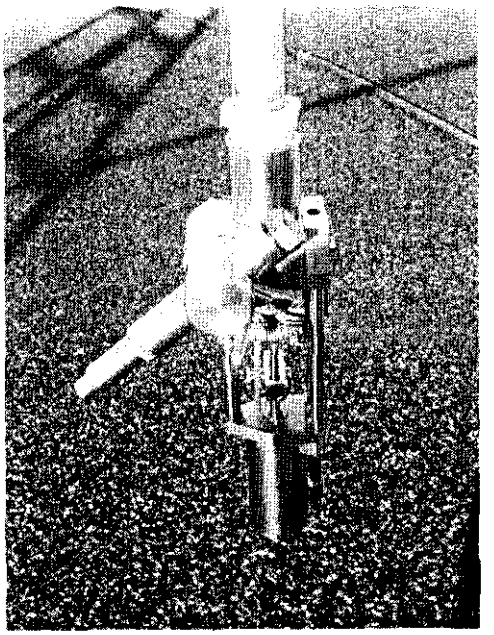


Figure 3-9. Fury™ 400 Tank Washer



The approximate location of each of the sprinklers' footprints on the waste surface is sketched in Figure 3-10. The area and flow rate of each nozzle and sprinkler are summarized in Table 3-2.

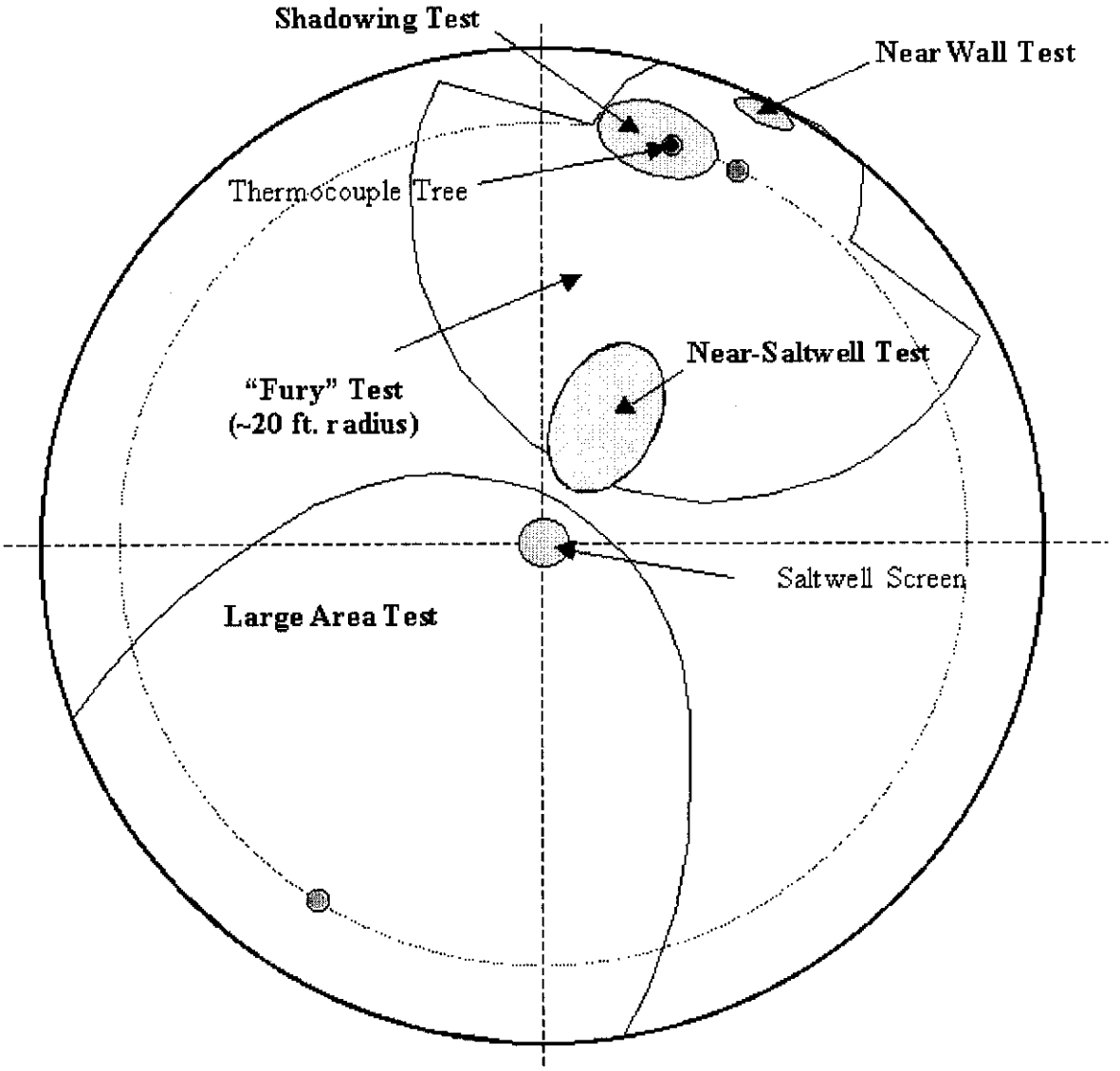
Table 3-2. Nozzle and Sprinkler Summary

Sprinkler or Nozzle Area (Riser)	Approx. Area (ft^2)	Elevation (ft)	Angle	Flow Rate (gpm)
Nelson™ Impact Large-area (Riser 7)	1728	~6.0	16° up toward ctr.	~6.5
BEX 1/4 FP2540 25° Cone Near-wall (Riser 2)	38	~4.5	60° down	~3
BETE MP156NN 30° Cone Near-saltwell (Riser 2)	75	~8.5	horizontal	~4
BEX 1/2 S16 55° Cone Shadowing (Riser 2)	88	~4.5	45° down	~2.5
Fury™ Tank Washer (Riser 2)	675	~4.0	n/a	~10

Notes:

ctr = center
n/a = not applicable

Figure 3-10. Approximate Tank-Wide Spray Configuration



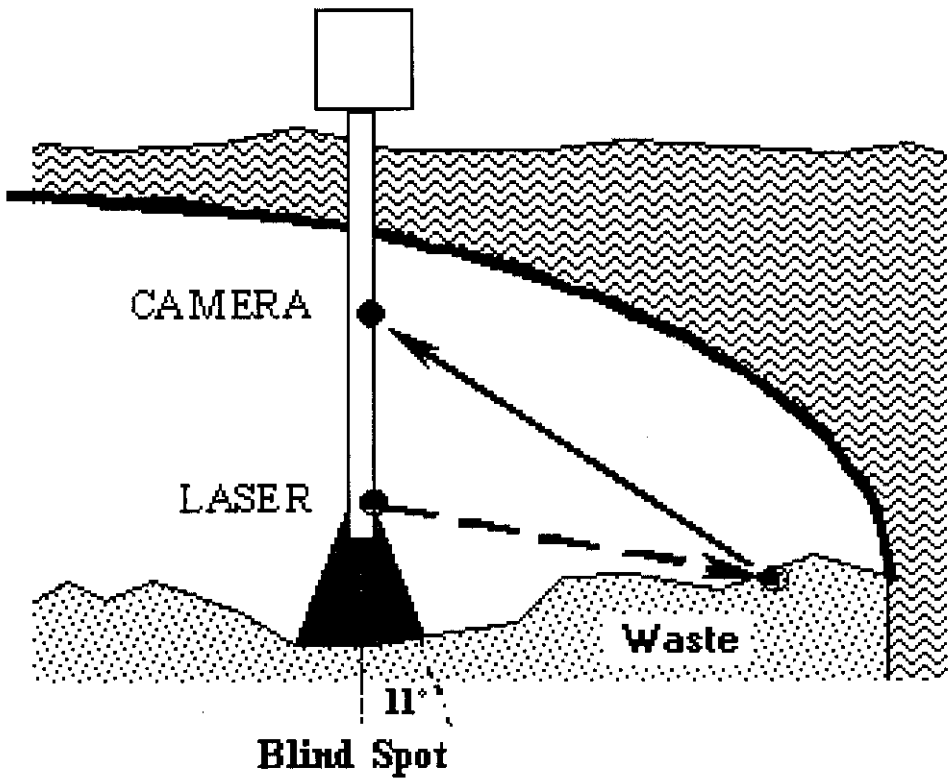
3.3.5 Topographical Mapping System

The Topographical Mapping System (TMS) was developed in 1993 with Tank Focus Area support by a team from Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Mechanical Technology Incorporated. It was specifically designed to support characterization and retrieval operations in the Hanford Site tanks. The TMS was identified as a potential candidate to measure the performance of the saltcake dissolution proof-of-concept. The TMS was first demonstrated in 1994 in a Hanford Site cold-test tank and was successfully

deployed in the Oak Ridge Gunite tanks in 1996. Tank waste volume measurement capability was added and successfully demonstrated in 1997.

The TMS illuminates a line on the waste with a laser and detects the reflection with a video camera as illustrated in Figure 3-11. The system scans the surface, creating a grid with resolution as high as 0.1 inch, and maps the surface with a typical accuracy of better than 0.25 inch at 45 feet. The TMS mast is 3.5 inches in diameter and can be deployed in a 4-inch riser. Measurements beyond a radius of about 45 ft are problematic because the camera has difficulty seeing the laser-illuminated line. Therefore, deployment in two locations is required to cover the entire tank when, as is the case in tank U-107, no centrally located riser is available.

Figure 3-11. Topographical Mapping System Operation



Estimates of waste volume changes determined by subtracting one scan from another are typically accurate to better than ~7 percent. The camera is blind in a 22-degree cone beneath the mast; therefore, for example, if the laser were 8 ft above the waste surface, the TMS could not map a 3.1-ft diameter spot directly beneath it. This would correspond to a 6.6-ft^2 area of waste, or roughly 0.2 percent of the entire waste surface. The TMS is also incapable of mapping anything in the shadow of an obstruction; the surface behind a thermocouple tree, for example, could not be mapped.

The TMS will be installed in the same riser with the sprinkler/nozzle set being used. The TMS will be positioned with respect to the sprinkler mast such that shadowing by the mast or other risers is minimized. In Riser 2, the TMS must be positioned to see past the thermocouple tree in Riser 1 to evaluate the volume of waste left by shadowing. In Riser 7, the TMS should be positioned so that shadowing by the sprinkler mast is toward the tank wall.

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4.0 PROCESS CONTROL

The saltcake dissolution operations will add water on the waste surface through several nozzles and sprinklers. The process will consist of three stages.

The first stage will involve saltwell pumping until all the supernatant is removed and approximately 10 kgal interstitial liquid is pumped to drain approximately the first foot of waste (i.e., the liquid level is about a foot lower than the salt surface and the waste in between is not saturated with liquid). The integration of dissolution operations with interim stabilization operations is covered in Section 4.1.

In the second stage, saltwell pumping will continue while three fixed nozzles, a sprinkler, and the tank washer are used to spray water on the waste. The sprinkler will cover a broad area prototypic of a system that might actually be deployed for retrieval. The three spray nozzles will cover smaller areas of waste to investigate specific phenomena. The tank washer will also cover a relatively large area. Each of these tests is described in detail in Section 4.2. Thereafter, in the third stage, saltwell pumping will continue (after the saltcake dissolution operations) until the interim stabilization criteria are satisfied.

Figure 4-1 depicts the general sequence of events for the proof-of-concept operations. The process will be controlled primarily by the specified volume of water added and the liquid level in the saltwell screen unless undesirable conditions (e.g., pooling of liquid, dilute liquid in the saltwell screen, or excessive channeling of the waste surface) are observed. The effects of water addition through each device will be evaluated as the operations progress. Measurement techniques include the following:

(1) Time dependence of saltwell pumping flow rate and saltwell liquid level,

(2) Visual (by video camera) observation of the waste surface,

(3) Periodic topographical mapping of the waste surface with the TMS,

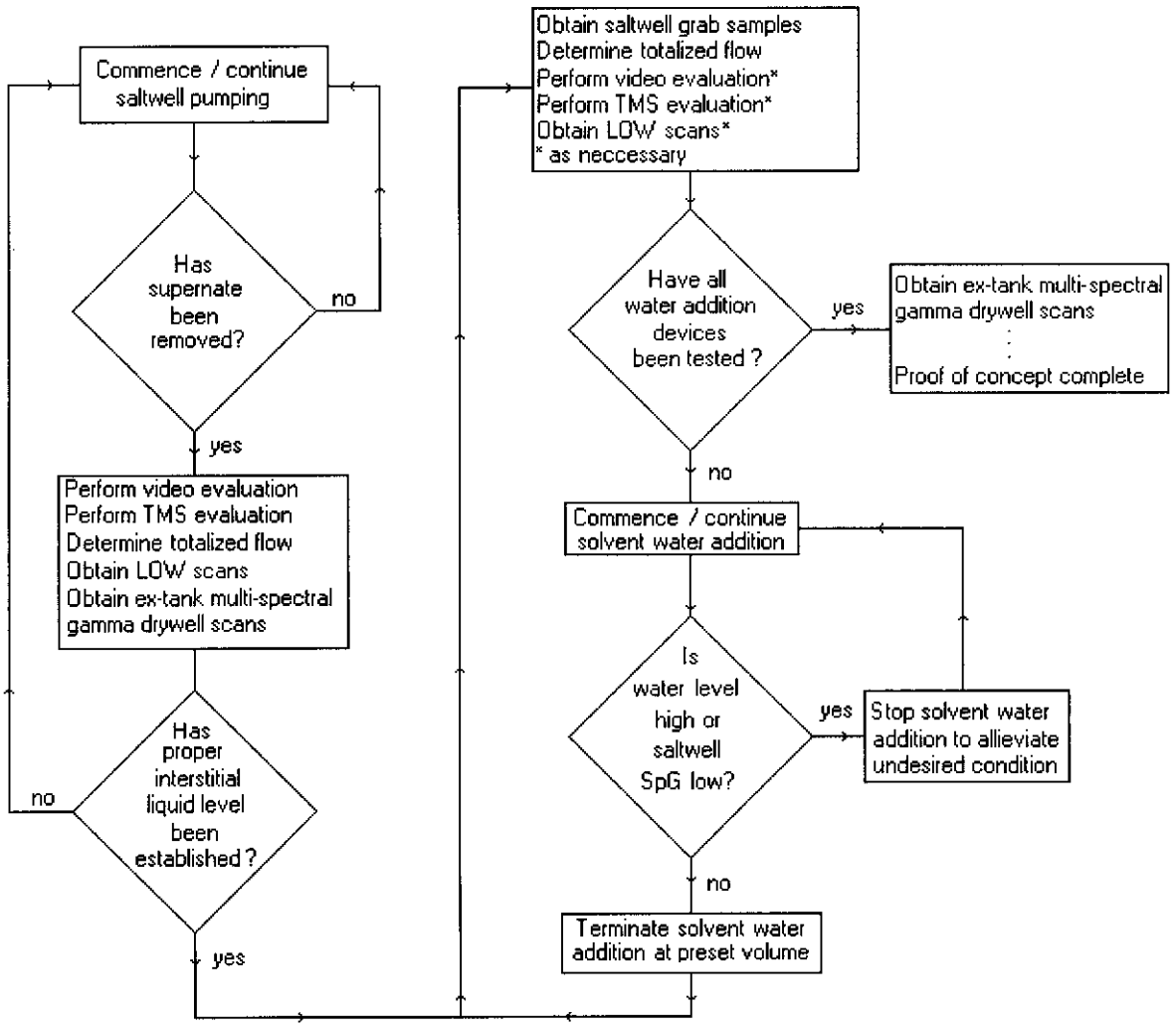
(4) Time dependence in both neutron and gamma logs in the tank LOW,

(5) Time dependence of waste temperatures, and

(6) Post-test distribution of composition and specific gravity of the saltwell liquid via grab samples.

Process sampling requirements and their schedule is discussed in Section 4.3. Additional information concerning the physical nature and terminology of the waste properties is given in Appendix C.

Figure 4-1. Proof-of-Concept Event Sequence



4.1 INTEGRATION WITH INTERIM STABILIZATION

One of the main advantages of the saltcake dissolution method is that it uses the existing saltwell pumping equipment to remove waste from the tank. Liquid removal by saltwell pumping needs to be integrated with water addition to insure the following:

- The drainable liquid inventory in the tank is kept at a minimum and an accurate mass balance is maintained,
- Water is added to drained saltcake to encourage effective dissolution,
- Saltwell liquid is diluted only as needed for effective transfer to minimize DST space used,

- The liquid level in the saltwell is kept sufficiently high to measure the specific gravity but below the interstitial liquid level as measured at the LOW, and
- Pumping is shut down to allow periodic grab samples representative of the dissolution process.

These constraints have the effect of requiring that the jet pump be operated when water is being added (except for the very low volume tests) and that water addition be intermittent to prevent over-filling the saltwell screen. The specific elements requiring integration are discussed in this section.

4.1.1 Brine Volume Constraints

There are two constraints on the amount of brine removed from the tank that effectively bound the volume of water that can be added. At a minimum, one of the goals stated in the project performance incentive (Appendix C) is for removing at least 100,000 gallons of brine during the operations period. This includes both the new brine created by dissolution and the pre-existing interstitial liquid that drains into the saltwell. There is no method to differentiate the brine produced by dissolution from the interstitial brine released during the proof-of-concept. The goal is the production or release of 100,000 gallons of brine <u>in</u> <u>excess</u> of the drainable liquid that would have been removed by saltwell pumping without dissolution. Both these constraints include any in-line dilution water required.

4.1.2 In-Line Dilution Ratio Specification

The amount of dissolution water necessary to achieve the 100-kgal objective is a function of the waste chemistry and the dilution ratio. Appendix C describes the equations used to calculate dissolution water requirements and presents calculations based on a 0.4:1 dilution ratio (i.e., each gallon of brine is diluted at the pump inlet with 0.4 gallons of water) to reach the maximum allowable transfer line specific gravity of 1.3. For a dilution ratio of 1:1, approximately 30 kgal of dissolution water must be added to produce the 100 kgal of (diluted) brine. Process data, such as liquid SpG and grab sample results, and other considerations may be used to modify the dilution ratio, which is currently set at 1:1 (CHG 2001g). The 1:1 ratio provides significant operating margin against concerns such as transfer-line heat-tracing and potential cold-weather transfers.

The specific gravity of the saltwell liquid desired for safe transfer to tank SY-102 is 1.3. The interstitial liquid density while dissolution is occurring is thought to be as high as 1.66 g/mL. This density requires a dilution ratio of 1:1 (water to undiluted liquid) to achieve the target specific gravity. The dilution ratio, D, can be determined from the liquid and target density by:

$$D = \left(\frac{\rho_L - \rho_{target}}{\rho_{target} - \rho_W} \right)$$

Where:

ρ_L = liquid density

ρ_{target} = target density

ρ_W = water density

For 100,000 gallons of diluted brine, 50,000 gallons of in-line dilution water is required. The dilution ratio may be adjusted if dip tube SpG measurements and/or grab samples indicate a significantly different liquid SpG. For example, an interstitial liquid density of 1.4 g/mL would require a dilution ratio of 0.4:1.

4.1.3 Saltwell Liquid Level Control

Normally, the liquid is maintained at the minimum possible level (a few inches above the jet pump inlet) after the supernatant is removed to maximize the hydraulic head and draining rate. However, this low level uncovers the upper dip tube that provides a specific gravity measurement in the saltwell screen. It is important to monitor the specific gravity because a low value is a clear indication that dilution water is running off the waste surface without dissolving saltcake. The liquid level will be maintained above the specific gravity tube during the duration of the proof-of-concept operations.

The liquid level will also be used to control water addition. The rate that brine is produced by water addition plus the draining rate of existing interstitial liquid into the saltwell and in-line dilution flow is expected to exceed the capacity of the jet pump. This will cause the saltwell liquid level to rise, eventually overflowing into unsaturated waste or even pooling above the waste surface. ***To prevent the undesirable accumulation of excess liquid, water addition must be shut down before the liquid level as measured in the saltwell rises above the interstitial liquid level determined from the last neutron log of the LOW.***

4.2 OPERATIONAL CONTROL

The saltcake dissolution proof-of-concept operations will be controlled by adding a predetermined volume of water through each nozzle and sprinkler in the order described below. During water addition, visual monitoring of the waste surface will be used to detect excess water accumulation or the development of undesirable waste surface features. Liquid level in the saltwell screen and the specific gravity of the liquid in the saltwell screen will be used to detect excess liquid accumulation and dilute liquid runoff. The spray will also be shut off in response to various off-normal conditions as described in Section 6.0.

Because of the large uncertainties in predictions and unforeseen effects that will likely be encountered, it is not possible to specify the entire process beforehand. Specific water volumes, spray durations, and waiting intervals, for example, will need to be adjusted during the operations. As required, this will be accomplished via one or more Process Memos issued by CHG Interim Stabilization Engineering to CHG Interim Stabilization Operations at the appropriate time expressing the technical consensus of the project.

4.2.1 Initiation of Proof-of-Concept Operations

Efficient saltcake dissolution via a surface water spray requires a significant depth of unsaturated waste. Because water is much less dense than the interstitial liquid, the water spray cannot penetrate supernatant or saturated waste. Saltwell pumping must first remove the supernatant and drain the interstitial liquid from the waste surface before water is added.

The supernatant volume in tank U-107 is estimated to be 33,000 gallons (CHG 2000d). At a drainable porosity of 0.25, almost 7,000 gallons more would drain from a 10-inch layer of waste for a total of about 40,000 gallons. Assuming a dilution ratio of 1:1, a pumping efficiency of 50 percent, and a pump capacity of 4 gpm, about 28 days of pumping will be required to remove the 40,000 gal.

Because there is considerable uncertainty in the supernatant volume and drainable porosity estimates, the proper time to initiate dissolution water spray must be determined from the preponderance of evidence from the surface level, neutron and gamma logs, saltwell pumping rate, and possibly waste temperatures. If the time required to drain ten inches becomes excessive, a shallower unsaturated layer may be acceptable. The instruction to begin the proof-of-concept operations will be documented in a Process Memo written by CHG Interim Stabilization Engineering to CHG Interim Stabilization Operations.

The proof-of-concept operations will be initiated from baseline sampling and measurements. This includes a TMS scan of the waste surface from Riser 2, neutron and gamma logs in the LOW in Riser 19, and grab samples at two levels in the saltwell screen. The saltwell screen will be allowed to fill prior to grab sampling. Sampling requirements are described in more detail in Section 4.3 below. Water additions can proceed after the initial video, TMS scan, and sampling are completed as described in following sections. If the TMS is not ready to support the start of the proof-of-concept operations, the SST Program Director must determine the need for the system and may authorize the start of proof-of-concept operations without it. This prerequisite must be reflected in the Process Memo from Interim Stabilization Engineering to Interim Stabilization Operations. Authorization to proceed forward with the proof-of-concept if the TMS is unavailable is provided by the Interim Stabilization Director.

4.2.2 Water Addition Operations

A series of eight separate water additions is planned to meet the goals of the saltcake dissolution proof-of-concept operations. Three initial tests in Riser 2 are intended to provide a quick

confirmation of the expectations of the behavior of the saltcake when sprayed with water. The next series of three tests, also in Riser 2, add larger volumes of water to investigate specific issues and to test the "Fury™" tank washer. The final two tests in Riser 7 are intended as a prototype of a full-scale retrieval operation covering a large fraction of the surface area.

The planned water addition volume and area for each test are listed in Table 4-1. The areas of the waste surface that are expected to be dissolved in each test are sketched in Figure 4-2. The area value in the table approximately corresponds to the shaded region in the figure. The volume of waste dissolved in the table represents the difference between the original waste volume and that of undissolved solids plus interstitial brine left after draining. The total brine includes initial drainable liquid, water added, dissolved solids, and in-line dilution. Based on the volume estimated to be dissolved, approximately 11 to 14 kgal of brine would have drained by saltwell pumping alone. Each group of tests is separated by sampling events as noted in the table and described in Section 4.3.

The planned water addition and sampling schedule is given in Table 4-2. The schedule for TMS and video scans is also included. As mentioned previously, the details may be adjusted based upon observations during performance of the dissolution activities. In addition to off-normal conditions discussed in Section 6.0, the following conditions apply unless Interim Stabilization issues specific exceptions via Process Memo:

- *Dissolution water will not be added when the saltwell pump is not operating, except for the three initial low-volume tests;*
- *The maximum daily amount of dissolution water will be limited so that it does not produce more brine than can be pumped in a 1-day period; and*
- *The addition of dissolution water will be stopped if the liquid level in the saltwell screen exceeds the most recently measured ILL as determined by neutron or gamma probe readings in the LOW. Addition of dissolution water may be resumed when the saltwell screen liquid level is below the ILL.*

Table 4-1. Water Addition Area and Depth Volume

Pattern/Test	Area (ft^2)	Waste Dissolved (gal)	Water Volume (gal)	Brine Volume (gal)
Near Saltwell - Initial	19	570	400	1,352
Shadowing - Initial	20	720	500	1,690
Near Wall - Initial	2	570	400	1,352
Near Saltwell - Channeling	150	2,900	2,000	6,760
Near Wall - Large Volume	1,105	11,400	8,000	27,040
Fury™ - Large Volume	1,105	4,300	3,000	10,140
Large Area A	2,000	11,400	8,000	27,040
Large Area B	2,000	11,400	8,000	27,040
TOTAL		**43,300**	**30,300**	**102,414**

Table 4-2. Water Addition and Sampling Schedule. (2 Sheets)

Day #	Activity	Notes	Water addition rate (gpm)	Water (gal)	Total water (gal)	Brine produced and liberated (gal)	Dilution water (gal)	Brine + dilution water (gal)	Total brine + dilution water (gal)	Estimated hours of water application	Cumulative brine pumped at 4 gpm, 50% eff
1	Video of tank surface Liquid grab sample #1 TMS scan #1										2,880
2	Initial near-saltwell test		3.25	400	400	676	676	1,352	1,352	2.1	5,760
	Initial shadowing test		2.25	500	900	845	845	1,690	3,042	3.7	
3	Initial near-wall test TMS scan #2		2.75	400	1,300	676	676	1,352	4,394	2.4	8,640
4	Near-saltwell, large volume channeling test	1	3.25	1,000	2,300	1,690	1,690	3,380	7,774	5.1	11,520
5	Near-saltwell, large volume channeling test Liquid grab sample #2	1, 2	3.25	1,000	3,300	1,690	1,690	3,380	11,154	5.1	14,400
6	Near-wall, large volume test	3	2.75	1,000	4,300	1,690	1,690	3,380	14,534	6.1	17,280
7	Near-wall, large volume test	3	2.75	1,000	5,300	1,690	1,690	3,380	17,914	6.1	20,160
8	Near-wall, large volume test	3	2.75	1,000	6,300	1,690	1,690	3,380	21,294	6.1	23,040
9	Near-wall, large volume test	3	2.75	1,000	7,300	1,690	1,690	3,380	24,674	6.1	25,920
10	Near-wall, large volume test	3	2.75	1,000	8,300	1,690	1,690	3,380	28,054	6.1	28,800
11	Near-wall, large volume test	3	2.75	1,000	9,300	1,690	1,690	3,380	31,434	6.1	31,680
12	Near-wall, large volume test	3	2.75	1,000	10,300	1,690	1,690	3,380	34,814	6.1	34,560
13	Near-wall, large volume test	3	2.75	1,000	11,300	1,690	1,690	3,380	38,194	6.1	37,440
14	Wait for draining & settling TMS scan #3				11,300				38,194		40,320
15	Fury test	4	4.75	1,000	12,300	1,690	1,690	3,380	41,574	3.5	43,200
16	Fury test	4	4.75	1,000	13,300	1,690	1,690	3,380	44,954	3.5	46,080
17	Fury test Liquid grab sample #3	2, 4	4.75	1,000	14,300	1,690	1,690	3,380	48,334	3.5	48,960
18	Wait for draining & settling				14,300				48,334		51,840
19	Wait for draining & settling TMS scan #4				14,300				48,334		54,720
20	Move TMS to R7				14,300				48,334		57,600
21	Move TMS to R7				14,300				48,334		60,480
22	Move TMS to R7 TMS scan #5				14,300				48,334		63,360
23	Large area Test A	5	3.25	1,200	15,500	2,028	2,028	4,056	52,390	6.2	66,240
24	Large area Test A	5	3.25	1,200	16,700	2,028	2,028	4,056	56,446	6.2	69,120

Table 4-2. Water Addition and Sampling Schedule. (2 Sheets)

Day #	Activity	Notes	Water addition rate (gpm)	Water (gal)	Total water (gal)	Brine produced and liberated (gal)	Dilution water (gal)	Brine + dilution water (gal)	Total brine + dilution water (gal)	Estimated hours of water application	Cumulative brine pumped at 4 gpm, 50% eff
25	Large area Test A	5	3.25	1,200	17,900	2,028	2,028	4,056	60,502	6.2	72,000
26	Large area Test A	5	3.25	1,200	19,100	2,028	2,028	4,056	64,558	6.2	74,880
27	Large area Test A	5	3.25	1,200	20,300	2,028	2,028	4,056	68,614	6.2	77,760
28	Large area Test A	5	3.25	1,200	21,500	2,028	2,028	4,056	72,670	6.2	80,640
29	Large area Test A Liquid grab sample #4 TMS scan #6	2, 5	3.25	800	22,300	1,352	1,352	2,704	75,374	4.1	83,520
30	Large area Test B	6	3.25	1,200	23,500	2,028	2,028	4,056	79,430	6.2	86,400
31	Large area Test B	6	3.25	1,200	24,700	2,028	2,028	4,056	83,486	6.2	89,280
32	Large area Test B	6	3.25	1,200	25,900	2,028	2,028	4,056	87,542	6.2	92,160
33	Large area Test B	6	3.25	1,200	27,100	2,028	2,028	4,056	91,598	6.2	95,040
34	Large area Test B	6	3.25	1,200	28,300	2,028	2,028	4,056	95,654	6.2	97,920
35	Large area Test B	6	3.25	1,200	29,500	2,028	2,028	4,056	99,710	6.2	100,800
36	Large area Test B Liquid grab sample #5	2, 6	3.25	800	30,300	1,352	1,352	2,704	102,414	4.1	103,680
37	Wait for draining & settling				30,300				102,414		106,560
38	Wait for draining & settling				30,300				102,414		109,440
39	Video of tank surface TMS scan #7				30,300				102,414		112,320
	TOTALS			30,300		51,207	51,207	102,414		159	112,320

Notes

eff = efficiency

1 Anticipated 3-day duration; water addition to be tied to pump performance, not to exceed 1,600 gal/day or total of 2,000 gal.

2 Collect grab sample quickly after water addition has been stopped.

3 Anticipated 10-day duration; water addition to be tied to pump performance, not to exceed 1,600 gal/day or total of 8,000 gal.

4 Anticipated 5-day duration; water addition to be tied to pump performance, not to exceed 1,600 gal/day or total of 3,000 gal.

5 Anticipated 10-day duration; water addition to be tied to pump performance, not to exceed 1,600 gal/day or total of 8,000 gal during large area test A.

6 Anticipated 10-day duration; water addition to be tied to pump performance, not to exceed 1,600 gal/day or total of 8,000 gal during large area test B.

4.2.2.1. Initial Tests in Riser 2

The first three tests are intended to serve as an initial confirmation of the predictions of the water volume required to dissolve a given volume of waste and to assess the general behavior of the waste and saltwell pumping system to water addition. Only the water estimated to dissolve the unsaturated waste under the nozzle footprint will be used. These areas are shown by the dark shading in Figure 4-1. If the unsaturated waste depth at the time of the tests differs significantly from that listed in Table 4-1, the water volumes may need to be adjusted in proportion.

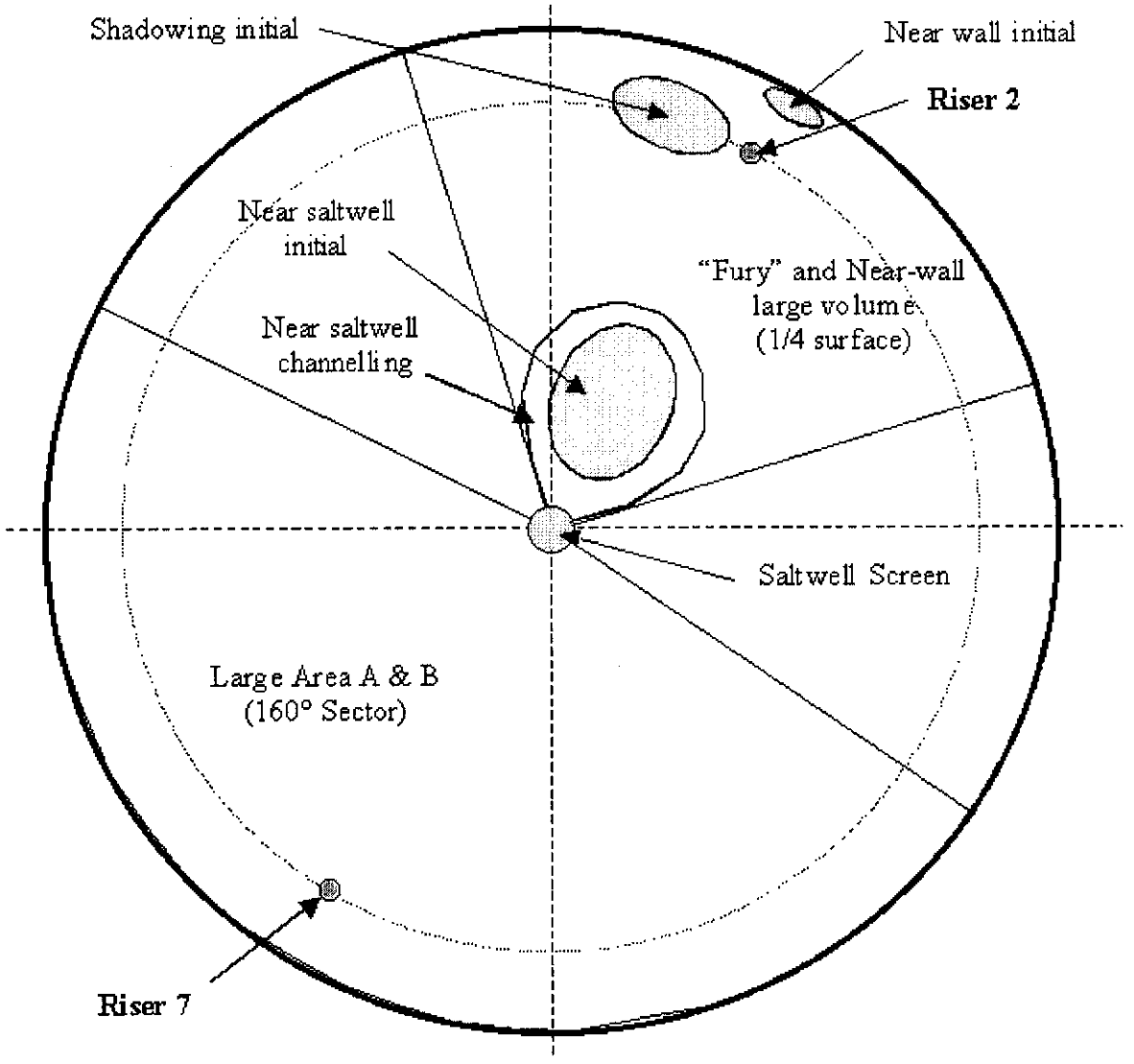
A CHG Process Memo from Interim Stabilization Engineering and applicable field conditions will define the actual test schedule. The areas of saltcake dissolved in each test are not expected to overlap. A shallow pool may appear to form in the depression under the spray. If the pool begins to fill the hole, the spray should be paused before it overflows.

If it appears that the volume of water given in Table 4-2 is dissolving a much greater or much smaller volume of waste than anticipated, the water volumes and schedule for the remaining tests must be re-evaluated. If the schedule is revised, the large area test should be given priority because it represents a full-scale retrieval operation more closely.

In the shadowing test, the spray is aimed directly at the adjacent thermocouple tree in Riser 1. It is designed specifically to assess whether the "shadow" behind a piece of hardware that blocks part of the spray pattern will leave an unacceptable amount of waste undissolved. Accordingly, water pooling in the dissolving depression under the spray pattern should be minimized to avoid dissolving the expected "ridge" behind the thermocouple tree.

A TMS scan will be obtained after the initial tests are completed. Comparison with the baseline TMS map will provide an accurate measure of the net volume of waste dissolved in each location and how far outside the immediate spray pattern the effects of water addition extend. Neutron/gamma logs will be run on approximately their normal weekly schedule.

Figure 4-2. Areas of Waste Expected to be Dissolved



4.2.2.2. Large Volume Tests in Riser 2

The large volume tests will investigate some specific issues to provide knowledge that will be useful in planning retrieval operations. Water additions will be limited so that the volume of brine produced per day does not exceed that which can be removed by the saltwell pump.

The first large volume test will apply a large volume of water (~2 kgal) in the near-saltwell pattern to address how likely channeling will occur and what its consequences might be. Channeling is perceived as an undesirable short-circuit of water through channels or ditches eroded or dissolved into the waste by excess water runoff. The spray is expected to influence an area about twice that of the actual near-saltwell spray pattern.

To observe channel development, the spray will be periodically shut off and any fog will be allowed to clear permitting a visual observation of the waste surface with the video camera. It is likely that water addition will have to be very intermittent in this test to control the liquid level in the saltwell screen. However, because the test is intended to create channels, the water spray should not be shut down for water pooling or overflow of the initial depression under the near-saltwell pattern. If channeling is observed that reduces the specific gravity in the saltwell screen below 1.3 or appears to be creating excessively deep trenches in the waste, the test will be terminated before the specified water volume is used. A grab sample is to be pulled as soon as practicable after water addition is complete.

The second test will apply a large volume of water (~8 kgal) in the near-wall pattern. Water is expected to migrate laterally through the unsaturated waste over the heavier brine at the interstitial liquid level. This should dissolve saltcake from the interstitial liquid level upwards causing the surface to slump over a large area estimated to be up to one-fourth of the surface area.

A shallow, widening liquid pool is expected to develop around the near-wall spray pattern, and some initial overflow of the original depression left from the initial tests can be allowed. It may be possible to observe a shallow pool of liquid accumulate in the depressions left from the shadowing test and initial near-saltwell test. Because the large volume near-wall test is expected to affect the waste over a large area, there will be a one-day waiting period prior to the Fury™ test to allow brine to drain and residual waste settling to occur.

The third large volume test will utilize the Fury™ 400 tank washer. The Fury™ tank washer has a relatively forceful spray that has the potential to erode the waste and may even be able to penetrate the interstitial liquid level a short distance. Therefore, it may be able to dissolve saltcake effectively even if it is liquid-saturated or channeling has occurred. The Fury™ test is conducted following prior large-volume water additions specifically to investigate this capability. Although the Fury™ has essentially a circular spray pattern, the proximity of Riser 2 to the tank wall means that more water will be deposited near the wall. The estimated area that will be exposed to water from the Fury™ is a quadrant centered at Riser 2, the same as in the near-wall large volume test.

Water addition will be paused as necessary to prevent filling the saltwell screen and to drain any widening pools of liquid that occur. If the specific gravity in the saltwell screen falls below 1.3 or liquid runoff appears to be creating deep channels or other adverse geometry in the waste surface, the test will be terminated before the specified water volume is used.

A grab sample will be taken from the saltwell screen immediately after the Fury™ test with the jet pump shut down to allow the saltwell to fill. If available, a TMS scan will be obtained following a three-day waiting period with the jet pump operating to allow for brine drainage and equilibration. The TMS will then be moved to Riser 7 and a baseline TMS scan taken for the large area tests to follow. Neutron/gamma logs will be run on approximately their normal weekly schedule, and additionally as necessary to support the proof-of-concept operations.

4.2.2.3. Large Area Test in Riser 7

The large-area test using the Nelson™ impact sprinkler is possibly the most important because it will add water at a rate and over an area that might be used in a full-scale retrieval operation. It is placed last in the schedule to allow time for the maximum amount of interstitial liquid draining and to create the maximum depth of unsaturated saltcake to dissolve. The large-area spray pattern covers approximately 40 percent of the waste surface. However, more of the water will be added near the tank wall and the excess is expected to flow azimuthally so that a sector spanning roughly 160 degrees will dissolve. The actual water volumes will be re-evaluated prior to the test based on the results of the preceding operations.

About half the total volume of water will be added in each of two stages in order that a TMS scan, neutron and gamma logs, and grab samples can be taken midway through the test and at the end. As before, water addition will be paused as necessary to prevent filling the saltwell screen and to drain any widening pools of liquid that occur. If the specific gravity in the saltwell screen consistently falls below 1.3 or liquid runoff appears to be creating deep channels or other adverse geometry in the waste surface, the test may be terminated before the specified water volume is used.

Grab samples will be obtained from the saltwell screen immediately after each stage of the large area test. The jet pump will be shut down and the saltwell screen allowed to fill prior to each sample. TMS scans will be taken after a three-day wait with the jet pump operating to allow time for the brine to drain. Neutron/gamma logs will be run on approximately their normal weekly schedule and additionally as necessary to support the proof-of-concept operations.

4.2.3 Shut Down of Proof-of-Concept Operations

After the last large-area test is complete and the final sampling event is performed, completion of the operations will be documented in a Process Memo from CHG Interim Stabilization Engineering. At that time, the disposition of the water addition equipment, cameras and TMS will be made. Saltwell pumping will continue without further constraint on liquid level in the saltwell screen until the tank is interim stabilized.

Weekly neutron logs, headspace hydrogen concentrations, waste level trends, and waste temperature histories, as well as the saltwell pumping data, will continue to be recorded. Comparing these data to the pumping behavior of other tanks will help assess whether water addition had any effect on the waste below the interstitial liquid level.

4.3 PROCESS SAMPLING REQUIREMENTS AND SCHEDULE

The waste surface level, waste temperatures, and headspace hydrogen concentration are currently monitored continuously and recorded in the TMACS system. Saltwell pumping data are also recorded continuously during the interim stabilization campaign. Discrete sampling events will also be performed at various times during the process to determine the progress of saltcake dissolution and to evaluate its effectiveness as a potential retrieval method. These include TMS scans to periodically map the waste surface, grab samples to measure the density and chemical composition of the liquid in the saltwell screen, and taking neutron and gamma logs in the LOW to determine how the distribution of water concentration changes. The schedule and specific requirements for each are described below.

4.3.1 Topographical Mapping

The TMS will be installed in the same riser as the active water addition system and TMS scans will be performed in both Risers 2 and 7. It should be mounted to minimize the waste surface area that is shadowed by the water addition system and by suspended hardware in adjacent risers. An additional requirement in Riser 2 is that the TMS be able to see at least a part of the area behind the thermocouple tree in Riser 1 to measure the effects of shadowing of the water spray. These requirements suggest that the TMS be mounted in the riser adapter assembly with an unobstructed view towards the center of the tank. In Riser 7 the TMS should also be installed on the inside (i.e., toward the tank center) of the sprinkler mast to minimize the shadowed area.

The schedule for TMS mapping is listed in Table 4-2. Baseline topographic maps are required in both Risers 2 and 7 because the TMS covers less than half of the waste surface from one location. After the baseline, topographic maps will be obtained from Riser 2 after the initial test series and after the large volume tests. A one-day wait is required after the latter. After the baseline, two topographic maps will be made in Riser 7, one midway and one after the end of the large area test. A three-day wait is required before the final map. Additional scans may be performed as opportunities arise (e.g., periods during which no water is applied because of pump failure or shutdown). In all cases, saltwell pumping is expected to continue during the waiting period and during the scans.

The volume difference between each pair of sequential maps will be computed to determine the amount of waste dissolved. The volume of specific features (e.g., mounds, ridges, channels, etc.) may also be calculated as appropriate. Use of the TMS as an LDMM tool is discussed in Section 5.0.

4.3.2 Grab Samples in the Saltwell Screen

Five grab sample events are scheduled for the project. These are reflected in Table 4-2. As soon as practicable after water addition ceases, one sample will be obtained from the top and a second sample from the bottom of the liquid column in the saltwell screen. The saltwell screen will be allowed to fill prior to grab sampling. The waiting periods prescribed for TMS scans do not apply to grab samples. The analyses will be performed on the samples to meet the requirements described in the Data Quality Objectives (CHG 2001e). Specific instructions regarding quality control, quality assurance, and reporting requirements to satisfy the Data Quality Objectives is provided by the Grab Sampling and Analysis Plan (CHG 2001f).

4.3.3 Neutron and Gamma Logs

Neutron logs in the LOW will be performed approximately weekly during saltwell pumping including periods of water addition and additionally as necessary to support the proof-of-concept operations. Gamma logs in the LOW will also be obtained at least once prior to surface water addition and at least twice after significant water additions. Gamma logs will be continued if they provide useful data on water migration. Spectral gamma scans from external tank drywells will be available both prior to and subsequent to the performance of the saltcake dissolution proof-of-concept operations. These spectral gamma scans provide a LDMM baseline for leak-detection questions.

5.0 LEAK DETECTION, MONITORING, AND MITIGATION (LDMM) STRATEGY AND APPROACH

The LDMM methodology of the tank U-107 saltcake dissolution demonstration consists of a baseline component and a technology development component. The baseline component consists of those elements that will be conducted to comply with the Interim Stabilization Program's leak detection requirements and the monitoring of existing drywells in the vicinity of tank U-107. The technology development component will be an appraisal of in-tank leak detection based on a total system mass balance. Process flow rates, liquid levels, and surface topography measurements (and their uncertainties) will be analyzed to determine the viability of this in-tank method of leak detection. If the new technology proves effective, it can be utilized in conjunction with the baseline methods or to enhance confidence in the final results.

Three baseline methods will be applied: a material balance between the saltwell pump totalizers and the volume increase in the receiver tank; continuous monitoring of transfer line and transfer pit leak detectors; and spectral gamma scans in the drywells surrounding tank U-107. Note that no in-tank volumetric measurements are part of the baseline monitoring program. The reasons for this will be discussed later in this section.

5.1 BASELINE LEAK DETECTION, MONITORING, AND MITIGATION STRATEGY AND APPROACH

The currently prescribed LDMM approach requires volumetric measurements to be performed in accordance with the Authorization Basis requirements on misrouting inspection during waste transfers (a part of normal saltwell pumping activities). These volumetric measurements will be coordinated with the periodic saltwell screen weight factor measurements, allowing an estimation of mass transfer out of the saltwell pumping equipment. This will allow the determination of a running mass balance on the tank that will be useful for process control purposes. This transfer balance calculation may be enhanced later, depending upon additional input provided by the TMS, estimates of remaining in-tank volume, analysis of saltwell grab samples, or a variety of other potential information.

5.1.1 Existing Saltwell Pumping Leak Detection, Monitoring, and Mitigation (LDMM) Techniques

The currently established protocol for tank U-107 saltwell pumping and concurrent proof-of-concept operations is shown in Table 5-1:

Table 5-1. Selected Requirements and Guidance for Tank 241-U-107 Leak Detection

Document	Title	Section(s)
HNF-SD-WM-SAR-067 (1)	*Tank Farms Final Safety Analysis Report*	4.4.7 Safety Function(s)
HNF-SD-WM-TSR-006 (2)	*Tank Farms Technical Safety Requirements*	TSR-AC 5.12 Transfer Controls LCO 3.1.3 - Transfer Leak Detection Systems
HNF-IP-1266 (3)	*Tank Farm Operations Administrative Controls*	5.12 Transfer Controls
TO-020-210	*Respond to West Area Leak Detection Alarms*	Various
TO-430-102	*241-SY-102 Material Balance*	Various
TO-505-107 (Draft)	*Perform 241-U-107 Saltwell Pumping*	Various
ARP-T-501-001	*Respond to Alarms at 241-U Farm*	Various
TF-ERP-005	*Emergency Response Procedure 005 Radiological Release*	Various

Notes:

(1) CHG (2001c)
(2) CHG (2001b)
(3) CHG (2001d)

The additional instrumentation and sample analysis activities specified for the proof-of-concept operations provide further information by which to refine mass balances and applicable sensitivity. Such information may allow a more accurate determination of such quantities as saltcake porosity, pumpable liquid, drainable liquid, retained gas volume, and released gas volume, all of which are parameters that complicate the issue of SST leak detection.

Procedural guidance in accordance with the Table 5-1 directives provides the performance criteria required of 200 West Area saltwell pumping activities.

5.1.1.1. Material Balance Techniques

- Data recording and manipulation requirements are specified in TO-430-102: Performed via data sheets; procedure has provisions to allow transfers into tank SY-102 while this tank is performing a cross-site transfer to AP-Farm. It also accounts for miscellaneous additions into or transfers from tank SY-102.

- Material balance reset requirements: Material balance discrepancy exceeds threshold criteria; tank SY-102 level ≥ 393 inches.
- Material balance shutdown requirements: The material balance discrepancy is monitored at 30-minutes and 1-hr after the start of a transfer. Thereafter it is monitored every 2-hrs during the transfer and a final calculation within 2-hrs of transfer termination. Whenever material balance discrepancy (MBD) exceeds threshold criteria, all transfers are terminated while the Shift Manager and the Interim Stabilization Operations Engineer (ISOE) are notified.

Table 5-2 reproduces the 241-SY-102 Received Data Sheet; Table 5-3 reproduces the Material Balance Discrepancy Data Sheet; Table 5-4 reproduces the Surveillance Frequency Data Sheet.

Table 5-2. Tank 241-SY-102 Received Data Sheet

241-SY-102 RECEIVED DATA SHEET						
Date: Time:						
Current SY-102 Level* (<393 inches OR limit) C_{SY-102}						
SY-102 Initial Level (inches) A_{SY-102}						
SY-102 Level Change (C_{SY-102} - A_{SY-102}) D_{SY-102}						
Current AP-____ Level** (inches) C_{241-AP}						
AP-____107 Initial Level** (inches) A_{241-AP}						
241-AP Level Change** (C_{241-AP} - A_{241-AP}) D_{241-AP}						
SY-102 Received (D_{SY-102} + D_{241-AP}) W_{SY-102}						
241-AP Shutdown Level*** (inches) B_{241-AP}						
241-AP Drained (<2.8)**** (C_{241-AP} - B_{241-AP}) X_{241-AP}						
Operator Initials						
ISOE End of Shift Review Initials:						
ISOE Review Signature:				Date		

* ENRAF accuracy is 0.25 inch (688 gal.) per TO-400-200.
IF the current SY-102 LEVEL (C_{SY-102}) is > 393 inches OR limit per Process Memo, NOTIFY the Shift Manager/ISOE AND ENSURE the active transfers are shut down with the referenced procedures.
** Only used when a cross-site transfer is in progress, otherwise "NA."
FIC accuracy is 0.25 inch (688 gallons) per Internal Memo 7C242-92027, Rev. A.
*** Only used during cross-site transfer temporary shut downs, otherwise "NA."
**** Only used during cross-site transfer temporary shut downs and for 2 hours following a cross-site transfer restart, otherwise "NA."

Table 5-3. Material Balance Discrepancy Data Sheet

MATERIAL BALANCE DISCREPANCY DATA SHEET						
Date: Time:						
241-S Allowable MBD (0.15* or NA) $Z_{241\text{-}S}$						
241-SX Allowable MBD (0.20* or NA) $Z_{241\text{-}SX}$						
241-U Allowable MBD (0.50* or NA) $Z_{241\text{-}U}$						
244-TX Allowable MBD (1.69 during Pump/Flush, 0.05 Agitate/Final, or NA) $Z_{244\text{-}TX}$						
244-S Allowable MBD (0.27 during Pump/Flush, 0.17 Final, or NA) $Z_{244\text{-}S}$						
SY-102 Allowable MBD $Z_{SY\text{-}102}$	0.25	0.25	0.25	0.25	0.25	0.25
241-AP Allowable MBD*** (0.25 + X $_{241\text{-}AP}$ or NA) $Z_{241\text{-}AP}$						
Total Allowable MBD**** ($Z_{241\text{-}S} + Z_{241\text{-}SX} + Z_{241\text{-}U} + Z_{244\text{-}TX} + Z_{244\text{-}S} + Z_{SY\text{-}102} + Z_{241\text{-}AP}$)						
MBD**** ($W_{SY\text{-}102}$ - Y)						
Operator Initials						
Interim Stabilization Operations Engineer (ISOE) End of Shift Review Initials:						
ISOE Review Signature:				Date		

* *Only used when waste TRANSFERRED (W) from at least one U, S, or SX Farm tank, otherwise "NA."*
*** Only used during cross-site transfers, otherwise "NA."
**** IF the MBD (+ or -) exceeds the TOTAL ALLOWABLE MBD, NOTIFY the Shift Manager/ISOE AND ENSURE the active transfers are shut down with the referenced procedures.

Table 5-4. Material Balance Discrepancy Data Sheet

MATERIAL BALANCE DISCREPANCY DATA SHEET						
Date: Time:						
S Complex Total Transferred ($W_{S\text{-}102} + W_{S\text{-}109} + W_{SX\text{-}101} + W_{SX\text{-}103} + W_{SX\text{-}105}$) = Y_S						
U Complex Total Transferred ($W_{U\text{-}102} + W_{U\text{-}105} + W_{U\text{-}106} + W_{U\text{-}109}$) = Y_U						
Operator Initials						
ISOE End of Shift Review Initials:						
ISOE Review Signature:				Date		

* Only used when waste TRANSFERRED (W) from at least one U, S, or SX Farm tank, otherwise "NA."
*** Only used during cross-site transfers, otherwise "NA."
**** IF the MBD (+ or -) exceeds the TOTAL ALLOWABLE MBD, NOTIFY the Shift Manager/ISOE AND ENSURE the active transfers are shut down with the referenced procedures.

5.1.1.2. Leak Detection Techniques

A leak detection system has been installed in all pump pits and valve pits in the West Area Tank Farms associated with U-Farm saltwell transfers.

Waste leaks that occur in the primary pipes of encased transfer lines will be directed through the encasement to waste transfer-associated structures. Waste may also leak directly into a waste transfer-associated structure through piping, valves, pumps, or jumpers. These waste leaks may produce significant onsite consequences with gamma shine being the dominant contributor to dose and the mechanisms of spray, splash/splatter, and wet entrainment being lesser contributors. The primary means for mitigating the onsite consequences from such waste leaks is to detect the leak, shut down the transfer pump, and take response actions to limit exposure to onsite and facility workers. There are two strategies for responding to leaks that are detected by the transfer system leak detectors. One strategy involves relying on operator action to shut down the waste transfer pump, and the other strategy involves relying on the saltwell leak detector interlock to automatically shut down the pump. The safety function of the transfer leak detection systems is to detect waste transfer system leaks in waste transfer-associated structures and to provide an alarm to alert operators to take mitigative action to shut down the transfer pump (or other motive force) and to take response actions to limit exposure to onsite and facility workers, therefore, limiting the volume of waste leaked and the time that workers are exposed to the leaked waste, thereby decreasing the consequences of the Waste Transfer Leak accident. The transfer leak detection systems may also be connected to the saltwell leak detector system, which will automatically shut down the transfer pump.

Transfer-associated structures, which include process and valve pits, diversion boxes, and cleanout boxes, are provided with leak detectors located in the structure. The leak detectors have electrodes that can be short-circuited by a conductive medium (e.g., liquid waste) and cause a change in state of the monitoring circuitry. When liquid waste short-circuits the leak detector electrodes, an alarm is generated. Leak detectors may be connected to the saltwell leak detector system, which will automatically shut down the transfer pump upon receipt of an alarm signal. The control and alarm functions associated with the leak detector are testable.

Leak detectors are located inside waste transfer-associated structures and are sometimes located in a sump in the pit. In the event of a leak, the smaller floor area of a sump causes a faster level increase for the same volume of leaked waste and thereby provides an earlier alarm signal. The leak detector creates an audible and visual panel alarm and activates the interlock for transfer pump shutdown; if no interlock is installed, the panel alarm prompts operator action to terminate transfer pump operation.

The existing transfer leak detection systems are adequate for the required safety functions. Conductivity probes have performed reliably as waste transfer-associated structure leak detectors for many years, with a mean time between failures approaching one year. The operability of each process pit, diversion box, valve pit, and cleanout box leak detector (and its associated alarm and control circuitry) that is physically connected to a waste transfer pump not under an administrative lock shall be verified quarterly by a functional test.

The assumption for the baseline leak detection techniques is that the leak detector systems are operable and operating. The operability assumptions include the following provisions.

- During a liquid waste transfer, all of the leak detectors associated with lines physically connected (as defined in Section 1.1 of HNF-SD-WM-TSR-006 [CHG 2001b]) to the waste transfer pump being actuated must be operable.

- To ensure that the pit leak detection system is operable, the alarm and control functions activated by the leak detector are functionally tested quarterly.

An operable transfer leak detection system consists of at least one leak detection system installed near the structure's floor in a manner that will enable it to detect a leak such that waste is prevented from escaping to the surrounding environment. The operability requirement includes either failsafe alarm functions or interlocks associated with the leak detection system.

A leak detection system in an activated alarm state is incapable of providing indication of leakage during future transfers through its associated structure. If an alarm occurs, operator actions are taken in accordance with alarm response procedures.

Therefore, the general procedure for leak-detector alarm response provides for:

- Upon receipt of a leak-detection alarm, verify cause of the alarm.
- If a leak is verified as the cause of the alarm:
  - Inform the Shift Manager,
  - Perform additional corrective and recovery actions as directed by the Shift Manager, and
  - Perform radiation surveys.

Typical corrective / recovery actions for verified leak detections at U-Farm include:

- Ensure saltwell pump and all common header pumps are shut down.
- Ensure Administrative Lock Condition is established on the transfer pump(s) per HNF-IP-1266, Chapter 5.20, "Administrative Lock Program" (CHG 2001d).
- Ensure Shift Manager/Interim Stabilization Operations Engineer (ISOE) is notified of alarm(s) and contact Environmental Operations Compliance Services per Environmental On-Call List.
- Investigate possible causes/effects and notify Shift Manager/ISOE of finding(s).
- Obtain appropriate pumping procedure and perform steps as directed by Shift Manager/ISOE.

5.1.2 External Tank Leak Detection

The existing ex-tank drywell system will continue to be employed as secondary leak detection for the tank U-107 demonstration project. Typically, identifying the source of a leak based on changes in an external drywell can be problematic and uncertain. If changes are identified in a drywell adjacent to a particular tank, there can be a variety of possible causes, such as migration of an existing nearby contamination plume, mobilization of old transfer line leakage due to rainwater or flooding, surface contamination flowing down the sides of a tank, or a variety of alternate explanations. In the end, the true source of the contamination is often hard to determine with any degree of confidence. In the case of tank U-107, the spectral drywell analysis should be much more definitive than normal.

Tank 241-U-110 (to the immediate west of tank U-107) and tank 241-U-104 (to the immediate east) are both declared leakers, and the drywells surrounding tank U-107 to the north, east, and west are already contaminated from these pre-identified leaks. Spectral gamma characterization logs run in 1995 and 1999 have already established that the uranium from these leaks is migrating through the soil, rather than remaining stationary. This would make identifying a new leak from tank U-107 extremely difficult.

The tank chemistry is significantly different between tank U-107 and the adjacent leakers. Both tanks 241-U-104 (U-104) and 241-U-110 (U-110) are primarily sludge tanks, containing a very high uranium content in the 6000 to 15000 microcurie per gram range, (based on limited core samples). They also contain very little cesium-137, when compared to the typical Hanford Site tank. In fact, the contaminated drywells surrounding tank U-107 indicate only uranium and the occasional background-level trace of cesium. Tank U-107 contains mostly evaporated product from the S Evaporator. This waste is primarily saltcake with a very high cesium-137 content and almost no uranium. Based on laboratory values, the cesium content in tank U-107 is approximately 40 to 50 times higher than that in tanks U-104 or U-110. If the cesium-rich liquids from tank U-107 were to leak into the soil during the project, the surrounding drywells would most likely indicate significant cesium increases. If the only drywell change noted is a continuing movement of uranium with no new cesium peaks, a sound tank can be strongly implied for tank U-107.

Another factor that makes this technique much more applicable than usual is that the drywell coverage is very good around the perimeter of tank U-107. There are three wells to the east, one to the north, two to the west, and one to the south, providing a total of seven that are fairly equally spaced. When compared to the typical Hanford Site SST, this coverage is far better than normal.

MACTEC ERS has been contracted to perform baseline spectral gamma scans in all seven surrounding drywells. These will be logged prior to the start of saltwell pumping operations with the Spectral Gamma Logging System to document any continuing isotope movement, (the same high-resolution system that was used in 1995 and 1999). The newly developed radionuclide assay system (RAS), based on the faster repeat scan capability of a sodium iodide (NaI) crystal detector, will also be run in order that it can be calibrated against the Spectral Gamma Logging System under near-identical conditions. At least one set of RAS scans will be taken during the

dissolution process and another set at the conclusion of the project. Any isotope movement or changes in drywell activity during the demonstration project will be documented and reported, with a particular emphasis on increases in cesium-137 concentration. If any abnormal changes are identified, a full leak investigation will be immediately initiated per procedure (CHG 2000c).

5.2 DEVELOPMENT OF A TOTAL MASS BALANCE APPROACH UTILIZING THE TOPOGRAPHICAL MAPPING SYSTEM

In addition to measuring the total volumes of liquid transferred and in-line dilution water added, the proof-of-concept operation requires measurement of the total volume of water sprayed on the waste surface. This should provide a comparison of total liquid in versus total liquid out. It should be noted that dissolution would significantly complicate any total system mass balance computation, because soluble solids dissolution can significantly change liquid densities. Current LDMM techniques are incapable of accurately discerning changes in waste volumes within a SST for reasons to be discussed later in this section. The waste surface maps produced by the TMS may assist in determining the total volume of waste dissolved, which can be used to refine a mass balance computation. To apply the TMS data and perform a true system mass balance calculation, an accurate interstitial liquid level measurement, a good estimate of released gas volume, and a porosity determination would also be required. Grab sampling may also provide useful information for a mass balance.

A total system mass balance calculation will not be performed as part of the baseline LDMM strategy for tank U-107. New technologies will be tested, including the TMS, in an effort to advance the technique to the point where it may become usable for future projects.

The TMS has good potential to improve future LDMM performance, because the TMS offers improved sensitivity, accuracy, and 3-dimensional mapping capability, while offering new opportunities for data reduction and analysis. These features constitute added LDMM benefit provided by the tank U-107 proof-of-concept.

The Total System Mass Balance approach is based on the total volume change in the receiver vessel being equal to the input liquid volume corrected for any overall changes in the piping system volume and the overall tank volume. The volume of dissolution water into the tank can be metered and normally consists of raw water at a specific gravity of 1.0 with no solids. The volume in the receiving vessel (tank SY-102) can be measured by a level gauge on a flat liquid surface; therefore, the change in volume can be known with reasonable accuracy. The holdup volume of the piping system should not change and is easily calculated. This is the normal saltwell material balance approach. To perform a total system mass balance, one must also accurately calculate the remaining solid and liquid volumes in the tank, which is not currently attempted in the conventional saltwell material balance process.

If the waste has a liquid surface, the total tank volume can be determined with good accuracy, although the percentage breakdown of solids, liquids, and gasses may not be well known. If a liquid surface were maintained throughout the retrieval, the total system mass balance would be

greatly simplified. Once the liquid level drops below the solid surface, the process becomes much more complicated.

Given an ideal situation, the integrated average surface level could be determined by the TMS with minimal error due to the surface irregularities. The liquid interface (now below the solid surface) would be defined by the neutron probe in the LOW and by the dip tubes in the saltwell screen. If the waste has very good porosity and permeability, this interstitial liquid level would respond to changes and stabilize quickly to a planar interface, with the neutron interstitial liquid level and dip tubes providing very similar values. If the porosity were well known, it could be subtracted from the solid waste above the interstitial liquid level to provide a value for total drained solids. Likewise, if the porosity below the interstitial liquid level was well known, the remaining drainable interstitial liquid could be accurately estimated. If the volume of released gas was also metered during the process, the sum of all these components would equal the total mass in the tank, leading to a system-wide mass balance.

Tank U-107 is not an ideal case, and the problem is much more complex than the simplified situation outlined above. Every measurement has an error associated with it, and some can be very large or are unknown at this time. Part of the new technology development will be to quantify the error for each measurement and propose methods of reducing those errors. Normal metering errors can usually be quantified fairly easily and can often be corrected by employing newer technology. Four error sources that are more difficult to quantify are discussed below:

1. The accuracy of determining irregular, dry surface levels is not known. The TMS system has been designed to map the topography of the waste surface, but as the project continues, the caverns, pockets, depressions, and mounds are expected to increase, making the integration of "average" surface level potentially more difficult. The absolute error expected is not known at this time.

2. Once a liquid waste surface is lost due to pumping, determining the interstitial liquid level may be difficult. In wastes exhibiting poor porosity and permeability, the "bound" liquid component that remains above the interstitial liquid level after draining can be very high and not clearly discernable from the "free" or "drainable" portion. This is common in sludges and evaporator products with a high specific gravity. The native waste (prior to exposure to fresh water) may drain very slowly, and even if the interstitial liquid level is clearly discernable, it may not substantially change even over long periods of stabilization activities. The dip tube readings may not be stable enough to use with confidence without excessive stabilization time. This can make the estimation of remaining drainable interstitial liquid very difficult.

3. The volume of solids dissolved at any given time is determined from the changes in specific gravity in the pumped liquids. Small errors in the specific gravity can translate to large dissolved volume errors. Dip tube measurements are not particularly accurate and have a history of erratic specific gravity measurements. One of the objectives in this project will be to quantify those errors. If the errors appear excessive, improved instrumentation may be suggested for future projects.

4. The initial porosity of the waste is not known and is expected to change significantly during the operation. As waste solids are dissolved by the introduction of fresh water, the bound water around those solids and any high-viscosity liquid gels will be mobilized and pumped away as free liquid. Wherever fresh water percolates, void spaces and channels will be created through the waste solids. The dissolution process itself will create porosity in the waste that did not exist in its native state. The overall waste porosity will increase as the dissolution process continues, up to 100 percent if all solid material is ultimately removed. Estimating the effective average system porosity at any moment in time will be very difficult.

The project will attempt to quantify and reduce these errors wherever possible. If the total system mass balance approach yields promising results, it will be used to support and confirm other leak detection techniques in the Baseline Strategy. Until the systematic errors are better understood and quantified, a total system mass balance will not be used for real-time process control.

6.0 RESPONSE TO OFF-NORMAL CONDITIONS

6.1 HIGH TANK HEADSPACE FLAMMABLE GAS CONCENTRATIONS

A safety control imposed upon the saltwell pumping operation is the flammable gas concentration control limit of 6,250 ppm of hydrogen in the headspace. This limit conservatively approximates 25 percent of the lower flammability limit (LFL) with a mixture of hydrogen, ammonia, methane, and other flammable gases in air. Typically, a passively ventilated SST will possess a headspace flammable gas concentration of at most a few percent of the LFL. In tank U-107, a Meggitt Safety Systems™ Hydrogen Cell measures the flammable gas concentration.

Tank U-107 contains 6,400 ± 2,000 standard cubic feet of retained gas (PNNL 2001b), a portion of which will be released during the dissolution process. Dissolution is expected to release this gas in proportion to the fraction of the waste in which the soluble solids are dissolved. This process is self-limiting and controllable. Water or dilute brine capable of dissolving solids is less dense than the saturated interstitial liquid in equilibrium with the solids. Therefore, solvent cannot penetrate below the pre-existing interstitial liquid in the waste and dissolution can only occur in waste that is not saturated with liquid. Once the solvent has become saturated, it is no longer capable of further dissolution and forms a barrier to the less-dense liquid from above.

This means that dissolution, and the associated gas release, can proceed no faster than the interstitial liquid can drain away. This is the primary mechanism that limits dissolution-induced gas releases. This self-limiting behavior makes gas release by dissolution controllable. The dissolution rate can be reduced relatively quickly by terminating pumping (accumulating brine forms a barrier to fresh solvent) and by shutting off the water spray (terminating the supply of fresh solvent).

Based on the fact that dissolution, and, therefore, gas release during dissolution, is limited by the rate at which brine drains from the waste, a bounding gas release can be computed given the saltwell pumping rate. Water is assumed to be added at a rate, Q_{WIN}, such that the resulting brine production rate is equal to the brine capacity of the saltwell pump, Q_{BOUT}. Based on the waste composition, the added water dissolves the original waste at a rate, Q_{DSLN}, which can be expressed as

$$Q_{DSLN} = [F_{DSLN}/F_{BRINE}]Q_{BOUT} \tag{6-1}$$

where F_{DSLN} is the volume of original waste in which soluble solids are dissolved per unit volume of water added and
F_{BRINE} is the volume of total brine produced (water added plus dissolved solids plus interstitial liquid liberated) per unit volume of water added.

In-line dilution is conservatively ignored in this calculation. Assuming that dissolution immediately releases all the gas stored in the waste being dissolved, the gas release rate, Q_{GAS}, is the product of the gas volume fraction, α, and the dissolution rate as follows,

$$Q_{GAS} = \alpha\, Q_{DSLN} = \alpha\, [F_{DSLN}/F_{BRINE}]Q_{BOUT} \qquad (6\text{-}2)$$

The solubility of tank U-107 waste is such that $F_{DSLN} = 1.83$ and $F_{BRINE} = 2.15$ (See Table C-3) and the gas volume fraction averages 0.17 (Table C-1). If a maximum of 2,400 gallons of water per day is applied and all of this water dissolves waste, the dissolution rate is 4,392 gal-waste/day. This is equivalent to an average saltwell pumping rate of 5,160 gal-brine/day or 3.58 gpm. Equation 6-2 indicates a corresponding gas release of 117 standard cubic feet per day. If the released gas is 50 percent hydrogen, as may be expected for saltcake waste, the release rate would be 59 ft^3 of hydrogen per day.

The effect of this gas release rate is dependent on the tank headspace and ventilation rate. A simple model has also been developed to include the increasing headspace due to dissolution (PNNL 2001a). Tank U-107 has a headspace of 59,000 ft^3 and is estimated to have a ventilation rate of 2.5 standard cubic feet per minute. Assuming that the 2,400-gallons per day water addition is continuous and using baseline hydrogen concentration of 500 ppm, the model predicts that the headspace hydrogen concentration would reach the action level of 6,250 ppm in 8 days, or 6 days with only barometric breathing (WHC 1993). The hydrogen concentration would eventually reach a maximum of 1.4 vol% (14,000 ppm), or roughly 35 percent of the LFL if water addition were continued until all the waste were removed. This would theoretically occur in 119 days. With only barometric breathing, the concentration would reach the LFL in 78 days of continuous water addition at 2,400 gallons per day. These calculations indicate that it will be very unlikely for the headspace hydrogen concentration to reach the action level during the planned tests.

The safety action is to initiate immediate shut down of operations. However, good operating practice will dictate that control action be taken before this concentration is achieved, if the flammable condition is the result of a controlled release. Any process change that will result in a headspace flammable gas concentration increase or rate of concentration increase that will exceed 6,250 ppm of hydrogen in the headspace should warrant appropriate operator response to place the saltwell pumping system in a safe configuration. Depending on which tank is experiencing the change, the corrective action should be to either reduce the rate of solvent water addition, reduce the rate of saltwell pumping, or both. If flammable gas concentrations do not respond to input corrective actions, operations must be terminated at 6,250 ppm of hydrogen. Both water addition and saltwell pumping will be shut down if the headspace hydrogen concentration exceeds the limiting value.

6.2 HIGH AMMONIA OR VOLATILE ORGANIC COMPOUND CONCENTRATION IN 241-U FARM

The water dilution of caustic ammonia-water solutions decreases the solution pH, tending to drive dissolved gaseous ammonia into solution as ammonium hydroxide. Therefore, the addition of water to the Hanford Site tank wastes is not expected to increase ammonia emissions. Also, a water spray is a very effective ammonia scrubber as was shown during dilution of tank SY-101 (PNNL 2000). Precautions for volatile gases in the tank farms are taken.

Environmental, Safety, Health, and Quality Assurance Ammonia and Volatile Organic Compound (VOC) monitoring in the SST Farms states that:

- Detection of 25 ppm ammonia or 2 ppm VOC at ground level requires mask use in-farm, and
- Detection of 250 ppm ammonia or 25 ppm VOC at ground level requires immediate transfer system shutdown and tank farm evacuation.

Ammonia and VOC are monitored via periodic surveys by Industrial Hygiene personnel using portable air monitors.

6.3 LOSS OF ELECTRIC POWER

In the event of a loss of electric power, solvent water addition for the saltcake dissolution proof-of-concept operations shall be manually secured, as the solenoid valve on the pump, instrumentation, and control (PIC) skid will de-energize shut upon loss of power.

6.4 SALTWELL JET PUMP FAILURE OR DEGRADATION

Solvent water addition for the saltcake dissolution proof-of-concept operations shall be manually terminated if there is a failure of the saltwell pump. An automatic interlock between the saltwell pump and water supply solenoid valve terminates the dissolution spray water flow. The dissolution tests shall proceed when the jet pump is repaired or replaced if the problem is determined not to have resulted from surface water addition and if the schedule permits.

6.5 TRANSFER LINE PLUG

Solvent water addition for the saltcake dissolution proof-of-concept operations shall be terminated if the transfer line is determined to be plugged. The dissolution tests shall proceed when the transfer line plug is cleared, if plugging is determined not to have resulted from surface water addition during the proof-of-concept activities. The dissolution operations shall proceed when the transfer line leak is repaired if the schedule permits.

6.6 UNCONTROLLED WATER FLOW THROUGH TEST NOZZLES

Solvent water addition for the saltcake dissolution proof-of-concept operations shall be terminated if the dissolution water system is determined to be leaking. Tests may proceed if the water addition system is repaired.

6.7 DISSOLUTION WATER SYSTEM LEAK, IN-TANK OR EX-TANK

Solvent water addition for the saltcake dissolution proof-of-concept operations shall be terminated until the leak is repaired.

6.8 ADVERSE WASTE CONFIGURATION DURING DISSOLUTION

Adverse waste configurations are those that could cause damage to the saltwell screen, the tank dome, or other hardware by the weight or motion of waste should slumping, cave-in, or similar failures occur. If such a condition develops, solvent water addition for the saltcake dissolution proof-of-concept operations shall be terminated. If the adverse waste condition is the result of water addition from Riser 2 and is determined not to pose an immediate hazard, the large-area test shall proceed in Riser 7.

6.9 SOLIDS BUILDUP IN SALTWELL SCREEN

It is possible that runoff of brine during dissolution may transport small insoluble particles into the saltwell screen where they could settle out and accumulate, eventually degrading jet pump performance. If this occurs, standard interim stabilization procedures for clearing solids from the saltwell screen will be followed.

6.10 LOSS OF IN-TANK CAMERA

The shift manager will evaluate the situation. If in-tank video capability cannot be restored, solvent water addition for the saltcake dissolution proof-of-concept operations shall be terminated.

6.11 LOSS OF TOPOGRAPHICAL MAPPING SYSTEM

Because the TMS is optional instrumentation for the dissolution proof-of-concept operations, activities may continue as planned if the TMS becomes inoperable. A failure of the TMS may require its removal from the tank for repairs. If the TMS fails after proof-of-concept operations are underway, the test will be continued without the TMS, as long as the remainder of the

LDMM techniques remain functional. The test crew will attempt to determine the cause of the TMS failure and document it. If the TMS can be repaired, the Interim Stabilization and Shift managers will make the determination to postpone the proof-of-concept operations to permit the repair or replacement of the TMS.

6.12 LEAK DETECTED IN-TANK

If tank U-107 is suspected of leaking at any time during dissolution proof-of-concept operations, the leak assessment process outlined in HNF-SD-WM-PROC-021, Rev. 3, Section 17.1, "Tank Leak Assessment Process" shall be immediately initiated (CHG 2000c). This process can be triggered by anomalous data from any legitimate leak detection source, either in-tank or ex-tank. A Leak Assessment Expert Panel will be convened to review all available data, and an Occurrence Report will be filed, indicating that the tank is under investigation as a potential leaker. The recommendation of the Expert Panel will be presented to the Plant Review Committee (PRC), who will make a formal declaration of the tank status, (either "sound" or "assumed leaker").

As soon as data are received that indicate a possible leak, the dissolution proof-of-concept activities will be immediately suspended and the equipment placed in a safe condition. Dissolution operations will not be restarted unless the tank is declared "sound" following the procedure referenced above. During this time, saltwell pumping will continue, because that is the only available method to mitigate the severity of a potential leak. If a tank is determined to be leaking, standard practice is to initiate emergency saltwell pumping as soon as possible. Therefore, if saltwell pumping is already underway, it should continue during the leak evaluation.

If the tank is ultimately determined to be "sound," the dissolution process may be restarted. If it is determined to be an "assumed leaker," further dissolution proof-of-concept activities will be terminated, and the saltwell pumping will continue until the tank is interim stabilized based on current Interim Stabilization requirements

6.13 LEAK IN TRANSFER PIPING OR PITS

Upon alarm actuation, the appropriate enunciator panel board verified is for the presence of the alarm and the shift manager is notified. The alarm must be identified as an actual leak, instrument malfunction, or maintenance activity. If a leak is verified, saltwell pumping will be secured. A Health Physics Technician dose rate survey is required at the specific location of the alarm. The shift manager will evaluate the situation and specify the recovery actions per ARP-T-501-001, *Respond to Alarms at U-Farm.*

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7.0 PERMITTING STRATEGIES

7.1 RADIOACTIVE AIR PERMITTING

The existing air permit addressing radioactive air emissions during saltwell pumping did describe addition of water to the tank being saltwell pumped, but there was no description of planned water application to the surface of the saltcake. Low volume water applications to a moist saltcake surface would not be expected to generate any appreciable aerosols or increase the potential to emit during saltwell pumping. As a result, a revision to the existing radioactive air permit was determined to be the appropriate regulatory action.

Two new sections were prepared to revise the radioactive air permit (Section 6.5, "Salt Cake Dissolution" and Section 10.9, "Potential Annual Unabated Emissions During Salt Cake Dissolution"). The proposed revisions were discussed with representatives of the U.S. Department of Energy, Office of River Protection (ORP), and the Washington State Department of Health (WDOH). The final language was documented on a Notice of Construction (NOC) revision form, which was approved by WDOH on December 18, 2000 (DOE-RL 2000a).

7.2 NON-RADIOACTIVE AIR PERMITTING

The non-radioactive air permit for saltwell pumping did not describe water additions to the surface of the saltcake during saltwell pumping. The air permit used a conservative method to calculate toxic air pollutants and assumed that all gasses trapped in the tank solids were released to the tank headspace as the liquids are saltwell pumped out of the tank. Therefore, no increased emissions would result, if a portion of the saltcake in the tank was dissolved and an NOC revision form was determined to be the appropriate regulatory action.

A new section (Section 4.1.5, "Salt Cake Dissolution") was prepared and discussed with representatives of ORP and the Washington State Department of Ecology (Ecology) air section. The final language of the permit revision was approved by Ecology on December 17, 2000 (DOE-RL 2000b).

7.3 DANGEROUS WASTE PERMITTING

Single-shell tanks are covered by a single *Resource Conservation and Recovery Act* (RCRA) Part A permit. The permit was last updated on December 22, 1999, and applies to all SSTs. The permit contains the T01 process code, which allows in-tank treatment of wastes and a restriction that no more than 600,000 gallons of wastes can be treated in a single day. The applicable portion of the permit is provided below:

> "Treatment of the mixed waste in the SST System occurs when solids and interstitial liquids are separated and/or cooling liquids are added (TO1). These treatment processes involve, but are not limited to, mechanical retrieval, sluicing, and saltwell pumping of the mixed waste. The SST System has a process design limit of 2,271,240 liters (600,000 gallons) per day based on the simultaneous pumping of two SSTs in a 24-hour period. Ancillary equipment used for the transfer of liquid mixed waste consists of: (1) centrifugal pumps capable of pumping liquid mixed waste at 1,514 liters (400 gallons) per minute, (2) induction pumps capable of pumping liquid waste from the saltwell at 19 liters (5 gallons) per minute, and (3) associated valves and piping to the DST System. Mechanical equipment, sluicing equipment, and similar treatment/processes are not limited to the processes described previously."

While the Part A permit does not specifically discuss the addition of water to SSTs, the Appendix to the Consent Decree for saltwell pumping states: "The addition of dilution water to tanks shall not be counted towards the pumpable liquid volume or the liquid volume remaining to be removed." It is clear from this language that water can be added to SSTs for dilution and that it is considered acceptable.

Addition of solvent water to SSTs to dissolve saltcake was discussed in Appendix B of the *Single-Shell Tank Interim Stabilization Project Plan* (CHG 2000a), as an alternative that could be used to accelerate the removal of mixed wastes from SSTs. By exercising a limited version of this alternative while saltwell pumping an SST, it could be verified that this alternative could be used to accelerate the removal of wastes from an SST and reduce the risk to the public and the environment.

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APPENDIX A

STATIC DIFFUSION OF AQUEOUS $NaNO_3$ SALT

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STATIC DIFFUSION OF AQUEOUS $NaNO_3$ SALT

The physics behind the principle of operation of the Low Volume Density Gradient (LVDG) retrieval system are difficult to mathematically describe. The retrieval method utilizes a concentration driving force to move the water-soluble salts from a region of high concentration (saltcake and interstitial liquids) to the region of lower concentration (water added via the retrieval system).

A relatively simple analytic solution to the physical situation can be derived if convection can be disregarded. As a method to justify the efficacy of the Low Volume Density Gradient (LVDG) operation, this may be a reasonable simplification, because of the low water addition rates compared to the volumes of tank waste involved. The results will be more conservative because convection will not be acting to enhance the concentration driving forces involved.

The general continuity equation for mass transfer in rectangular coordinates is:

$$\frac{\partial C}{\partial t} + \nabla \bullet (C\vec{v}) = -\nabla \bullet \vec{J}$$

The definitions [and units] of the components in this equation are:

C = concentration of the species of interest in the control volume $[\text{mass length}^{-3}]$

t = time $[\text{time}]$

∇ = del operator or directional derivative $(\frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z})[\text{length}^{-1}]$

$\vec{v}$ = velocity of the moving fluid $[\text{length time}^{-1}]$

$\vec{J}$ = the mass flux of the species of interest through one face on the control volume $[\text{mass length}^{-2}\ \text{time}^{-1}]$

The definitions [and units] of the terms in this equation are:

$\frac{\partial C}{\partial t}$ .... = rate of change of mass in the control volume $[\text{mass length}^{-3}\ \text{time}^{-1}]$

$\nabla \bullet (C\vec{v})$ = gradient of the product $C\vec{v}$ (also written as $\frac{\partial C\vec{v}}{\partial x} + \frac{\partial C\vec{v}}{\partial y} + \frac{\partial C\vec{v}}{\partial z}$ or the mass gain or loss in the control volume) $[\text{mass length}^{-3}\ \text{time}^{-1}]$

$-\nabla \bullet \vec{J}$ = positional variation of mass flux through the control volume

$\left[\text{mass length}^{-3}\ \text{time}^{-1}\right]$

The general continuity equation can be simplified by considering:

(1) the situation of no bulk flow ($\vec{v} = 0$) and,

(2) variation in only one spatial dimension (x),

(3) assuming the applicability of Fick's Law of Diffusion:

$$(\vec{J} = -D_{ab}\nabla C = -D_{ab}\frac{\partial C}{\partial x})$$

This yields the simplified continuity equation:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D_{ab}\frac{\partial C}{\partial x}\right) = D_{ab}\frac{\partial^2 C}{\partial x^2} \quad \text{or} \quad \frac{\partial^2 C}{\partial x^2} - \frac{1}{D_{ab}}\frac{\partial C}{\partial t} = 0$$

In this case, the resulting partial differential equation is parabolic, and substitution via combination of variables will permit expressing it as an ordinary differential equation. An additional convenience is that this ordinary differential equation has an analytical solution.

If a non-dimensional dependent variable (concentration Φ) is defined as

$$(\Phi = C/C_0),$$

where C_0 is the steady-state salt concentration in the liquid phase, and a non-dimensional independent variable is defined as a function of both position x and time t as

$$(\eta = \frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}),$$

the original partial differential equation simplifies to the ordinary differential equation:

$$\frac{\partial^2 \Phi}{\partial \eta^2} + 8\eta\frac{\partial \Phi}{\partial \eta} = 0$$

This can be shown by differentiating the non-dimensional concentration function with respect to the original independent variables and substituting these values into the original partial differential equation:

$$\Phi = \Phi(\eta) = (C/C_{\max}) \qquad \eta = \frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}$$

$$\frac{\partial \Phi}{\partial x} = \frac{\partial \Phi}{\partial \eta}\frac{\partial \eta}{\partial x} \rightarrow \frac{\partial^2 \Phi}{\partial x^2} = \frac{\partial^2 \Phi}{\partial \eta^2}\left(\frac{\partial \eta}{\partial x}\right)^2 + \frac{\partial \Phi}{\partial \eta}\frac{\partial^2 \eta}{\partial x^2}$$

$$\frac{\partial \Phi}{\partial t} = \frac{\partial \Phi}{\partial \eta}\frac{\partial \eta}{\partial t}$$

So that,

$$\frac{\partial \eta}{\partial x} = \frac{\partial}{\partial x}\left(\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}\right) = \frac{1}{2}\sqrt{\frac{1}{D_{ab}t}} \qquad \frac{\partial^2 \eta}{\partial x^2} = \frac{\partial}{\partial x}\left(\frac{\partial \eta}{\partial x}\right) = \frac{\partial}{\partial x}\left(\frac{1}{2}\sqrt{\frac{1}{D_{ab}t}}\right) = 0$$

$$\frac{\partial \eta}{\partial t} = \frac{\partial}{\partial t}\left(\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}\right) = -x\sqrt{\frac{1}{D_{ab}}}\left(t^{-\frac{3}{2}}\right)$$

Substituting the dimensionless concentration function (Φ) in place of the concentration (C) into the partial differential equation,

$$\frac{\partial^2 C}{\partial x^2} - \frac{1}{D_{ab}}\frac{\partial C}{\partial t} = 0 \qquad \frac{\partial^2 \Phi}{\partial x^2} - \frac{1}{D_{ab}}\frac{\partial \Phi}{\partial t} = 0$$

Substituting the values of the non-dimensional independent variable (η) differentiated with respect to x and t:

$$\frac{\partial^2 \Phi}{\partial \eta^2}\left(\frac{\partial \eta}{\partial x}\right)^2 + \frac{\partial \Phi}{\partial \eta}\frac{\partial^2 \eta}{\partial x^2} - \frac{1}{D_{ab}}\frac{\partial \Phi}{\partial \eta}\frac{\partial \eta}{\partial t} = 0$$

$$\frac{\partial^2 \Phi}{\partial \eta^2}\left(\frac{1}{2}\sqrt{\frac{1}{D_{ab}t}}\right)^2 + \frac{\partial \Phi}{\partial \eta}(0) - \frac{1}{D_{ab}}\frac{\partial \Phi}{\partial \eta}\left(-x\sqrt{\frac{1}{D_{ab}}}\left(t^{-\frac{3}{2}}\right)\right) = 0$$

$$\frac{\partial^2 \Phi}{\partial \eta^2}\left(\frac{1}{4D_{ab}t}\right) + 0 + \frac{x}{D_{ab}^{\frac{3}{2}}t^{\frac{3}{2}}}\frac{\partial \Phi}{\partial \eta} = 0$$

Divide equation through by $(\frac{1}{4D_{ab}t})$:

$$\frac{\partial^2\Phi}{\partial\eta^2}+4x\sqrt{\frac{1}{D_{ab}t}}\frac{\partial\Phi}{\partial\eta}=0$$

Substituting for x and t in terms of η, $\eta=\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}$,

Therefore, $8\eta=4x\sqrt{\frac{1}{D_{ab}t}}$ so $\frac{\partial^2\Phi}{\partial\eta^2}+8\eta\frac{\partial\Phi}{\partial\eta}=0$

The general solution of this ordinary differential equation takes the form:

$$\Phi(\eta)=\mathrm{A}\frac{\sqrt{\pi}}{2}\mathrm{erf}(\eta)+\mathrm{B}$$

Where the constants A and B are determined from the specific boundary conditions applicable to the problem.

This solution can be verified by substituting for η and Φ in terms of the original independent variables x and t,

$$C(x,t)=(C_0)[A\frac{\sqrt{\pi}}{2}erf(\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}})+B]$$

Differentiating the solution with respect to the independent variables gives:

$$\frac{\partial C}{\partial x}=(C_0)(A\frac{1}{2\sqrt{D_{ab}t}})\exp(\frac{-x^2}{4D_{ab}t})$$

$$\frac{\partial^2 C}{\partial x^2}=-(C_0)(A\frac{1}{4\sqrt{D_{ab}t}})(\frac{x}{D_{ab}t})\exp(\frac{-x^2}{4D_{ab}t})$$

$$\frac{\partial C}{\partial t}=-(C_0)(A\frac{1}{4\sqrt{D_{ab}t}})(\frac{x}{t})\exp(\frac{-x^2}{4D_{ab}t})$$

Substituting into the original partial differential equation $(\frac{\partial^2 C}{\partial x^2}-\frac{1}{D_{ab}}(\frac{\partial C}{\partial t})=0)$,

$$-(C_{\max})(A\frac{1}{4\sqrt{D_{ab}t}})(\frac{x}{D_{ab}t})\exp(\frac{-x^2}{4D_{ab}t})-\frac{1}{D_{ab}}(-(C_{\max})(A\frac{1}{4\sqrt{D_{ab}t}})(\frac{x}{t})\exp(\frac{-x^2}{4D_{ab}t}))=0$$

Dividing the equation through by $[-(C_{max})(A\frac{1}{4\sqrt{D_{ab}t}})(\frac{x}{t})\exp(\frac{-x^2}{4D_{ab}t})]$ shows that the solution obtained satisfies the original partial differential equation: $\frac{1}{D_{ab}} - \frac{1}{D_{ab}} = 0$

When the boundary conditions for: $\frac{C(x,t)}{C_0} = [A\frac{\sqrt{\pi}}{2}\mathrm{erf}(\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}}) + B]$ are specified as:

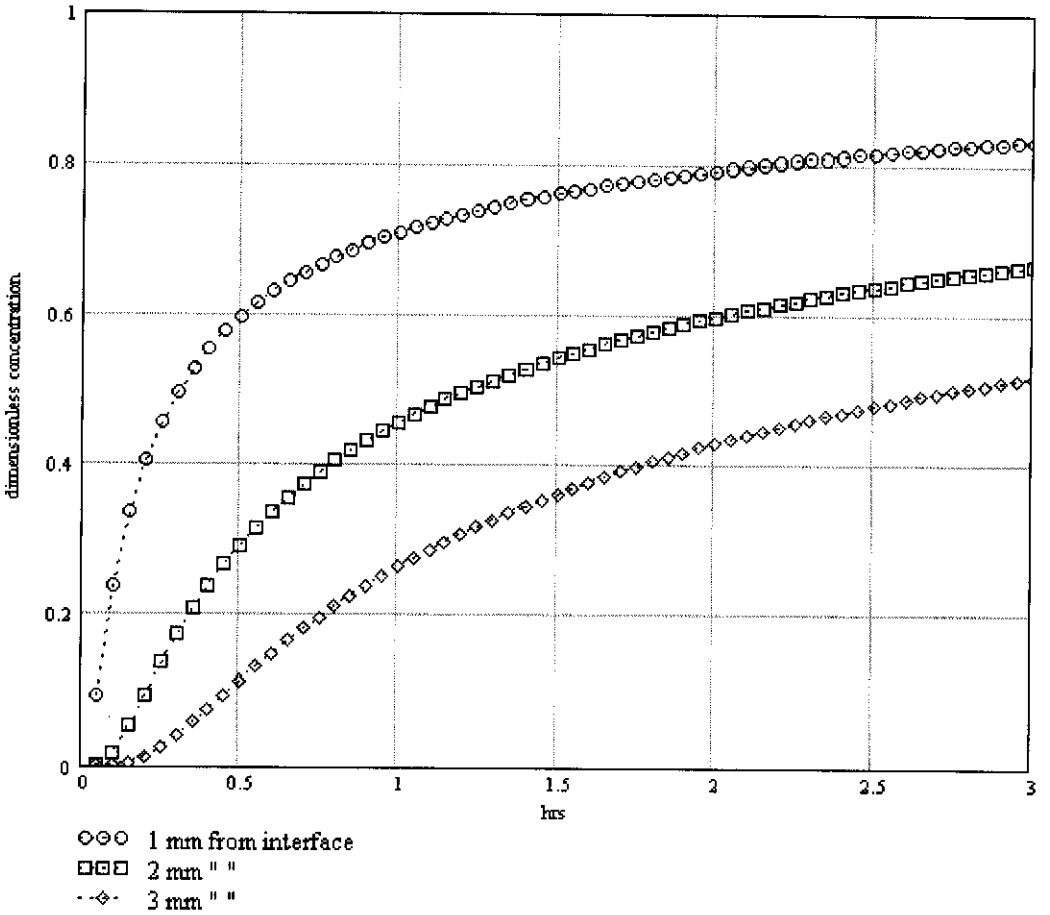
$C(x,t) = (C_0)$ for any time t at x = 0 and $C(x,t) = (0)$ for any time t at x = ∞.

The constants are solved as: $A = -\frac{2}{\sqrt{\pi}}$ and $B = 1$

This yields: $\frac{C(x,t)}{C_0} = [1 - \mathrm{erf}(\frac{x}{2}\sqrt{\frac{1}{D_{ab}t}})]$

The value of the diffusion coefficient (D_{ab}) is assumed to be that of $NaNO_3$ in water, and is taken as 1×10^{-5} cm^2/sec. The solution, expressed as a function of time for positions 1, 2, and 3 millimeters (arbitrarily chosen distances) from the interface is shown in Figure A-1. This solution offers some degree of objective evidence that, with the distances and time scales applicable to Low Volume Density Gradient (LVDG) operation, noticeable and perhaps very effective results should be apparent:

Figure A-1. Static Diffusion of $NaNO_3$ into Pure Water



This solution shows that the sodium nitrate concentration reaches one-half the steady-state concentration at 1 mm from the interface in about 20 minutes.

APPENDIX B

TANK 241-U-107 WASTE CHARACTERIZATION

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TANK 241-U-107 WASTE CHARACTERIZATION

Tank U-107 was first filled in 1948. After being filled and sluiced several times, tank U-107 was last cleaned out in 1956. In 1957 - 1959, the tank received Reduction Oxidation (REDOX) coating waste supernatant. There was no further activity until 1968 - 1969 when several transfers were made to and from the tank. From 1972 to 1976, tank U-107 received a wide variety of waste from several tanks. Tank U-107 received and sent evaporator feed to and from several tanks from 1976 to 1980. The tank was removed from service in November 1980.

Tank U-107 contains saltcake, and it is the only U-Farm tank on the Flammable Gas Watch List with waste concentrated to classify as double-shell slurry feed. The current waste level is 157 inches, which may include 1 to 2 ft of supernatant. The tank is scheduled to be saltwell pumped starting in June 2001.

This section summarizes what is known about the waste in tank U-107 based on sample analyses and monitoring data. Many of the data are taken from the summary by Hedengren et al. (2001), updated to current conditions as of March 2001. Section B1.0 shows the histories of waste level, interstitial liquid level (ILL), temperatures, and neutron logs. Physical properties such as waste densities, particle size, and stratigraphy are discussed in Section B2.0, and estimates of the retained gas volume and composition are made in Section B3.0. The waste chemistry and dissolution behavior are summarized in Section B4.0, and some specific waste property issues are discussed in Section B5.0.

B1.0 LEVEL, TEMPERATURE, AND NEUTRON LOG HISTORIES

The waste level in tank U-107 has been rising at a rate of about 0.1 inch per year since 1990 as shown in Figure B-1. The sudden, 12-inch jump in surface level is due to a change in reference from the sidewall bottom to center bottom. Photographs taken in 1988 showed the entire surface to be covered with liquid with numerous small clumps of apparently floating material.

The neutron logs shown in Figure B-2 show the distribution of water in the waste (see Section B2.0). The high count above about 130 inches is consistent with supernatant or a very high liquid fraction. Below the supernatant, from 100 to about 130 inches, is a region of low count, which may indicate retained gas. The neutron profiles of all of U-Farm Watch List tanks were similar prior to pumping. Figure B-3 compares the 1997 logs by shifting the profile for each tank by 500 count units on the abscissa. Except for tank U-103, each tank has a prominent high-count layer on top of a region with a lower count.

The three U-tanks that have been saltwell pumped have not responded equally. The 2000 neutron logs for tanks U-103, U-105, and U-109 are compared in Figure B.4 with each profile shifted by 500 count units as in the previous figure. The overall shape of the neutron profile is approximately preserved in each tank with the lower 60 to 80 inches are essentially unchanged. However, it appears that more liquid was removed from tank U-105 than from tank U-103 and

considerably more from tank U-109. Based on the relatively coarse appearance of core sample extrusions, liquid drainage from tank U-107 waste is expected to be similar to that of tank U-109.

Figure B-1. Waste Level and Interstitial Liquid Level for Tank 241-U-107

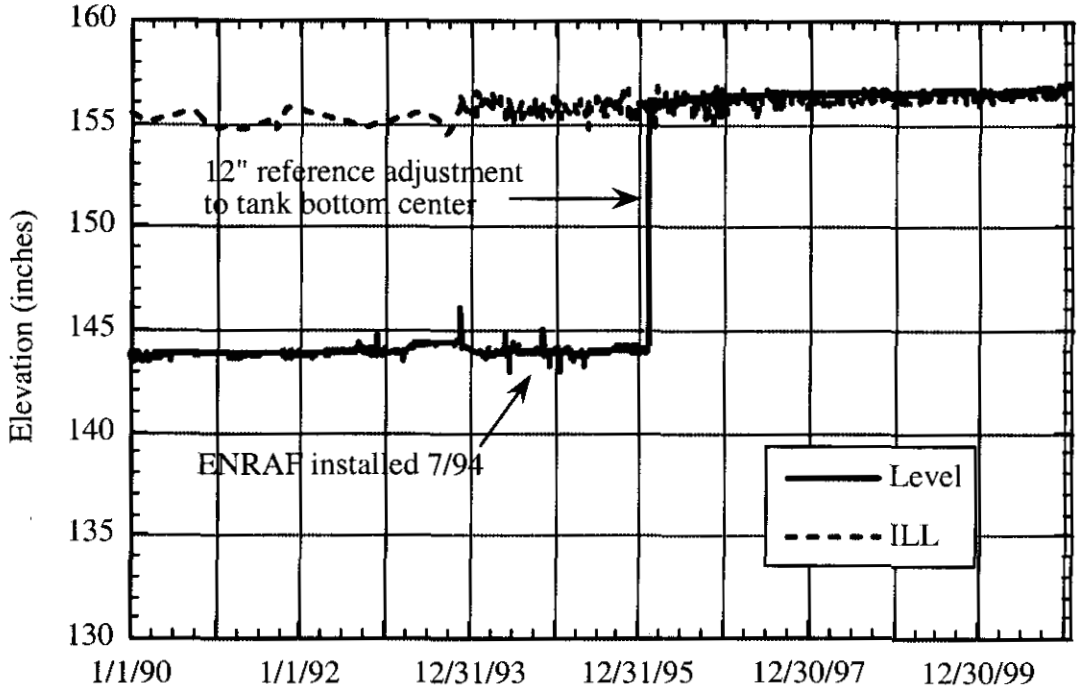


Figure B-2. Tank 241-U-107 Neutron Logs

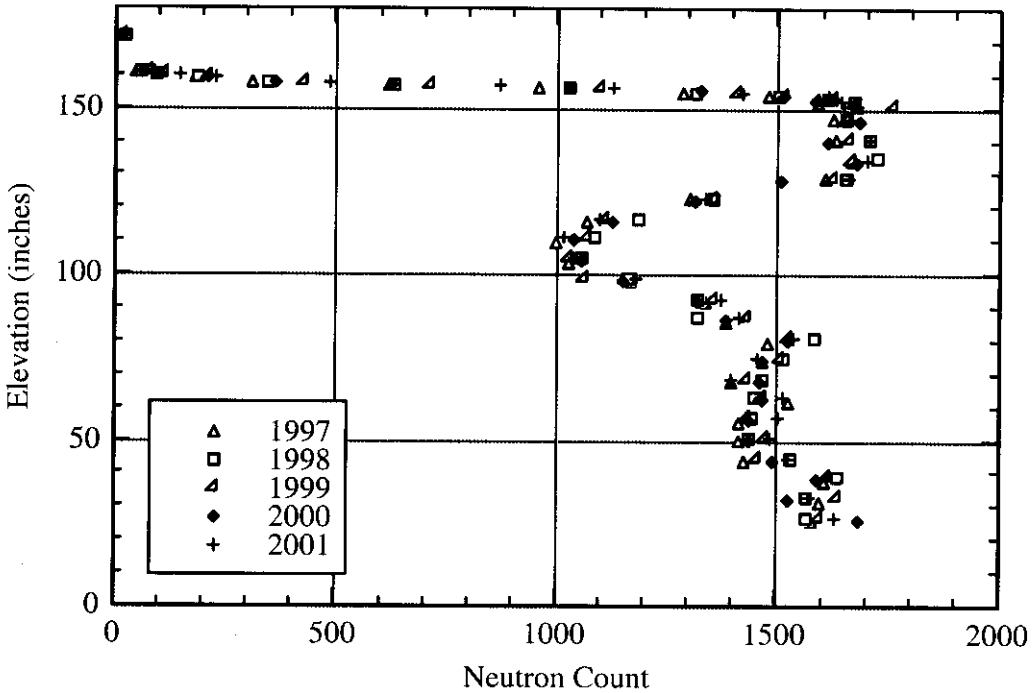


Figure B-3. Pre-Saltwell Pumping Neutron Logs for Several U-Farm Tanks

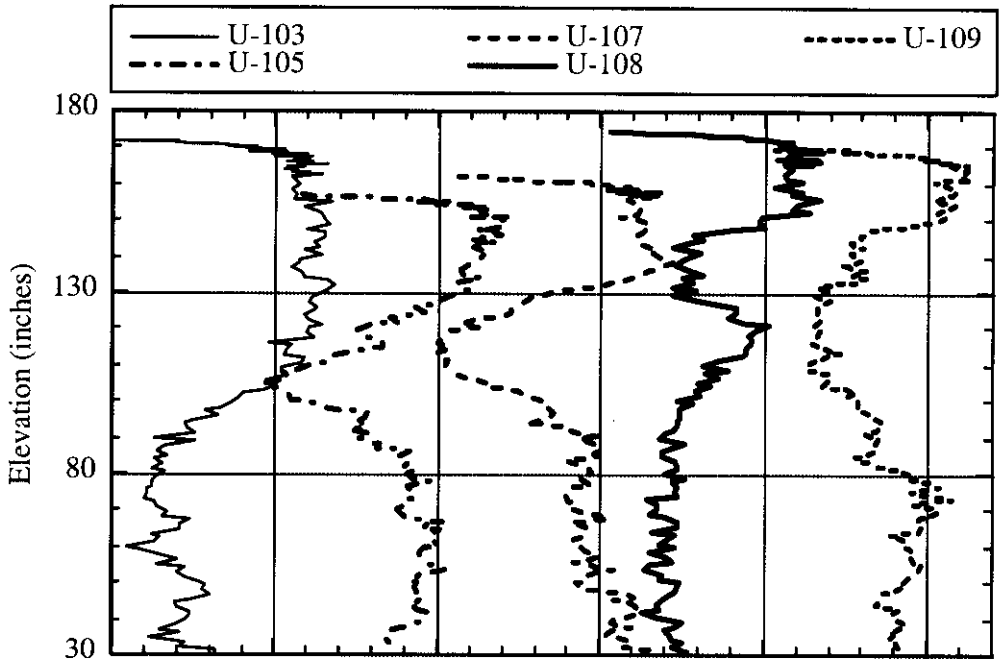
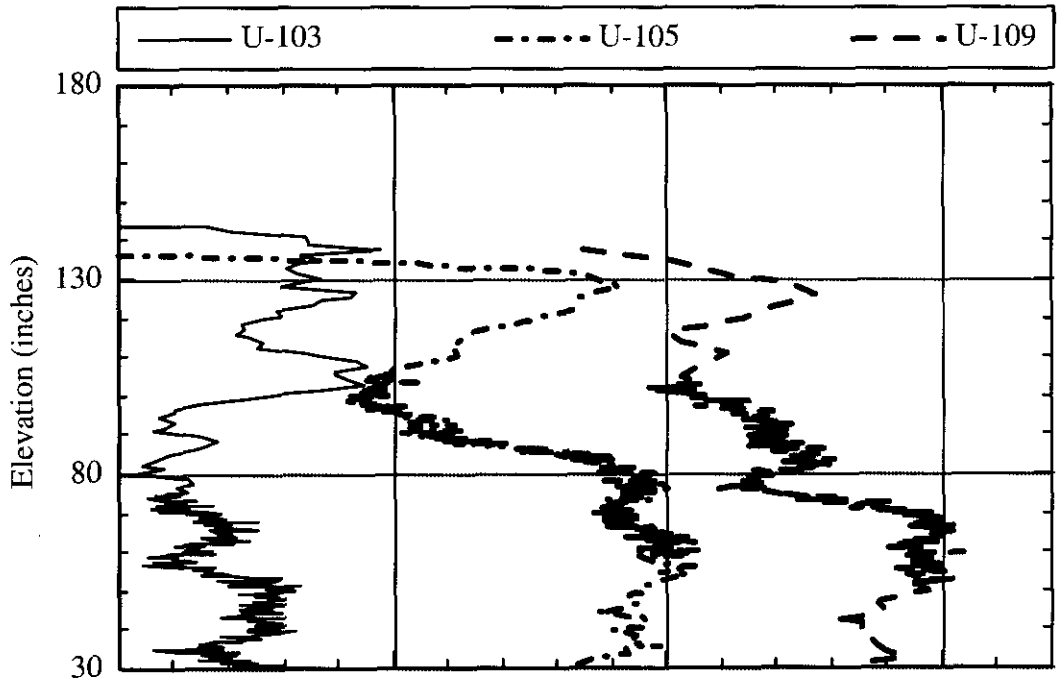
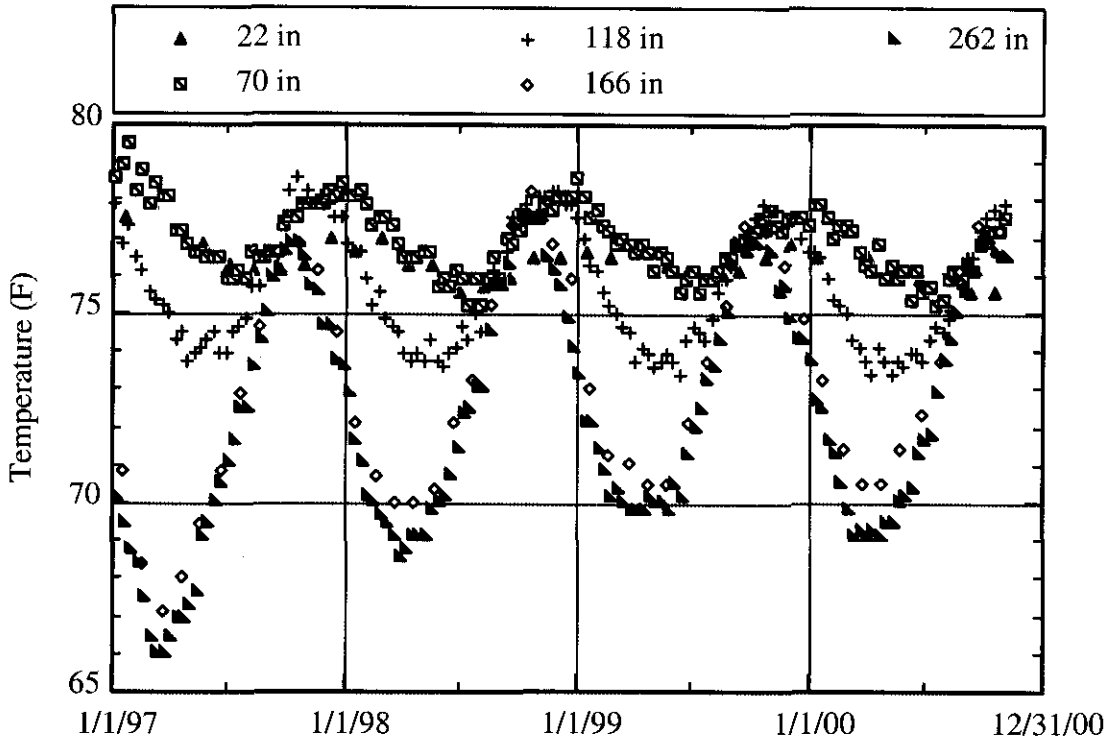


Figure B-4. Post-Saltwell Pumping Neutron Logs for Three U-Farm Tanks



The temperature profile for tank U-107 is shown in Figure B-5. The waste in tank U-107 is relatively cool with a peak temperature of only 78 °F. However, since the thermocouple tree is out at about the 32-ft radius, the temperatures in the central region could be somewhat higher. During the annual cycle, the headspace temperature actually exceeds the temperature at the 22-inch thermocouple. Within the annual cycle of 2 to 5 °F, the waste temperature up to 118 inches is fairly uniform varying between 73 and 78 °F.

Figure B-5. Waste Temperature History in Tank 241-U-107



B2.0 WASTE PHYSICAL PROPERTIES

All of the physical property information about tank U-107 waste has been obtained from core samples. However, because the waste temperature of 70 to 80 °F is close to typical hot cell temperatures, the ex-tank properties should closely approximate in-tank conditions.

B2.1 DENSITY AND YIELD STRESS

The bulk waste densities are determined from the waste cores extruded on the sample tray in the hot cell. Liquid that drains off the tray during extrusion is included in the calculation. The stirring and other handling involved in filling a sample bottle to measure the density releases any large bubbles of gas present so the reported bulk density is assumed to be a degassed value.

The waste yield stress was estimated by observing behavior of waste cores during sample extrusion, using the technique developed by Gauglitz and Aikin (1997). This method is based on experiments that showed that during the standard horizontal extrusion process, waste simulants behaved in a reproducible manner that varied distinctively with strength. Two different waste simulants were used. Bentonite clay was mixed with different amounts of water to obtain shear strengths of 31 to 3,670 Pa. Kaolin/Ludox[8] was mixed with different amounts of salt and varying setup times were used to obtain shear strengths of 625 to 6,500 Pa. This method gave

[8] Ludox HS-30 is a trade name for a colloidal silica dispersion

estimates that were within a factor of two of those obtained by ball rheometry in the DSTs at the same elevation as the core samples. Therefore, the uncertainty is approximately a factor of 2.

The density and yield stress profiles developed from 1996 and 1998 core samples are shown in Figure B-6. The densities from the three different risers are quite consistent. All three risers are at 27 to 30 ft radius and are separated by approximately 90 degrees around the tank (see Figure 3-2). The low density of about 1.45 g/mL above 100 inches indicates a high water content in this layer. Below about 100 inches, the bulk density appears to increase with depth from about 1.6 g/mL to 1.8 g/mL. The yield stress behaves similarly. The upper wet layer has a very low, but non-zero, strength of 30 to 50 Pa, including the two high-density samples from just below the 140-inch elevation. The yield stress generally increases with depth, though with considerable scatter, from around 100 Pa to 400 to 600 Pa below 80 inches. All these samples are from near the periphery of the tank and may not be representative of waste in the central region.

B2.2 POROSITY AND LAYERING

Neither porosity nor particle size has been measured in tank U-107 waste. However, the appearance of the waste on the core extrusion tray is generally of coarse, sandy material with a relatively large particle size. The visual impressions of the core extrusions containing a significant length of solids (recorded during the evaluation of yield stress) are summarized in Table B-1. The segments are listed in order of depth. The top of Segment 1 is at the waste surface. The upper three segments appear to be very wet and coarse. Segments 4 and 5 appear to be drier with somewhat finer particles. This is consistent with the region of lower neutron count between about 80 to 120 inches (see Figure B-2). Segment 6 in Riser 7 showed a unique white gravelly material that contained a high concentration of sodium phosphate. The lowest Segments 7 and 8 are wet and coarse.

B3.0 RETAINED GAS VOLUME AND COMPOSITION

The waste level in tank U-107 is at 157 inches, of which the upper 1 to 2 ft may be supernatant. The level has risen very gradually (about 0.1 in./year) since 1990. Fourteen small spontaneous gas release events have been recorded by the tank's standard hydrogen monitoring system (SHMS-B) since March 1995. During the six years of SHMS monitoring, the maximum hydrogen concentration was 1,900 ppm, and the average is 840 ppm. The best estimate of the retained gas volume, 6,400 ± 2,000 standard cubic feet is taken as the average of the barometric pressure effect (BPE) calculation and neutron log integration (Hedengren et al. 2001). The waste level has risen 6 inches since 1981 (Whitney 1995) which would indicate a gas accumulation of about 2,600 cubic feet at 1 atm assuming an in situ pressure of 1.2 atm.

Figure B-6. Density and Yield Stress Profiles in Tank 241-U-107 Waste

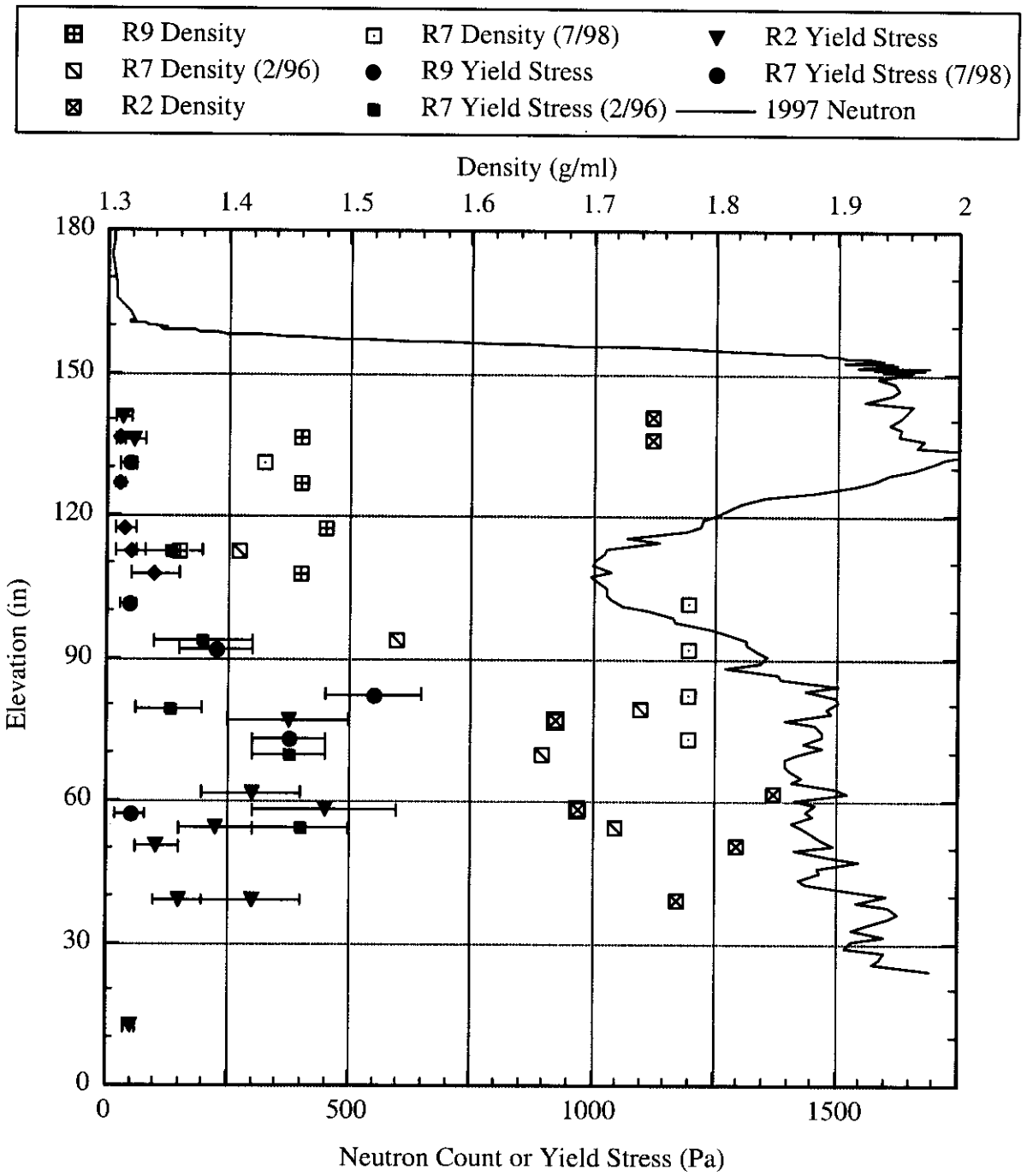


Table B-1. Visual Impressions of Tank 241-U-107 Core Extrusions

Riser and Date	Segment	Description of Extrusion
7, July 1998	1	"Very wet and coarse, like crushed, melting ice"
7, July 1998	1	"Very wet and coarse, like crushed, melting ice"
7, February 1996	2	"Very crumbly, like wet sand"
2, June 1998	2	"Wet coarse, clumpy"
9, February 1996	3	"Very coarse, heterogeneous"
7, February 1996	3	"Fairly crumbly, coarse, very rigid"
7, July 1998	3	"Homogeneous, droopy"
7, July 1998	3	"Clumpy, yet very wet, finely coarse like wet sand"
7, February 1996	4	"Smooth, not coarse, not rigid"
7, February 1996	4	"Less homogenous, coarse"
7, July 1998	4	"Firm, homogeneous"
7, July 1998	4	"Firm, homogeneous, a bit dryer, firmer, finely coarse"
7, February 1996	5	"Very crumbly"
2, July 1998	5	"Coarse, wet homogeneous"
7, July 1998	5	"Very crumbly, partially disintegrated upon extrusion. Appears heterogeneous damp sand"
2, June 1998	6	"Consistent, rigid, not coarse"
2, June 1998	6	"Dark-brown chunk, appears wet and coarse, does not crumble or droop"
2, July 1998	6	"Quite coarse, appeared like it should crumble"
7, July 1998	6	"White moist solids like gravel; did not crumble, hard individual ~1/2-inch pieces"
2, July 1998	6A	"Wet and coarse, spread across tray"
2, July 1998	7	"Wet, somewhat coarse."
2, July 1998	8	"Wet, coarse material at end"

The retained gas composition in tank U-107 has not been measured. However, Retained Gas Sampler data for tanks U-103 and U-109 showed 23 percent and 25 percent hydrogen, respectively. Although there is considerable uncertainty, tank U-107 might be expected to have a similar hydrogen fraction because their chemical compositions are similar. Based on tanks U-103 and U-109 data, the balance of the gas is about 40 percent nitrogen, 33 percent nitrous oxide, and 1 percent ammonia with traces of methane and other gases.

B4.0 WASTE CHEMISTRY

Tank U-107 is the first in a cascade series of three tanks that includes tanks U-108 and U-109. After a series of transfers of metal waste, the tank was emptied and the heel jet-sluiced in 1956. Transfers to and from the tank resulted in it receiving REDOX coating waste supernatant, N-Reactor and T-Plant decontamination wastes, and laboratory waste. The waste volume in tank

U-107 was recorded to be as low as[9] 77 kgal (about 37 inches of waste depth) in 1978 and 89 kgal (about 42 inches of waste depth) in 1980. After the latter low point, tank U-107 was refilled with slurry from partial neutralization evaporator campaigns at the 242-S Evaporator (Hedengren et al. 2001).

Based on waste transfer records alone, the waste below and above about 42 inches elevation would be expected to have different compositions. The Tank Layer Model (Agnew et al. 1995) defines tank U-107 solids layers of 76 kgal (up to 37 inches) and 14 kgal (an additional 5 inches of waste depth), derived from unknown sources. Above this 42-inch level, the model states that the waste solids were derived from salt slurry. Neutron scans (Figure B-2) suggest four "layers" with distinctly different liquid fractions at the location of the LOW:

- Above about 125 in., a high-liquid layer is present corresponding to the supernatant layer;
- Between 85 in. and the bottom of the supernatant layer is a low-liquid region which is believed to contain a gas fraction of 15 to 20 vol%, on average;
- Between about 40 in. and 85 in. is a region of fairly constant and moderate liquid fraction, probably containing less than 10 vol% gas; and
- Below 40 in. the waste liquid content varies but is higher on average than in any other layer except the supernatant.

In general, the six sets of core samples taken in 1996 and 1998[10] agreed with the neutron scans in placing the bottom of the supernatant layer at between 120 and 130 in. elevation. The only exceptions seen were in Core 242R, where completely liquid samples were found down to about 85 in., and in Segment 245-2R, where liquid was present down to 105 in. These samples are probably non-representative because they were taken from waste that had been disturbed by prior sampling. Core 242R was obtained a few days after Core 242 had been taken in the same riser and location (Riser 2), and it seems likely that supernatant had penetrated down into the hole left by the previous core. Similarly, Segment 245-2R was also from a re-taken core.

Given the evidence for the existence of somewhat well defined layers, the waste composition has been examined in terms of those layers.

B4.1 COMPOSITION OF SOLIDS AND LIQUIDS

The average compositions (in terms of major constituents) of the different waste layers are given in Table B-2. The table also contains composition data from the recently prepared tank U-107 waste composite, as well as an estimate of the overall average constituent concentrations based on the tank U-107 Best-Basis Inventory[11] as of July 30, 1999, and the overall waste volume given by Hanlon (2000). Certain features of the waste are evident from the table:

[9] TWINS database, WSTRS.XLS file for U-107, accessed March 22, 2001.
[10] TWINS database, consolidated sample analysis results and observations, accessed January 2001.
[11] TWINS database, Best-Basis Inventory summary file for U-107, accessed October 18, 2000.

- The average liquid fractions in the waste (calculated by dividing tracer concentrations in bulk samples by the concentration in appropriate liquid samples) range from 40 vol% to 60 vol%. The top layer of solids, the one of greatest concern for the dissolution test, contains 42±4 vol% liquid, based on an analysis of available H_2O, K^+, Cl^-, and NO_2^- data.

- The low average density of the top layer of solids implies a liquid fraction of 90 vol%. This high liquid volume fraction is not consistent with the calculated liquid fraction, or with the large amount of nitrate that is clearly present in excess of what is in solution. The unusually low average density of the top layer has been assumed to be incorrect.

- The top solids layer clearly contains precipitated sodium phosphate, but in significantly lower quantity than in lower solids layers. The lower-solubility and insoluble analytes, such as Al, Cr, and Fe, are also present at lower concentrations in the top layer than in lower layers. Given the low fluoride content, the sodium fluoride phosphate double salt would not be expected to be a significant contributor to solids, compared to sodium phosphate. (This has a bearing on potential line plugging, since sodium phosphate is likelier to cause plugs than sodium fluoride phosphate.)

- The tank U-107 composite contains substantially more phosphate and metal analytes than the top solids layer and, therefore, would be expected to provide a lower-bound estimate of the top-layer solubility. This difference in composition is to be expected, because the composite was intended as a whole-tank composite and, therefore, had to include the less-soluble wastes from the lower layers. In particular, the composite included sample 245:06, which according to the analysis results must have been composed of nearly pure $Na_3PO_4 \cdot 8H_2O$.

- The upper and lower liquids have consistently different concentrations of tracer analytes.

We used the layer-average composition data in Table B-2 to calculate the solids composition in the top solids layer and in the tank U-107 composite. The approach was as follows. First, assume some liquid volume fraction ω_L. Second, use ω_L and an appropriate liquid concentration of analyte i to calculate the precipitated mass concentration of a chemically plausible analyte-containing solid in the bulk waste.

$$c_{i,s} = (c_i - \omega_L c_{i,L}) * (M_{i,s} / M_i) \qquad \text{(B-1)}$$

where $c_{i,s}$ = g/L bulk waste of a plausible solid containing analyte i
c_i = g/L bulk waste of analyte i
$c_{i,L}$ = g/L liquid of analyte i, for whatever liquid is appropriate
$M_{i,s}$ = molecular weight of a plausible solid containing analyte i, per mole of i in the solid
M_i = molecular weight of analyte i

Third, calculate the volume of each solid per volume of bulk waste, using the density $\rho_{i,s}$ of each solid. Finally, add these together to find the total volume fraction of the waste occupied by bulk solid, ω_s'.

$$\omega_s' = \sum_i c_{i,s} / \rho_{i,s} \tag{B-2}$$

If $(1 - \omega_s')$ does not equal the assumed ω_L, iterate on ω_L until it does.

Table B-3 shows the solids compositions that were obtained, together with the solids that were assumed for each analyte, the solids densities, and the iterated liquid volume fractions that were obtained. The supernatant liquid was used to provide the liquid composition for the top solids layer, while an average of the supernatant and lower liquid composition was used for the tank U-107 composite. The solids in the tank U-107 composite contained more than three times as much lower-solubility material as the tank U-107 top solids layer.

The Water Analyzer module of the Environmental Simulation Program (ESP) (OLI 1998) was run using the bulk composition of the top solids layer as input, to provide a check on the purely analysis-based results in Table B-3. At 25 °C (the approximate temperature both in the analysis laboratories and in the tank), the program predicts that the top solids layer contains 64 vol% liquid and has a bulk density of 1724 g/L. The predicted solids composition is given in Table B-3. The predicted liquid density is 1.442 g/cc, the liquid water content is 52.4 wt%, and the dry solid density is 2.216 g/cc. These predictions match the data well, with the exception of the bulk density (as already noted, the measured bulk density was unreasonably low).

Table B-2. Average Compositions in Tank 241-U-107 Waste (Based on Degassed Waste Volumes). (2 sheets)

	Based on Core Samples						U-107 Composite [f]	Best-Basis Inventory
	Supernatant [a]	Liquid Below 85" [b]	Bulk Solids Above 85" [c]	Bulk Solids, 40" – 85" [d]	Bulk Solids below 40" [e]	Average All Bulk Solids		
Sodium salts								
Na (g/L)	218	234	318	363	369	348	364	273
OH^-	28						38	
NO_3^-	222	158	768	784	571	716	598	449
NO_2^-	96	152	38	72	59	56	49	82
PO_4^{3-}	3.5	2.8	17	24	60	32	89	27
SO_4^{2-}	5.8	3.5	7.2	4.0	1.8[g]	4.6[g]	3.2	6.1
F^-	0.48	0.25	0.39[g]	0.26[g]	0.64	0.42[g]	0.42	0.47
TOC	3.8		1.4[h]	5.5[h]	0.5[h]	2.5[h]	4.0	4.0
$C_2O_4^{2-}$	0.58		2.0[g]	5.1[g]	1.4[g]	2.8[g]		
TIC	4.0		5.3	9.2[h]	0.97[h]	5.3[h]	4.4	5.0
Metals								
Al (g/L)	22	40	9.2	29	64	32	21	32
Cr	0.71	0.28	1.4	5.5	4.0	3.5	4.0	2.5
Fe	< 0.03	0.13	0.19	2.5	2.5	1.6	1.8	1.2
Mn	< 0.01	0.033	0.06	0.84	1.1	0.62		0.58
Si	0.18	0.25	0.24	0.87	2.3	1.1	1.1	0.44
U	< 0.30	< 0.30	< 0.30	0.33[g]	0.33[g]	0.21[g]		0.69
Zr	< 0.01	< 0.01	< 0.01	0.01[g]	0.01[g]	0.01[g]		0.015
Density (g/L)	1400	1440	1490	1730[h]	1770[h]	1610		
Liquid tracers								
H_2O (g/L)	717	688	273	487	389	378	409	
Cl^-	7.7	12	3.4	6.4	5.5	5.0	4.1	6.9

Table B-2. Average Compositions in Tank 241-U-107 Waste (Based on Degassed Waste Volumes). (2 sheets)

	Based on Core Samples						U-107 Composite [f]	Best-Basis Inventory
	Supernatant [a]	Liquid Below 85" [b]	Bulk Solids Above 85" [c]	Bulk Solids, 40" – 85" [d]	Bulk Solids below 40" [e]	Average All Bulk Solids		
K^+	2.9	4.2	1.3	2.3	1.8	1.8	1.7	2.5

Notes:

" = inches

(a) Arithmetic average of samples 129:01, 129:02, 135:01, 242:01, 242:2A, and 245:01. Drainable liquid samples were chosen, avoiding those that were retakes.

(b) Arithmetic average of drainable liquid from samples 242R:05, 245:5R, 245:6R, and 245:7R.

(c) Vertically-integrated average of samples 129:03, 134:02, 134:03, 135:2R, 245:03. Despite their low density, none of these samples contained drainable liquid or measurable hydrostatic head fluid.

(d) Vertically-integrated average of samples 134:04, 242:05, 242:06, 242R-06, 242R:6A, 242R:07 (upper half), 245:04, and 245:5A.

(e) Vertically-integrated average of samples 242:07, 242R:07 (lower half), 242R-08, and 245:06.

(f) The composite was made from material taken from samples 245:01 (lower half solids), 135:02R, 245:03, 245:04, 245:06, and 242R:07. Equal masses were taken from all samples, except that a double aliquot was taken from sample 245:06.

(g) About half or more of the samples contained concentrations below the minimum detection limit (MDL); for these samples, a value of half the MDL was used during integration.

(h) About half or more of the samples had no measurement of this analyte. The average is therefore, unavoidably, approximate.

Table B-3. Solids Compositions in Tank 241-U-107 Waste

Analyte	Solid Compound	Solid density (g/cc)	Weight percent of solid in dry solids		
			U-107 solids above 85 in.		U-107 composite data
			Core data	ESP predicted[(a)]	
NO_3^-	$NaNO_3$	2.261	91	91	68
NO_2^-	$NaNO_2$	2.168	0	0	0
PO_4^{3-}	$Na_3PO_4 \bullet 8H_2O$	1.656	4.9	6.2	28
TIC	$Na_2CO_3 \bullet H_2O$	2.250	3.3	0	2.4
SO_4^{2-}	Na_2SO_4	2.68	0.60	0	0.13
$C_2O_4^{2-}$	$Na_2C_2O_4$	2.34	0.26	0.4	
F^-	NaF	2.558	0.03	0	0.05
Al	$Al(OH)_3$	2.441	0	2.1	1.4
Cr	Cr_2O_3	5.21	0.03	0.2	0.54
Fe	FeOOH	4.268	0.01	0	0.28
liquid volume fraction (iterated, for core data)			56 vol%	64 vol%	51 vol%

Notes:

ESP = Environmental Simulation Program

(a) ESP also predicts trace quantities (0.1 wt% apiece or less) of Bi_2O_3, $Ca_5OH(PO_4)_3$, $CaFe_2O_4$, $KAlSiO_4$, $LaPO_4.2H_2O$, MnO_2, $Na_2U_2O_7$, $Ni(OH)_2$, and ZrO_2.

B4.2 BULK WASTE DISSOLUTION CHARACTERISTICS

Sequential dissolution tests were conducted on the tank U-107 waste composite. The experimental method was similar to that documented by Herting (2000). In summary, about 20 g of water was added to 41.6 g of composite and tumbled for at least 20 hours, after which the mixture was centrifuged and the liquid decanted and analyzed. The process was then repeated until five contacts had been carried out. Solids remaining after the fifth water contact underwent acid dilution and analysis.

Table B-4 shows some of the preliminary results of the sequential dissolution tests. Some of the most important features of the results are as follow:

- The sodium nitrate seems to have been entirely dissolved in the first contact. Therefore, less than a 1:1 by volume dilution ratio was required to dissolve the 68 wt% of the solids.

- No substantial amount of sodium phosphate dissolved until the highly soluble sodium nitrate and nitrite were essentially gone. The analyses show that the PO_4^{3-} solubility increased from 5.4 g/L liquid at the first contact, when the liquid was nearly saturated with nitrate (at 367 g/L), to 40 g PO_4^{3-}/L liquid when the nitrate concentration had been reduced to 10 g/L. It follows that if nitrate or nitrite were added to the liquid from, for example, the third contact, a substantial amount of sodium phosphate would re-precipitate.

- Only about 30 vol% more decantable liquid was released on the first contact than was added as diluent volume. Based on the saturated solution density of 1.4 g/mL and the water content of 51 wt%, diluent water would be expected to expand, as a result of becoming saturated, to occupy a volume about 40 percent greater than the original water volume. The observed lower volume of liquid release must have resulted from increased liquid retention by the centrifuged solids, relative to the retention by original solids. This may simply reflect the fact that the centrifuged solids were not drained, and would have contained interstitial liquid.

- Chloride did not behave like a completely dissolved species, based on its relatively slow removal. This casts doubt on its accuracy as a liquid tracer.

- Only 45 to 55 percent of the aluminum in the composite was removable. The Al/NO_2^- ratio in the liquid was nearly constant through all five contacts. This suggests that the aluminum that was originally in the solids remained there and did not leach out, while the originally dissolved aluminum behaved like a liquid tracer. It is unlikely that the insoluble Al was in the form of an aluminosilicate, given the small Si/Al ratio in the original wastes and in the final post-dissolution solids. Aluminum hydroxide is more probable.

- Dissolution was effectively complete by the time a dilution ratio of 3.3:1 (by volume) had been reached, based on the small change in centrifuged solids volume between the 4th and 5th contacts.

A simplified model of these dissolution tests was also applied assuming a two component solid (soluble and insoluble) and a two-component liquid (water and dissolved solid). A similar analysis was conducted on tank SY-101 experimental dilution data (PNNL 2000), and the results compared well with the actual in-tank dilution (Johnson et al. 2000). Expressions were derived for the following experimental data in terms of parameters describing the two-component system:

- Weight fraction of water in the liquid,
- Volume of initial sample,
- Volume of diluted sample,
- Density of centrifuged liquid,
- Weight fraction of centrifuged solids relative to initial sample mass,
- Volume fraction of centrifuged solids relative to initial sample volume, and
- Weight fraction of dry solids in the centrifuged solids.

A least-squares regression was used to fit the derived expressions to the experimental data. Parameter values which approach those determined from the core samples and best-basis inventory were achieved when the residual error in the centrifuged liquid density was weighted

much more than that of the other parameters. The results are provided in Table B-5. Note that the fraction of soluble solids was approximately 70 percent that determined from the core samples. As has been discussed, however, the tank U-107 composite used for dissolution studies had substantially more phosphate and metal analytes than the top solids layer from the core samples.

B4.3 WASTE SOLUBILITY DEPENDENCE ON TEMPERATURE

The Environmental Simulation Program (ESP) was run for the top layer of waste at 50 °C and compared to the 25 °C results to determine which solubilities were most affected by temperature. The total solids volume fraction decreases from 36 percent to 31 percent as a result of the temperature increase. As a result, the water fraction in the liquid decreases from 52.4 wt% to 47.5 wt%.

The Environmental Simulation Program (ESP) predicts that at the higher temperature all of the $Al(OH)_3$ is dissolved and is found in the form of a hydroxide complex, $Al(OH)_4^-$. Because hydroxide was consumed to form the complex, the pH of the liquid is lower, which decreases the solubility of the trace solids $KAlSiO_4$ and $Ni(OH)_2$. However, these have little effect on the amount or behavior of solids. Some major solids dissolve at the higher temperature: 47 percent of the $Na_3PO_4 \cdot 8H_2O$ dissolves and the rest shifts to $Na_3PO_4 \cdot 6H_2O$, 8.9% of the solid $NaNO_3$ dissolves, and 1.1 percent of the solid $Na_2C_2O_4$ dissolves. A small amount of carbonate and sulfate precipitate as $Na_6(SO_4)_2CO3$, which makes up an estimated 0.8 wt% of the dry solids at 50 °C.

In general, the solids whose solubility is most increased by a temperature increase are the more significant low-solubility solids, $Al(OH)_3$ and $Na_3PO_4 \cdot 8H_2O$. However, it should be noted that these are also the solids that are most likely to reprecipitate as gels if the temperature is lowered (for example, potentially in the transfer line).

Table B-4. Results of Tank 241-U-107 Composite Dissolution Tests

	1st Contact	2nd Contact	3rd Contact	4th Contact	5th Contact
Cumulative diluent volume added per original sample volume	0.88	1.70	2.50	3.34	4.19
Cumulative decantable liquid generated per diluent volume added	1.32	1.25	1.23	1.21	1.17
Volume of centrifuged solids as fraction of original sample volume	0.63	0.46	0.31	0.15	0.13
Density of liquid	1.42	1.14	1.12	1.08	1.07
Water wt% of liquid	49.9	83.6	88.0	87.3	96.6
Density of centrifuged solids	1.54	1.50	1.41	1.47	1.20
Hydroxide concentration (g/L)	8.4	3.3	1.6	1.3	
Percent of NO_3^- removed	82.7	97.7	99.5	99.9	100
Percent of NO_2^- removed	81.9	97.1	99.8		100
Percent of K^+ removed	84.6	100			
Percent of SO_4^{2-} removed	73.7	95.1	98.7		99.5
Percent of Cl^- removed	55.2	69.0	99.6		100
Percent of F^- removed	58.6	76.6		91.7	100
Percent of PO_4^{3-} removed	5.1	18.7	48.8	85.8	98.6
Percent of Si removed	58.0	71.1	78.7	83.8	90.9
Percent of ^{99}Tc removed	61.6	76.4	80.1	82.0	82.5
Percent of TIC removed	65.7	79.9	80.6	81.6	82.1
Percent of ^{137}Cs removed	60.1	71.9	73.6	74.0	74.3
Percent of TOC removed	40.4	63.5		64.7	66.4
Percent of Al removed	44.6	53.2	54.6	55.0	55.3
Percent of Cr removed	8.8	14.3	15.6	16.0	16.2
Percent of $^{89/90}Sr$ removed	2.2	2.5	2.6	2.7	2.7
Percent of gross alpha removed					0.48

Table B-5. Conceptual Model Results for Tank 241-U-107 Composite Dissolution Tests

Parameter	Value
Liquid density (g/mL)	1.45
Bulk degassed waste density (g/mL)	1.76
Mass fraction of water in liquid	0.49
Mass fraction water in degassed waste	0.23
Dry solids volume fraction in degassed waste	0.43
Dry solids density (g/mL)	2.19
Dissolved solids density (g/mL)	2.6
Fraction of solids that is soluble	0.53
Volume of dry solids dissolved per unit volume of water	0.39

B5.0 SPECIFIC WASTE PROPERTY ISSUES

Several concerns have been expressed about changes in the waste behavior or composition resulting from top-down water addition. These include sodium phosphate precipitation, caustic depletion, radionuclide concentration, and flammable gas releases. The initial evaluation outlined below indicates none of these effects is likely to be hazardous.

B5.1 PHOSPHATE PRECIPITATION

The dissolution data show that the first action of water on the waste will be to leach sodium nitrate out of the solids, as well as mixing with and diluting interstitial liquid. As the water moves down through the waste, it will leave behind a layer of solids that are increasingly rich in sodium phosphate. When water flows down through the top layer of nitrate-poor sodium phosphate, it will dissolve the phosphate salt and carry it in solution down into lower layers that are still nitrate-rich. At that point, the sodium phosphate will come out of solution as the nitrate dissolves. Therefore, there will consistently be a high-phosphate layer at the top of the waste.

Much the same will be true if the water runs over the surface of the waste rather than sinking in. Phosphate will be left behind, then be carried down in solution to parts of the waste surface or saltwell screen where nitrate is still in contact with the liquid, and finally reprecipitate there.

The phosphate layer may not be readily drainable, based on the apparent high liquid retention seen in laboratory dissolution. Therefore, a situation could arise where water added on top of the waste would run off because the top phosphate layer was saturated, making lower waste difficult to dissolve.

B5.2 CAUSTIC DEPLETION

Hypothetically, the addition of water to the waste could leave behind a dilute low-pH layer at the top of the tank, which could lead to enhanced tank wall corrosion. However, the tank U-107 composite dissolution data (Table B-3) show that even when the dilution ratio was 3.3:1 (by volume), the OH^- concentration still exceeded 0.01 M. The remaining PO_4^{3-} ion would tend to buffer the pH at 12 to 12.5, making it difficult to decrease the pH by dilution alone.

B5.3 RADIONUCLIDE CONCENTRATION

Another hypothetical issue is the concentration of insoluble transuranic (TRU) isotopes in the waste as more soluble waste constituents are dissolved and removed. As can be seen in Table B-3, only about 0.5 percent of the gross alpha in the tank U-107 composite was removed by water dissolution, while the overall solids volume was reduced by a factor of about eight. This implies that TRU solids would not dissolve and could be concentrated by a factor of eight in the part of the tank affected by the dissolution test. A greater degree of concentration is unlikely. Only a little volume reduction occurred between the 4th and 5th diluent contacts; therefore, greater dilution would not produce substantially greater dissolution and volume reduction.

Most of the core samples contained gross alpha concentrations of 0.1 μCi/g or less. There were some exceptions, all located below 85 in. elevation: samples 134:04 (lower half), 134:05, 242:06, 242:07, 242R:08, and 245:05. These samples generally contained higher Al, Fe, and Cr than the samples with low gross alpha. The highest gross alpha concentration measured in any tank U-107 sample was 2.05 μCi/g in sample 242:07 (average elevation 39 in.).

B5.4 FLAMMABLE GAS RELEASES

Gas releases induced by saltwell pumping have been detected in several other U-farm tanks. The maximum hydrogen concentrations are summarized in Table B-6 (McCain 2000). The highest release of 4,930 ppm of hydrogen represents 12 percent of the lower flammability of hydrogen (40,000 ppm). The releases in the other U-tanks occurred relatively soon after saltwell pumping began, approximately when nearly all the supernatant has been removed. If this behavior is a pattern for tank U-107, an elevation of the hydrogen concentration on the order of 5,000 ppm can be expected in the first month of pumping.

Over the course of pumping, U-103 released 50 to 70 percent of its estimated gas content while tank U-105 released 14 to 24 percent of its gas, assuming it has the same fraction of hydrogen as measured by the RGS in tank U-103 (Johnson et al. 2001). Tank U-107 might be expected to release on the order of 50 percent of its retained gas based on this range of experience.

Water addition on top of the waste during pumping is expected to release all of the gas in the waste in which soluble solids are dissolved. Therefore, if the dissolution process were carried on to the entire tank, the total gas release would be higher than by saltwell pumping alone.

However, since the lighter dissolution water cannot penetrate the heavy brine below the interstitial liquid level, dissolution is not expected to cause larger episodic releases than would be induced by pumping alone.

Table B-6. Peak Hydrogen Concentrations during Saltwell Pumping in U-Farm Tanks

Tank	Pumping Start Date	Peak Hydrogen Concentration (ppm)	Date of Peak Concentration	Elapsed Time Since Pumping Start (days)
U-102	1/20/00	3,280	2/24/00	35
U-103	9/26/99	4,870	11/2/99	37
U-105	12/11/99	~1,600	~2/15/00	66
U-109	3/11/00	4,930	3/23/00	12

B6.0 REFERENCES

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APPENDIX C

DERIVATION OF TANK 241-U-107 DISSOLUTION METRICS

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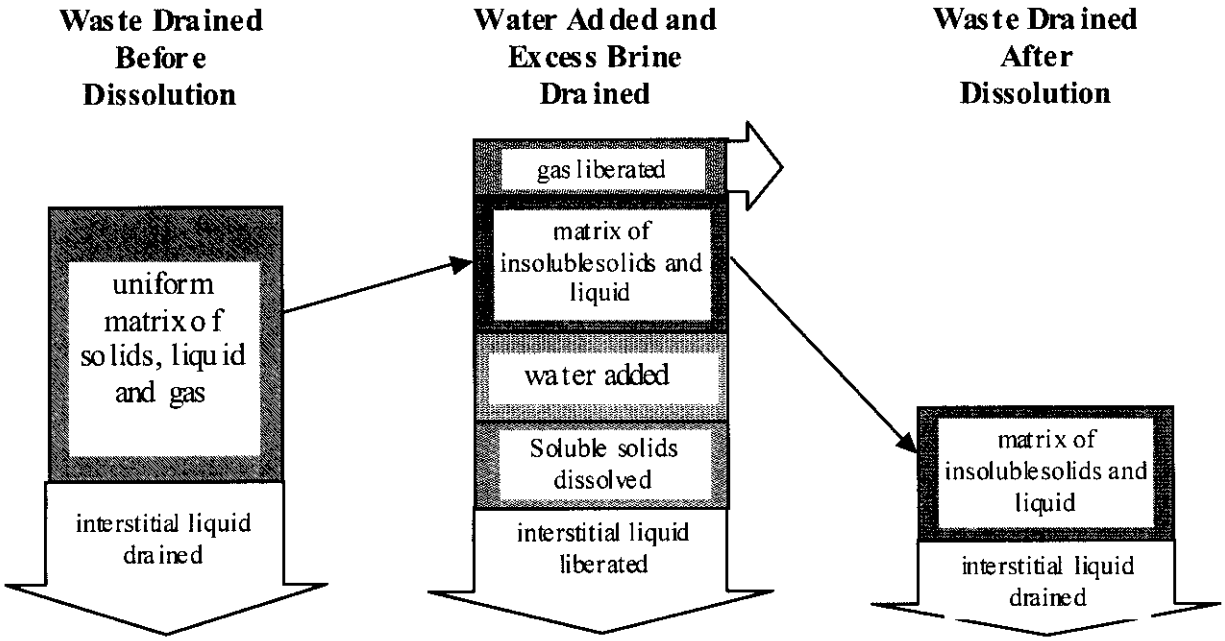
DERIVATION OF TANK 241-U-107 DISSOLUTION METRICS

The dissolution process is described by a general volume balance that tracks the disposition of the primary components of the waste. These include the insoluble and soluble solids, interstitial liquid, retained gas, and added water. During dissolution, soluble solids pass into the liquid and gas is released. The insoluble solids form a new bed of waste and the drainable fraction of the interstitial liquid and all new brine generated by dissolution drains away. The partitioning of these components for a specific tank is described in terms of solid and liquid waste densities and volume fractions derived from core sample analyses and dissolution tests on waste samples. The designation "soluble" and "insoluble" should be considered relative. "Soluble" solids are those that can be expected to dissolve during the transit time of the water to the saltwell screen. Some of the "insoluble" solids would dissolve if in contact with water for a longer time.

The model described in this section is basically a bookkeeping tool for the portion of the waste being dissolved. The initial physical configuration is assumed to be a uniform bed of waste consisting of soluble and insoluble solids, saturated liquid, and gas bubbles. The drainable liquid is removed so the diluent can penetrate. Added water is assumed to dissolve soluble solids sufficient to acquire a specified brine density. All of the retained gas is assumed to be liberated into the tank headspace during dissolution. Some of the brine created by dissolution, consisting of the interstitial liquid liberated during dissolution, added water plus dissolved solids, forms the interstitial liquid in the insoluble bulk waste matrix remaining. The excess brine is assumed to drain away. The drainable liquid is assumed to leave the remaining waste after dissolution. This process is illustrated in Figure C-1.

Figure C-1. Physical Representation of Dissolution Process



The waste prior to dissolution and the insoluble waste remaining after dissolution are described in terms of densities and volume fractions. The specific input parameters are as follows. The subscripts 0 and 1 refer to the initial and final waste condition, respectively:

α_0	volume fraction of gas in bulk waste (includes gas both in the form of bubbles and pore space if unsaturated) [12]
ϕ_{S0} , ϕ_{S1}	volume fraction of dry solids in bulk degassed waste
χ_{WL0}	mass fraction of water in the pre-dilution interstitial liquid
ρ_W	density of water diluent
ρ_0, ρ_1	density of bulk degassed waste
ρ_{L0}, ρ_{L1}	density of interstitial liquid
ρ_{SS}	density of dry soluble solids
F_{SS}	volume fraction of dry solids that are soluble
F_{D0}, F_{D1}	volume fraction of drainable liquid in bulk degassed waste

All quantities are referenced to a unit volume of water added. The volume of soluble solids dissolved and the volume of brine produced by dissolution per unit volume water added are related directly to the volume fraction of water in the liquid at saturation after dissolution of the main soluble components. The mass fraction of water in the bulk degassed waste is determined by

$$\chi_{W0} = \chi_{WL0} \frac{\rho_{L0}}{\rho_0}(1-\phi_{S0}) \tag{C-1}$$

The volume fraction of water in the pre-dilution interstitial liquid is given by

$$\phi_{WL0} = \frac{\chi_{W0}\rho_0}{(1-\phi_{S0})\rho_W} \tag{C-2}$$

The density of solids dissolved in the liquid can be calculated from the water volume fraction and the liquid density by

$$\rho_{SD} = \frac{\rho_{L0} - \phi_{WL0}\rho_W}{1-\phi_{WL0}} \tag{C-3}$$

[12] If ϕ_{PL} is the fraction of pore space volume occupied by liquid in unsaturated waste, the equivalent bulk gas volume fraction is given by:

$$\alpha = (1-\phi_S)(1-\phi_{PL})$$

Assuming that the density of the dissolved solids in the liquid does not change as the most soluble solids dissolve, the volume fraction of water in the liquid after dissolution can be computed from the densities with the following:

$$\phi_{WL1} = \frac{\rho_{SD} - \rho_{L1}}{\rho_{SD} - \rho_W} \tag{C-4}$$

The volume, β_{DL}, of liquid produced per unit volume of water added by dissolution only, including the water volume, is simply the inverse of ϕ_{WL1}. Other quantities describing the dissolution process can be quantified based on β_{DL} and other inputs. The dissolution parameters are summarized in the following list:

a. Volume of liquid produced per unit volume of water added:

$$\beta_{DL} = \frac{1}{\phi_{WL1}} \tag{C-5a}$$

b. Volume of dry soluble solids dissolved per unit volume of water added:

$$\beta_{SS} = \beta_{DL}\left(1 - \phi_{WL1}\right)\frac{\rho_{SD}}{\rho_{SS}} = \left(\beta_{DL} - 1\right)\frac{\rho_{SD}}{\rho_{SS}} \tag{C-5b}$$

c. Volume of original bulk waste in which soluble solids are dissolved per unit volume of waster added (i.e., volume of original waste affected by dissolution):

$$\beta_{BW} = \frac{\beta_{SS}}{\phi_{S0}F_{SS}\left(1 - \alpha_0\right)} \tag{C-5c}$$

d. Volume of dry insoluble solids remaining per unit volume of water added:

$$\beta_{IS} = \beta_{BW}\left(1 - \alpha_0\right)\phi_{S0}\left(1 - F_{SS}\right) = \beta_{SS}\frac{\left(1 - F_{SS}\right)}{F_{SS}} \tag{C-5d}$$

e. Volume of bulk insoluble waste remaining after dissolution per unit volume of water added:

$$\beta_{IW} = \frac{\beta_{IS}}{\phi_{SI}} \tag{C-5e}$$

f. Volume of drainable interstitial liquid removed from original waste prior to or during dissolution per unit volume of water added:

$$\beta_{LR0} = \beta_{BW} F_{D0} \tag{C-5f}$$

g. Volume of drainable interstitial liquid removed from bulk insoluble waste after dissolution per unit volume of water added:

$$\beta_{LRI} = \beta_{IW} F_{DI} \tag{C-5g}$$

h. Total volume of liquid created by dissolution to be removed by pumping (original interstitial liquid volume plus brine created by dissolution, less interstitial liquid in remaining waste after draining) per unit volume of water added.

$$\beta_{LR} = \beta_{BW}\left(1-\alpha_0\right)\left(1-\phi_{S0}\right)+\beta_{DL}-\beta_{IW}\left(1-\phi_{SI}-F_{DI}\right) \tag{C-5h}$$

i. Total volume of excess drainable liquid created by dissolution in excess of that which would have been removed by saltwell pumping per unit volume of water added.

$$\beta_{XL} = \beta_{LR} - \beta_{BW} F_{D0} \tag{C-5i}$$

The volume of liquid actually entering the double-shell tanks is greater than calculated by Equation C-5h or C-5i. The density of the liquid created is likely to be greater than desired for pumping through the transfer line. Further dilution water is added in the saltwell screen at the inlet of the jet pump to reduce the density to the target value in the transfer line. The in-line dilution ratio (volume of water added to incoming liquid volume) can be calculated from the post-dilution liquid density and the target density by

$$D = \frac{\rho_{LI} - \rho_{target}}{\rho_{target} - \rho_W} \tag{C-6}$$

The total volume of liquid and the volume in excess of that initially drainable that would be transferred out of the tank per unit volume of water added including the in-line dilution become, respectively,

$$\beta_{TLR} = \beta_{LR}(1+D) \tag{C-7a}$$

and

$$\beta_{TXL} = \beta_{XL}(1+D) \tag{C-7b}$$

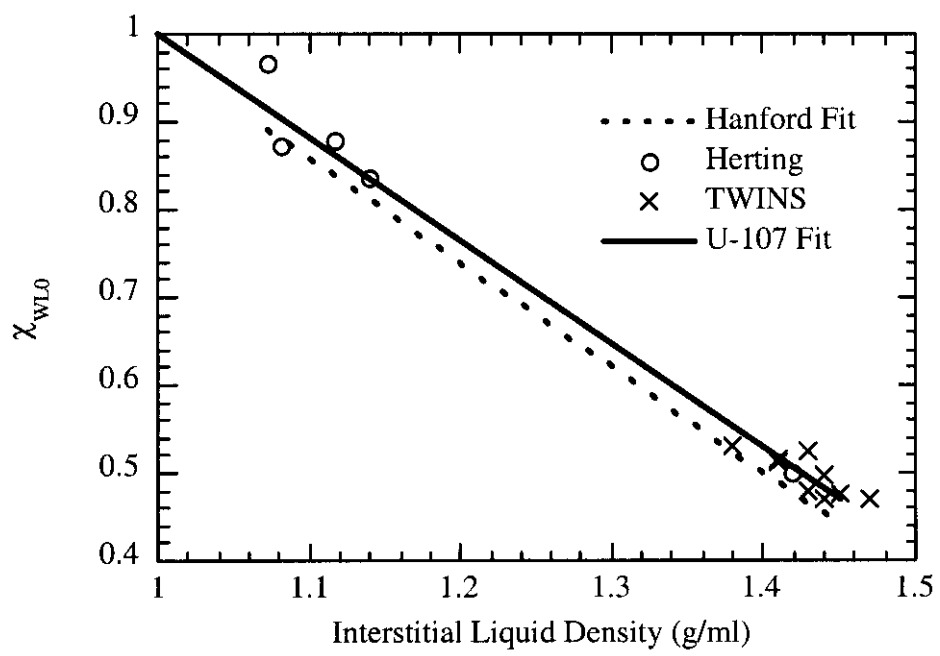
Application to Tank 241-U-107 Dissolution

The waste in tank U-107 is currently liquid-saturated and its properties are reasonably well described by the core sample analysis results from 1996-98 sampling events (TWINS) and other data (Hedengren et al. 2001). Additional data are available from dissolution tests on a tank U-107 composite sample by Herting.[13]

The mass fraction of water in the pre-dilution interstitial liquid is determined using the core sample data describing the mass fraction of water as a function of the interstitial liquid density. These data, as well as data from the dissolution tests and the fit from numerous concentrated solutions at the Hanford Site (including both single and double-shell tanks), are shown in Figure C-2. The results from the Hanford Site data have been successfully used for tank SY-101 (Rassat et al. 2000). However, the Hanford fit under-estimates the mass of water in the liquid as compared to the U-107 data from Herting and TWINS. Therefore, a fit to the tank U-107 data was used for this analysis and is described by

$$\chi_{WL0} = 1.1729\rho_{L0} + 2.1703 \tag{C-8}$$

Figure C-2. Mass Fraction of Water in the Interstitial Liquid as a Function of the Interstitial Liquid Density



Uncertainties for the input parameters are determined from the data sources, and uncertainties on the computed values are determined with a Monte Carlo simulation of the model. Both the

[13] Letter, D. L. Herting to D. G. Baide, February 12, 2001, subject: *Saltcake Dissolution Volume Results, Tank 241-U-107*, FH-0100932, Fluor Hanford, Richland, Washington.

inputs and outputs were constrained within physical limits in the simulation. The dry solids density (Equation C-9) was constrained to be between the product of the fraction of the solids that is soluble and the soluble solids density, and the soluble solids density. This constraint is based on the solid composition (see Table B-3, Appendix B). Output constraints included: limiting the insoluble solid density (Equation C-10) to be greater than the liquid density; limiting the volume of brine created by dissolution only per volume of water added (Equation C-5a) to be greater than 1.0; setting Equations C-5b through C-5f greater than zero; limiting all fractions to between zero and one; and constraining the dissolved solid density to be between the soluble solids density and 3.0 g/mL. The latter constraint was imposed based on the typical density increase of soluble salts upon dissolution.

The initial waste description is summarized in Table C-1. The point values are the medians. The range indicates the entire range (100 percent interval) of the inputs and the 95 percent confidence interval for the computed values. Distributions for the inputs are also included in the table.

Table C-1. Pre-Dissolution Waste Description for Tank 241-U-107

Parameter	Symbol	Value (range) Distribution
Input Values		
Gas volume fraction	α_0	0.17 (0.08-0.26) Uniform
Dry solids volume fraction in degassed waste	ϕ_{S0}	0.37 (0.30-0.45) Log-Normal
Fraction of solids that is soluble	F_{SS}	0.84 (0.60-0.90) Log-Normal
Liquid density (g/mL)	ρ_{L0}	1.44 (1.38-1.48) Log-Normal
Bulk degassed waste density (g/mL)	ρ_0	1.71 (1.61-1.81) Log-Normal
Dry soluble solids density (g/mL)	ρ_{SS}	2.21 (2.00-2.26) Triangular
Volume fraction drainable liquid in waste	F_{D0}	0.25 (0.20-0.30) Triangular
Computed Values		
Mass fraction of water in liquid	χ_{WL0}	0.48 (0.44-0.52)
Mass fraction water in degassed waste (Eq. C-1)	χ_{W0}	0.25 (0.22-0.28)
Volume fraction of water in original liquid (Eq. C-2)	ϕ_{WL0}	0.69 (0.65-0.73)
Dissolved solids density (g/mL) (Eq. C-3)	ρ_{SD}	2.42 (2.36-2.51)
Dry solids density (g/mL) (Eq. C-9)	ρ_{S0}	2.15 (2.03-2.24)
Dry insoluble solids density (g/mL) (Eq. C-10)	ρ_{IS}	1.90 (1.58-2.20)

Notes:

Eq. = Equation

The computed values are shown in the table because they are used in subsequent calculations or to check the consistency of the input values. The dry solids density (including both soluble and insoluble solids) and the dry insoluble solids density are given, respectively, by the following two equations:

$$\rho_{S0} = \frac{\rho_0 - (1 - \phi_{S0})\rho_{L0}}{\phi_{S0}} \tag{C-8}$$

$$\rho_{IS} = \frac{\rho_{S0} - F_{SS}\rho_{SS}}{(1 - F_{SS})} \tag{C-9}$$

The post-dissolution waste properties are much more uncertain. In the tank, dilution water will be added slowly to unsaturated waste. The most soluble species will dissolve immediately and drain away with the saturated brine. The less-soluble solids will settle while being continually exposed to fresh water. Therefore, the effective water contact time with the waste will vary greatly with depth. Assuming the solid volume fraction remains constant, however, yields densities consistent with those found in Herting's dissolution tests. Table C-2 shows the post-dissolution input and computed parameter values.

Table C-2. Post-Dissolution Waste Description for Tank 241-U-107

Parameter	Symbol	Value (Range) Distribution
Input Values		
Liquid density (g/mL)	ρ_{L1}	1.42 (1.36-1.46) Log-Normal
Bulk degassed waste density (g/mL)	ρ_1	1.54 (1.49-1.59) Triangular
Target density for transfer	ρ_{target}	1.30
Volume fraction drainable liquid in waste	F_{D1}	0.10 (0.05-0.15) Uniform
Computed Values		
Volume fraction of water in liquid (Eq. C-4)	ϕ_{WL1}	0.71 (0.68-0.73)
In-line dilution ratio (Eq. C-6)	D	0.40 (0.29-0.50)
Dry (insoluble) solids density (g/mL) (Eq. C-10)	$\rho_{S1} = \rho_{IS}$	1.90 (1.58-2.20)
Volume fraction of dry solids in bulk waste (Eq. C-11)	ϕ_{S1}	0.26 (0.13-0.78)
Mass fraction of water in bulk waste remaining (Eq. C-12)	χ_{W1}	0.34 (0.10-0.40)
Vol. fraction of pores with liquid after draining (Eq.C-13)	ϕ_{PL1}	0.86 (0.54-0.93)

Several values are computed somewhat differently than for input. The dissolved solids density was computed with Equation C-3 and the volume fraction of water in post-dissolution liquid via Equation C-4. The dry solids volume fraction is a pre-dissolution input. The post-dissolution

dry solids volume fraction is derived from the definition of the bulk density assuming the dry insoluble solids density does not change. It is expressed as

$$\phi_{SI} = \frac{\rho_I - \rho_{LI}}{\rho_{IS} - \rho_{LI}} \tag{C-11}$$

The mass fraction of water in the bulk waste remaining is given by

$$\chi_{WI} = \phi_{WLI} \frac{\rho_W}{\rho_I}(1 - \phi_{SI}) \tag{C-12}$$

The volume fraction of liquid within the pore space of the bulk insoluble waste after draining is computed from the fraction of the total liquid that is drained by

$$\phi_{PLI} = 1 - \frac{F_{DI}}{1 - \phi_{SI}} \tag{C-13}$$

The equivalent bulk gas volume fraction after draining is exactly equal to F_{DI}.

The results of dissolution defined by Equations C-5a to C-5i are given in Table C-3.

Table C-3. Dissolution Metrics for Tank 241-U-107 Waste

Parameter per unit volume of water added	Symbol	Value (Range)
Volume of liquid created by dissolution only	β_{DL}	1.42 (1.36-1.47)
Volume of dry soluble solids dissolved	β_{SS}	0.46 (0.41-0.52)
Volume of bulk waste in which solids are dissolved	β_{BW}	1.83 (1.43-2.46)
Volume of dry insoluble solids remaining	β_{IS}	0.10 (0.05-0.25)
Volume of bulk insoluble waste remaining	β_{IW}	0.38 (0.10-1.19)
Reduction in bulk waste volume by dissolution	-	1.43 (0.86-1.97)
Volume of liquid drained from original waste	β_{LR0}	0.46 (0.34-0.64)
Volume of liquid drained from bulk insoluble waste	β_{LRI}	0.04 (0.01-0.13)
Total volume of free liquid created by dissolution	β_{LR}	2.15 (1.71-2.53)
Total volume of free liquid created in excess of SWP	β_{XL}	1.69 (1.24-2.00)

Notes:
SWP = saltwell pumping

To illustrate the range of the results for the volume of bulk waste in which solids are dissolved per unit volume of water added, the distribution is shown in Figure C-3. The distribution for the total volume of free liquid created by dissolution per unit volume of water added is shown in Figure C-4.

Figure C-3. Distribution of the Volume of Bulk Waste in which Solids are Dissolved per Unit Volume of Water Added

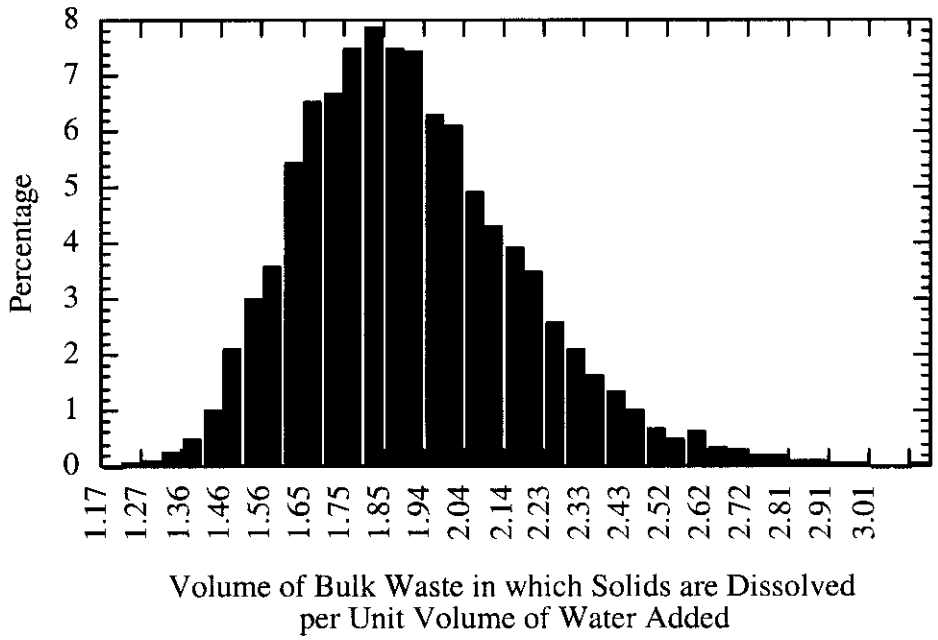
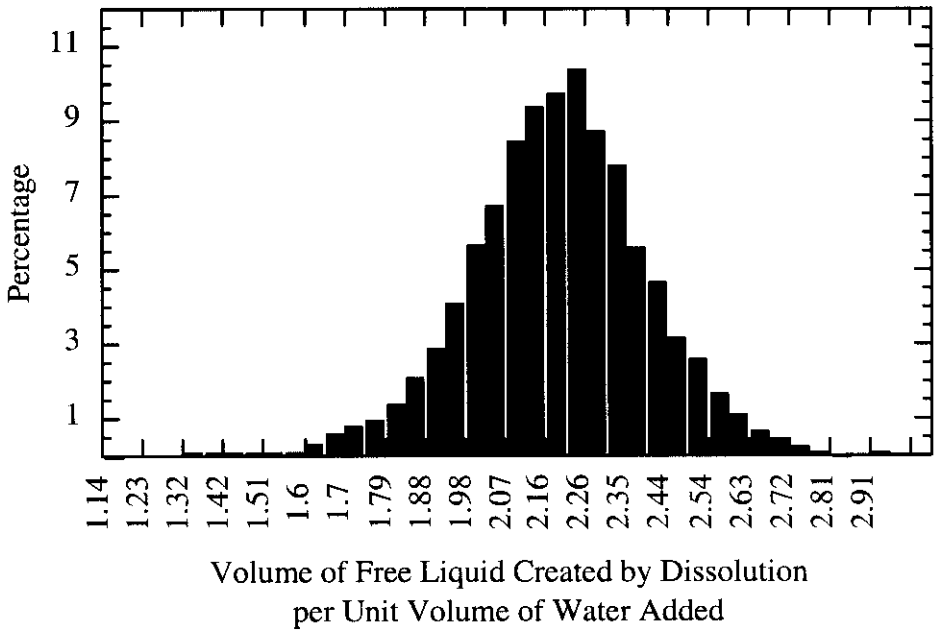


Figure C-4. Distribution of the Total Volume of Free Liquid Created by Dissolution per Unit Volume of Water Added



A target value of 100,000 gallons of brine has been established that is to be transferred to the double-shell tanks during the proof-of-concept demonstration. The minimum volume of water that must be added to reach this target can be calculated by dividing 100,000 gallons by the total feet liquid created per unit volume of water added and including the required in-line dilution water.

$$V_{AddedWater} = \frac{V_{BrineTarget}}{(1+D)\beta_{LR}} \tag{C-14}$$

At the same time, a maximum 100,000 gallons of brine over and above what would be drained during saltwell pumping has been allocated in the double-shell tank system to accommodate this test. The maximum volume of water to be added to stay within this constraint is given by

$$V_{MaxWater} = \frac{V_{BrineLimit}}{(1+D)\beta_{XL}} \tag{C-15}$$

The global effects of dissolution can be determined from the total volume of water added and the metrics in Table C-3. These values are shown in Table C-4 in both gallons and inches (over the entire tank area). It appears that the progress of saltwell pumping may limit the amount of water that can be effectively used. The 33 to 43 kgal of water to be added will theoretically dissolve 22 to 28 inches of bulk waste over the entire tank area. The water addition system to be installed will apply water to only 1/2 to 2/3 of the tank area. Based on the progress of saltwell pumping in other tanks, it is doubtful that much more than 20 inches of unsaturated waste can be provided during the duration of the demonstration. Therefore, water addition may be limited by the waste available for it to penetrate.

Table C-4. Dissolution Volumes for at Least 100,000 gallons of Total Brine but Less than 100,000 Gallons in Excess of Drainable Liquid

Quantity [kgal (inches)] {Range (kgal)}	Limits	
	100 kgal total brine	100 kgal above drainable
Volume of water to be added	33.4 (12.1) {27.2-41.8}	42.6 (15.5) {34.6-56.9}
Volume of brine produced by dissolution only	47.3 (17.2) {39.4-58.6}	60.1 (21.9) {50.0-80.8}
Net volume of brine liberated and drained	24.4 (8.9) {12.2-31.2}	31.0 (11.3) {16.7-40.0}
Volume of in-line dilution water added	28.6 {22.6-33.5}	28.6 {22.6-33.5}
Volume of bulk original waste dissolved	60.7 (22.1) {49.9-84.9}	77.1 (28.0) {60.6-121.9}
Volume of bulk insoluble waste remaining	12.6 (4.6) {3.2-45.1}	16.0 (5.8) {4.0-64.2}
Reduction in bulk waste volume by dissolution	47.2 (17.2) {34.4-57.1}	60.1 (21.9) {45.1-75.4}

The distributions for the volume of water to be added under the limits of 100 kgal total brine and 100 kgal above drainable are shown in Figures C-5 and C-6, respectively.

Figure C-5. Volume of Water to be Added for 100 kgal of Total Brine

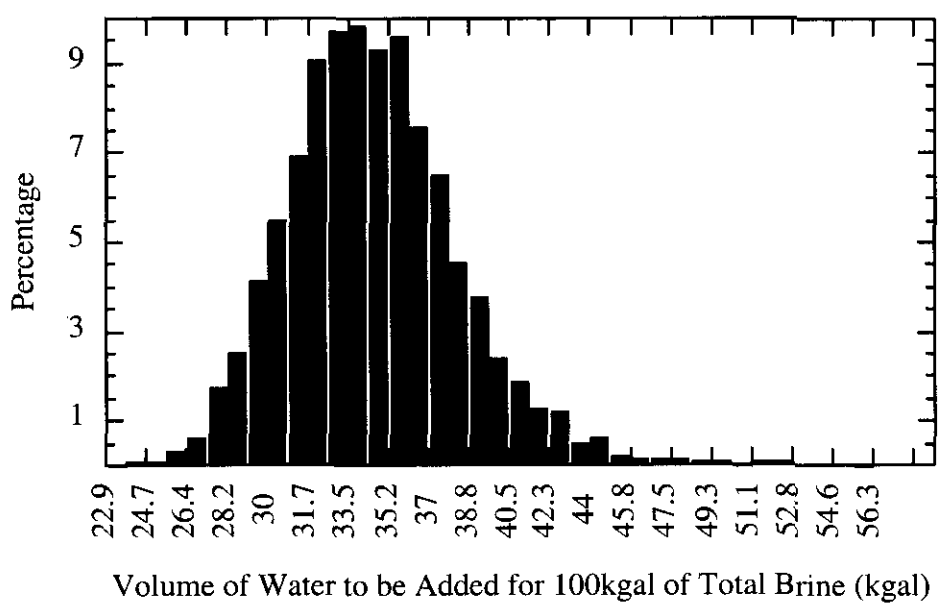
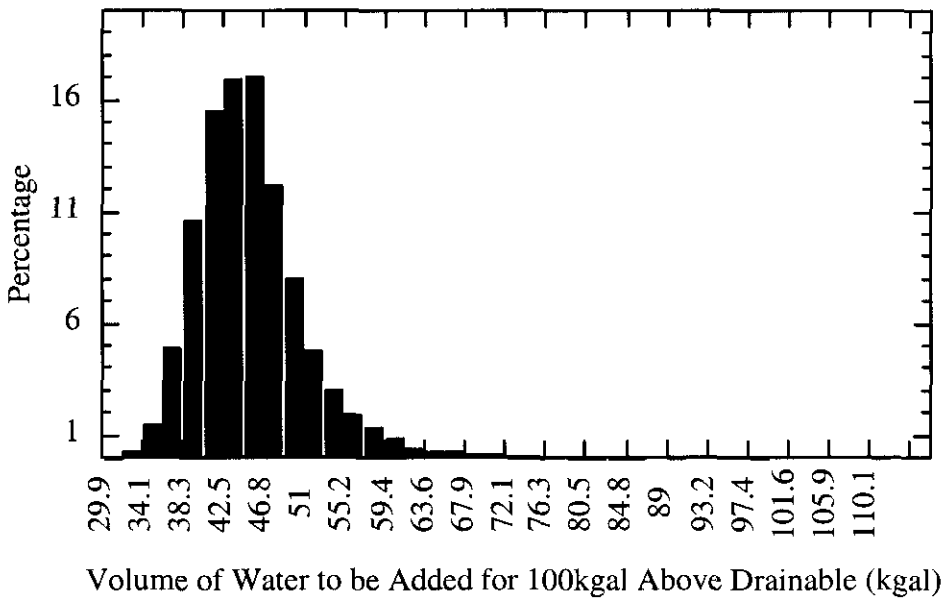


Figure C-6. Volume of Water to be Added for 100kgal Above Drainable



A somewhat different picture appears when considering how the entire waste volume in the tank might dissolve. Excluding supernatant, there is about 338 (325-350) kgal of bulk solids in tank U-107. Assuming the waste is uniform and that all of it can be drained, the dilution water required to dissolve this waste can be estimated by dividing the bulk waste volume by the volume of waste dissolved per unit volume of water added, β_{BW} (Equation C-5c). The result is that 184 (137-238) kgal of water will theoretically dissolve all the soluble salts in the tank leaving about 70 (20-184) kgal or 25 inches of insoluble waste. Including the in-line dilution, the operation would transfer 555 (396-681) kgal of brine to the double-shell tanks.

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