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2	1	Cog. Eng. D.G. Baide		6-12-03	57-70						
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Tank 241-U-107 Saltcake Dissolution Proof-of-Concept Retrieval Demonstration Operational Results

D. G. Baide
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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Abstract: This document presents the results of the salt cake dissolution proof-of-concept retrieval demonstration conducted in tank 241-U-107. A water distribution system was operated in conjunction with the interim stabilization saltwell pumping equipment to retrieve and remove additional waste from the tank.

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D. G. Baide
W. B. Barton

CH2M HILL Hanford Group

L. A. Mahoney
B. E. Wells
S. A. Hartley
J. L. Huckaby

Pacific Northwest National Laboratory

EXECUTIVE SUMMARY

Between December 2002 and February 2003, a partial proof-of-concept demonstration of waste retrieval by saltcake dissolution was carried out in tank 241-U-107 (U-107). Water was sprayed on the surface of the waste in tank U-107 to dissolve water-soluble salts, and as the resulting brine drained to a central saltwell, it was pumped out of the tank. The primary objective of the demonstration was to reduce the technical uncertainties of dissolution operations in future retrievals, including those scheduled for tanks 241-S-112 (S-112) and 241-S-102. Tank U-107 was chosen for the demonstration because the tests could be scheduled together with the removal of drainable liquids from the tank for interim stabilization, it had a high content of long-lived mobile radionuclides, and the waste composition and configuration were reasonably typical of the tanks that are to be fully retrieved in the near term.

The demonstration, as originally planned, included tests of water application methods ranging from narrowly focused sprays to a gentle, "sprinkler" spray over a broad area. A total of 10,601 gal of water was sprayed. Because of constraints imposed by a pre-existing transfer-line restriction and by simultaneous interim stabilization of tanks 241-U-108 and 241-U-111, the demonstration was terminated before the broad-area application methods were tested. Therefore, the results given in this document do not include the full range of methods.

The same operational constraints lowered the rate at which liquid could be pumped from the tank, so that on average one day of water addition was followed by five days of pumping to remove the added volume. The uninterrupted water addition that had been planned was not possible.

The data for the tests that were completed showed that local, focused sprays tended (as was expected) to result in the runoff of liquid that was not completely saturated with dissolved salts. The runoff from one spray area, near the tank wall, cut a channel in the waste surface to the central saltwell.

Primarily as a result of runoff, the dissolution brine (the liquid produced solely by dissolution, not including liberated interstitial liquid) was less than half saturated with dissolved salts. Based on a Monte Carlo simulation of a material balance on the liquid flows, the median estimate of the dissolution brine saturation during the demonstration period (December 2002 through February 2003) was 45 percent of the theoretical value. This calculation of saturation (and all other measures of waste removal) depended strongly on measurements of the liquid specific gravity in the saltwell.

The large uncertainty in the interpretation and measurement of the specific gravity produces a corresponding uncertainty in all of the waste removal estimates. Much of the uncertainty comes from the assumption that the in-line dilution water (which is injected near the pump inlet and the specific gravity instrument) could have mixed with other saltwell liquid and affected (reduced) the measured specific gravity. This assumption

could have led to an overestimation of the brine saturation, but was required because of limitations of the existing instrumentation. The uncertainty also results from an assumption, unavoidable in the absence of chemical analyses of concurrent grab samples, that low specific gravity reflected subsaturation in all the waste salts, rather than saturation in the less soluble salts such as sodium phosphate. The latter situation might have arisen in the latter part of the test, if the added water came into contact only with waste that had already been leached of sodium nitrate.

Assuming complete saturation of the dissolution brine, the water-application tests that were performed would in theory have removed 19,100 gal of bulk waste (including the pre-existing void volume) and produced 21,900 gal of total brine (including both dissolution brine and interstitial liquid, but excluding in-line dilution). The actual total brine production between December 3, 2002, and February 28, 2003 was estimated at 4,260 gal of dissolution brine and 13,180 gal of interstitial liquid (median values). The estimated median volume of removed bulk waste was 1,780 gal. Given this limited bulk waste volume, most of the interstitial liquid removed is attributable to drainage unassociated with dissolution. As of the end of February 2003, the median total dissolution water removed was 3,890 gal, less than half of the added water. Interim stabilization pumping was still removing dissolution water (and the waste dissolved in it) three weeks after the end of spraying. Therefore, the total amount of waste removed by dissolution could be more than twice as high as that measured at the end of February, considering the dissolution water that remained to be removed and the possibility of higher saturation in later-removed brine.

An analysis of the waste temperatures during the demonstration showed that the endothermic dissolution of salts (primarily sodium nitrate) caused the local temperature to drop to 5 °C (42 °F), which was 10 °C (18 °F) below the spray water temperature and 20 °C below the waste temperature. This cooling could have worked together with runoff in reducing the brine saturation; most of the sodium salts are less soluble at lower temperatures.

The demonstration, as planned, employed not only the standard instrumentation in the tank and in the interim stabilization system, but two new instruments. One was the Topographic Mapping System (TMS), which had been successfully deployed at Oak Ridge and tested at the Hanford Site before installation in tank U-107. Because of problems with assembly, it was not functional after installation in the tank, so volume changes at the waste surface could not be measured quantitatively. The other new instrument, which was still considered to be in development, was a gamma monitor on the transfer line. Although the instrument was not calibrated, it showed trends in the concentration of gamma radiation that were qualitatively useful in interpreting saltwell specific gravity measurements.

In general, the results for the tests that were completed matched the qualitative expectations, with runoff occurring because of the high local water application rates and with undersaturation of the brine as the result. The latter tests in the planned demonstration, which were not performed, would have applied water at lower intensity, a

more likely approach for actual retrieval operations. Because the extent of runoff depends strongly on the rate of water application per unit area, among other factors, completion of the demonstration is required to assess the effect of lower-intensity spraying that could allow water to percolate into the waste. If the remaining tests of the demonstration were performed, their usefulness would be enhanced by (1) allowing continuous pumping and (2) providing for some form of chemical analysis, with regular sampling being adequate for test purposes.

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TERMS

atm	atmosphere
CGM	combustible gas meter
CH2M HILL	CH2M HILL Hanford Group, Inc.
Ci	Curies
cm	centimeters
DOE	U.S. Department of Energy
DST	double-shell tank
Ecology	Washington State Department of Ecology
ESP	Environmental Simulation Program
ft	feet
ft^2	square feet

TERMS, Continued

ft^3	cubic feet
g/cc	grams per cubic centimeters
g/mL	grams per milliliter
gal	gallons
gpm	gallons per minute
HHF	hydrostatic head fluid
ILL	interstitial liquid level
in.	inches
kg/L	kilograms per liter
kg/m^3	kilograms per cubic meters
kgal	kilogallons
LFL	lower flammability limit
LOW	liquid observation well
m	meters
m^3	cubic meters
PCP	Process Control Plan
ppm	parts per million
RAS	radionuclide assessment system
scf	standard cubic feet
SGLS	spectral gamma logging system
SHMS	Standard Hydrogen Monitoring System
SpG	specific gravity
SWP	saltwell pumping
TIC	total inorganic carbon
TOC	total organic carbon
TMACS	Temperature Monitoring and Control System
TMS	Topographical Mapping System
TWINS	Tank Waste Information Network System
WFT	saltwell weight factor
yrs	years
°C	degrees Celsius
°F	degrees Fahrenheit
μCi/cc	
μCi/mL	
μg/mL	

1.0 INTRODUCTION

This document describes the methods for and outcome of saltcake dissolution proof-of-concept operations in tank 241-U-107 (U-107). Here, "saltcake dissolution" is defined as a method by which water-soluble salts will be retrieved from the Hanford Site radioactive waste tanks by dissolution, rather than sluicing or mechanical agitation, as the primary mobilizing mechanism.

Tank U-107 was identified as posing the highest long-term risk to the Columbia River of all single-shell tanks (SSTs) because of the tank's high content of mobile, long-lived radionuclides (^{99}Tc, ^{14}C, ^{79}Se, ^{129}I, ^{234}U, ^{235}U, and ^{238}U). In addition, the waste in tank U-107 was similar enough in composition to that in tank 241-S-112 (S-112) to make the U-107 proof-of-concept results applicable in predicting dissolution in the full-tank retrieval demonstration in tank S-112. (At the time the U-107 proof-of-concept was initiated, the S-112 retrieval was to be carried out by dissolution, but has subsequently been changed to a modified sluicing method.)

Tank U-107 was also an opportunistic choice because it was scheduled for interim stabilization at a time that would complement the proof-of-concept operational activities. Conducting the proof-of-concept operations concurrent with interim stabilization of the tank was more cost efficient. Coordinating the installation of saltwell pumping equipment with the installation of the saltcake dissolution water distribution system further reduced costs.

The proof-of-concept demonstration installed and operated a water distribution system to dissolve a portion of the saltcake and employed the standard interim stabilization system installed on tank U-107 to remove the brine produced. This proof-of-concept was expected to provide information on spray nozzle selection and effective spray patterns, and in-tank saltcake solubility data to help in the design of a full-tank retrieval demonstration system.

Saltwell pumping in tank U-107 began in August 2001, and continued with breaks in operations through November 2002. The start of proof-of-concept operations were initially delayed because of constraints imposed by a pre-existing transfer line blockage and by stabilization operations on other tanks required to reach a Consent Decree milestone for remaining pumpable liquids. The proof-of-concept demonstration was initiated in December 2002, and continued through February 2003 when a management decision to terminate the activity was made based on the need to perform a caustic chemical flush of the transfer line to alleviate the continuing blockage problem. Saltwell pumping recommenced at the end of February 2003 and is ongoing (May 2003).

1.1 BACKGROUND

The strategy for retrieval of wastes from the SSTs is to develop robust retrieval equipment and methods that, once demonstrated successfully, can be applied with minimal modifications to many tanks. The demonstration of a saltcake retrieval method was negotiated by CH2M HILL Hanford Group, Inc. (CH2M HILL), the U.S. Department of Energy (DOE), and the State of Washington Department of Ecology (Ecology) as the M-45-03C milestone of the Tri-Party Agreement:

> "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 leak detection monitoring and mitigation (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. When the U-107 proof-of-concept operations were first planned, CH2M HILL had selected saltcake dissolution as the retrieval method to be demonstrated in tank S-112 and to satisfy the M-45-03C milestone (CH2M HILL 2000). An acceleration of the schedule for complete retrieval of waste from tank S-112 has resulted in modifications of the retrieval equipment and methods to be used (Barton et al. 2003). The retrieval method to be used in S-112 is a modified sluicing method, which combines saltcake dissolution with water jets to erode and dissolve the saltcake. The effectiveness of this method in tank S-112 and subsequent tanks depends on the effectiveness with which the sluiced waste can be dissolved, so the overall results of the U-107 operations remain pertinent.

Large-scale retrieval by saltcake dissolution (whether accompanied by sluicing or not) has not been demonstrated in a Hanford Site waste tank. Accordingly, there are associated technical uncertainties:

- Does dissolution form deep ditches, caverns, or mounds, or damage suspended hardware by static loads of adhered waste masses or dynamic loads of shifting waste?

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

- Will process operations control be impaired by combining the demands of controlled water addition with those of established saltwell pumping operations?

- Are leak detection techniques that do not require long shutdown periods for monitoring a quiescent and stagnant liquid surface effective?

To address these uncertainties, and possibly identify other issues that have not been envisioned, proof-of-concept operations were planned for tank U-107.

1.2 OBJECTIVES

The primary objective of the proof-of-concept operations was 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 were all the issues and potential effects of the dissolution behavior that cannot be reliably predicted beforehand. Secondary objectives included the reduction of risks associated with the waste in tank U-107, the development of equipment, plans, and procedures that could be extended to the retrieval of tank S-112, and the deployment of a waste surface topography mapping system.

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 were to 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 leak-detection developmental strategy and approach;

- The cause(s) of adverse behavior such as dilute liquid in the saltwell screen, excessively nonuniform 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 could alternatively be deemed successful if it showed that the saltcake dissolution retrieval method is fundamentally unworkable or impractical for reasons that cannot be alleviated by adjusting the process.

2.0 PROCESS EQUIPMENT AND DEPLOYMENT

A summary of the overall saltcake dissolution operations concept and the saltwell pumping process along with a description of the waste and the equipment involved is given in Estey et al. (2003). The process equipment and instrumentation are summarized again here, together with a timeline of the design and deployment of the system. The tank and riser allocation, instrumentation, saltwell pumping system, and water distribution hardware are described in Section 2.1. The original purpose of each spray nozzle is also described. The design and deployment timeline of the water distribution system is presented in Section 2.2.

2.1 PROCESS EQUIPMENT AND INSTRUMENTS

This section's summary description of the process equipment and instrumentation and the planned data gathering is based on the U-107 Process Control Plan ("PCP"; Estey et al. 2003). The actual and planned data and instrumentation are compared in Table 2-1.

Table 2-1. Planned versus Actual Data Gathering.

Data	Planned	Actual
Topographic Mapping System (TMS)	Baseline; at four intermediate points during demonstration; final state.	Not performed. TMS operated during pre-installation tests but not after installation in tank U-107.
Saltwell grab sampling	Baseline; at three intermediate points during demonstration; final state.	Baseline only.
Neutron log	Baseline and weekly during demonstration.	Baseline and approximately weekly during demonstration.
Gamma log	Baseline and at least twice thereafter.	Not performed.
ENRAF[1]	Regular schedule.	Regular schedule.
In-tank videos	Not defined in PCP.	Baseline; two intermediate points; near final state.
Gamma monitor on transfer line	Not planned.	Continuous monitoring; not calibrated.

Built in 1944, tank U-107 is a first-generation single-shell tank with a primary steel liner and concrete dome with a nominal operating capacity of 530,000 gal. 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). Most of the risers in tank U-107 are located at about 30 ft from the tank

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

center. Table 2-2 and Figure 2-1 (taken from the PCP) give the locations of the risers and the instruments and equipment they contain.

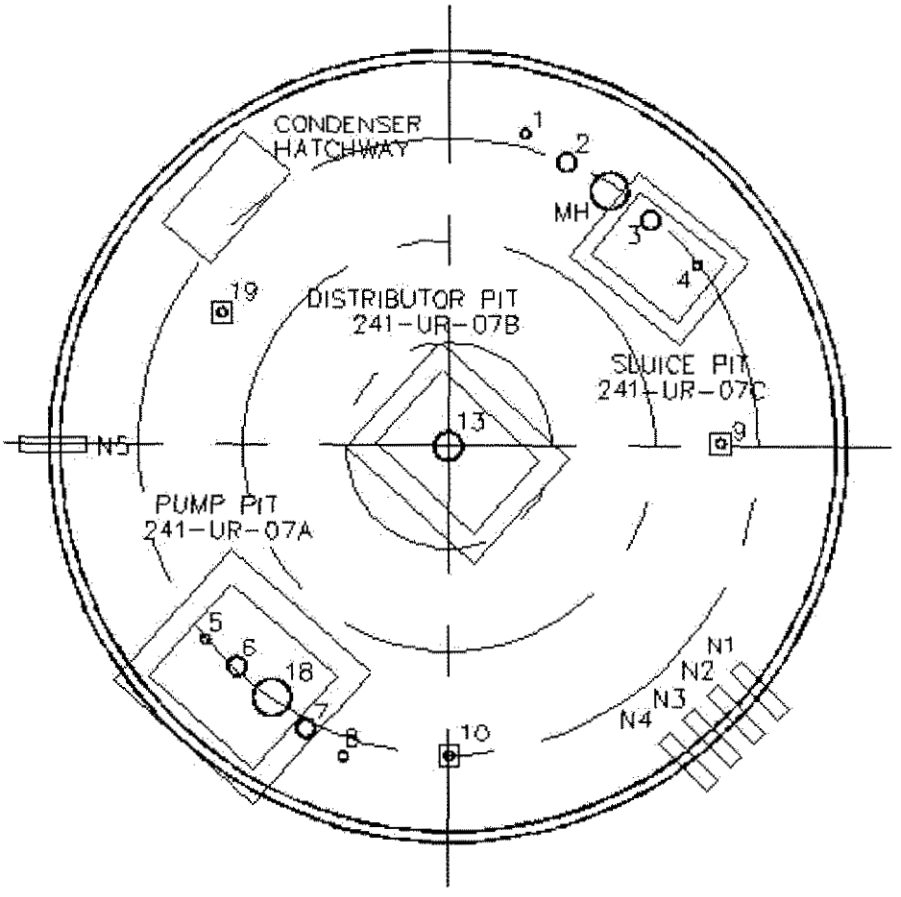
Table 2-2. Tank 241-U-107 Riser Description.

Riser No.	Diameter (in.)	Description And Comments
1	4	Temperature Probe
2	12	Fixed water spray nozzle assembly, Fury[2], and TMS
7	12	Impact sprinkler and TMS
8	4	ENRAF level gauge
9	4	Video camera
10	4	Standard Hydrogen Monitor System / Breather Filter
13	12	Saltwell screen and jet pump
19	4	Liquid Observation Well

Notes:

TMS = Topographical Mapping System

Figure 2-1. Tank 241-U-107 Plan View.



[2] Fury is a trademark of the Chemdet Corporation, Port Washington, New York.

The waste surface level was measured by the ENRAF buoyancy gauge in riser 8. The ENRAF records level in 0.025-cm (0.01-in.) increments and is able to resolve level changes to within ± 0.025 cm (0.01 in.). However, surface irregularity and the uncertainty in the reference position could produce a systematic error in the absolute elevation of 2 to 20 cm (1 to 8 in.).

The Topographical Mapping System (TMS) was designed to support characterization and retrieval operations in the Hanford Site tanks. It was demonstrated in 1994 in a Hanford Site cold-test tank and 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. The system scans the surface, creating a grid with resolution as high as 0.1 in., and maps the surface with a typical accuracy of better than 0.25 in. at 45 ft. 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. Estimates of waste volume changes determined by subtracting one scan from another are typically accurate to better than ~7 percent.

Vertical temperature measurements are taken from the thermocouple tree in riser 1, with readings monitored and recorded through the Temperature Monitoring and Control System (TMACS). The lowest thermocouple is located at 22 in. above the tank bottom with the next eight spaced 24 in. apart (46 in., 70 in., 94 in., 118 in., 142 in., 166 in., 190 in., and 214 in.) and the last two at 262 and 310 in. Only the first six thermocouples are within the waste. The last five indicate the headspace temperature. The uncertainty in the absolute temperature is estimated to be ±1.8 °C (3 °F) while temperature changes of less than 0.1 °C (0.2 °F) can be resolved (PNNL 1995).

The tank headspace hydrogen concentration is monitored by a Standard Hydrogen Monitoring System (SHMS). It consists of two electrochemical cells; one covers a high range (0 to 10 percent by volume), the other a low range (0 to 1 percent by volume) of hydrogen concentrations. Data are recorded by connection to the TMACS and by the onboard chart recorder. When the electrochemical cells are not functioning and tank-intrusive operations are underway, flammable gas concentrations in the headspace are measured twice daily by Industrial Hygiene technicians.

A liquid observation well (LOW) is located in riser 19 to monitor the interstitial liquid level (ILL). A LOW is a fiberglass pipe installed in the tank through a riser for the purposes of monitoring the waste liquid level. The bottom of the pipe is capped to prevent waste fluids from filling the LOW and the top is open to allow an operator to lower a neutron probe for detection of water in the waste surrounding the LOW. The neutron probe consists of a neutron source adjacent to a thermal neutron detector. The detector response is a good indicator of the water content and, therefore, the liquid fraction, in the vicinity of the LOW.

A schematic of a typical saltwell pumping system is given in Figure 2-2. Pressure and flow-metering instrumentation and the three dip tubes used to measure the specific gravity and depth of liquid in the saltwell screen are shown. 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 two other tubes, the weight factor and the specific gravity tubes, extend to almost the bottom of the saltwell screen. A differential pressure meter connected between the weight factor 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 tube and the specific gravity tube (which are precisely 25.4 cm different in length) is used to determine the specific gravity of the liquid. During operation, several measurements are automatically logged every three minutes and are downloaded to a file-server daily:

(1) In-line dilution water flow rate into the jet pump inlet;

(2) Transfer flow rate (saltwell liquid delivered plus in-line dilution);

(3) Position of the diaphragm-operated valve (which sets the transfer flow rate);

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

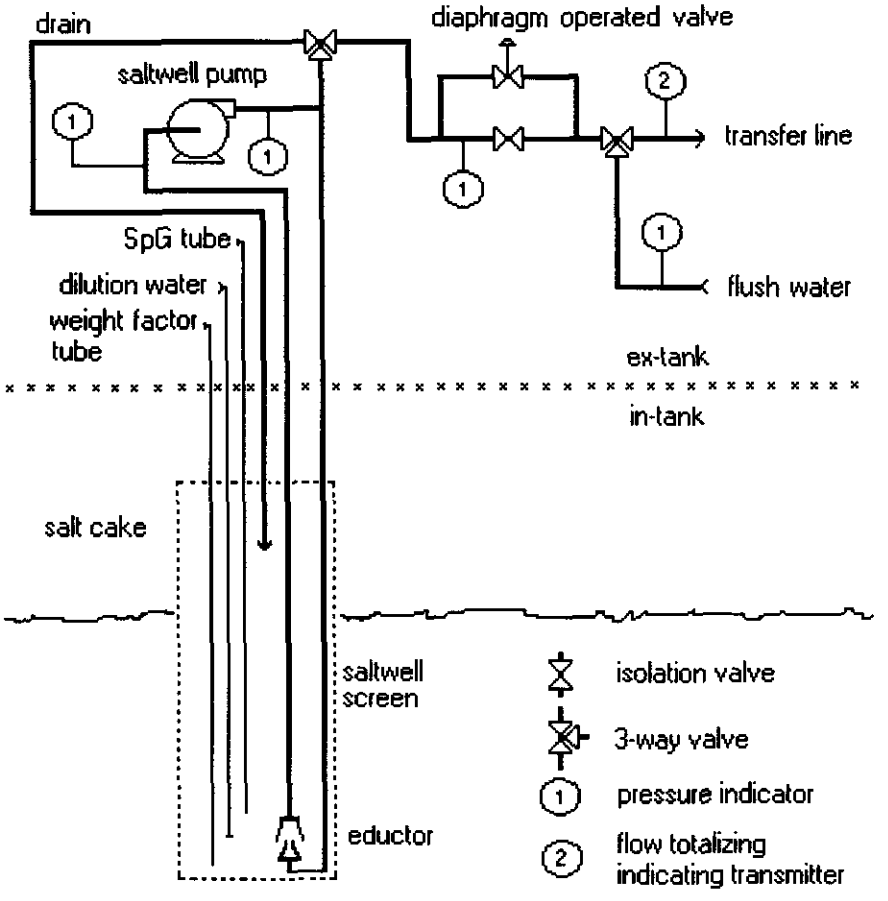
(5) System pressure at pump suction, pump discharge, and transfer line; and

(6) Liquid head pressure, or "weight factor," in the saltwell (as registered by the dip tubes).

The "in-line" dilution water is injected into the saltwell screen near the pump inlet. The injection point is not immediately adjacent to the dip tube instruments, but it is possible for the water to mix through part of the saltwell volume, especially during periods when saltwell pumping rates are low. In such cases, the specific gravity measured by the dip tubes understates the specific gravity of the waste liquid entering the saltwell; the extent of the understatement is uncertain.

A gamma radiation monitor was installed on the transfer line not far from the tank. The monitor measured the gamma count rate. This, together with the flow rate measured by the standard saltwell pumping system, was used to estimate the μCi/cc of total gamma in the flow (on the assumption that ^{137}Cs was the dominant gamma-emitter). The instrument was not calibrated and was considered to be in development. Midway through the proof-of-concept demonstration, on December 22, 2002, a collimator was installed to block background radiation from reaching the sensor.

Figure 2-2. Typical Saltwell Pumping System.



The saltcake dissolution system consists of a series of nozzles and sprinklers to add water in several specific patterns. There are three spray nozzles in riser 2, each pointing in a different direction. One is aimed at the thermocouple tree in riser 1 ("shadowing"), another at the waste surface near the tank wall ("near-wall"), and the third toward the saltwell screen ("near-saltwell"). Also included in riser 2 is a Fury tank washer. The Fury tank washer is mounted at the base of the fixed nozzle assembly to spray a circular area approximately 20 ft in radius. Riser 7 contains one line to a Nelson[3] impact sprinkler.

The approximate location of each of the sprinklers' spray patterns on the waste surface is sketched in Figures 2-3 and 2-4. Figure 2-3 shows the planned spray patterns as laid out in the PCP, while Figure 2-4 shows the ones that were used. The area and flow rate of each planned nozzle and sprinkler are summarized in Table 2-3; the nozzles that were actually used during the test are in boldface.

[3] Nelson is a trademark of the L. R. Nelson Corporation, Peoria, Illinois.

Figure 2-3. Approximate Tank-Wide Spray Configuration (Planned).

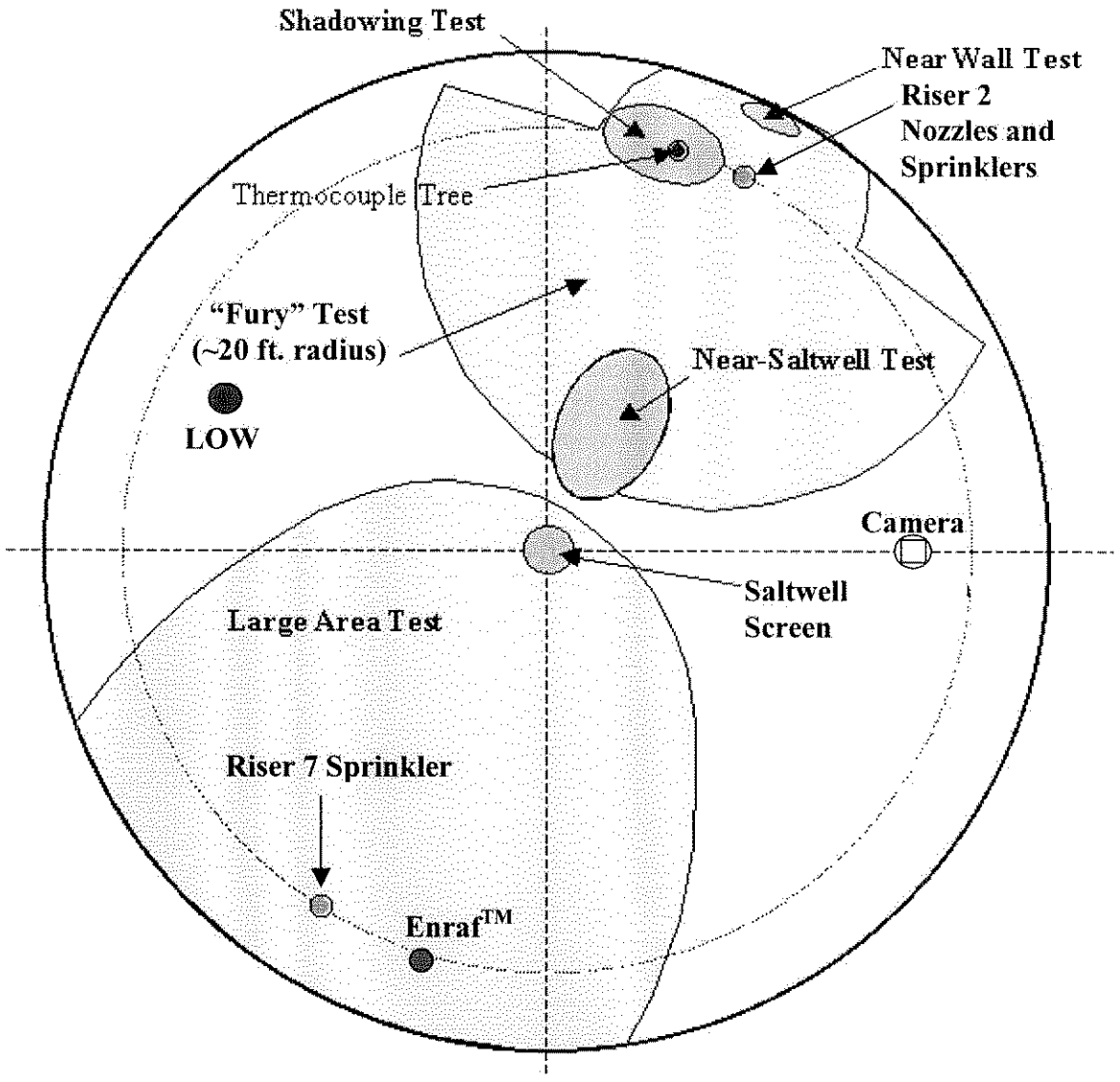


Figure 2-4. Approximate Tank-Wide Spray Configuration (Actual).

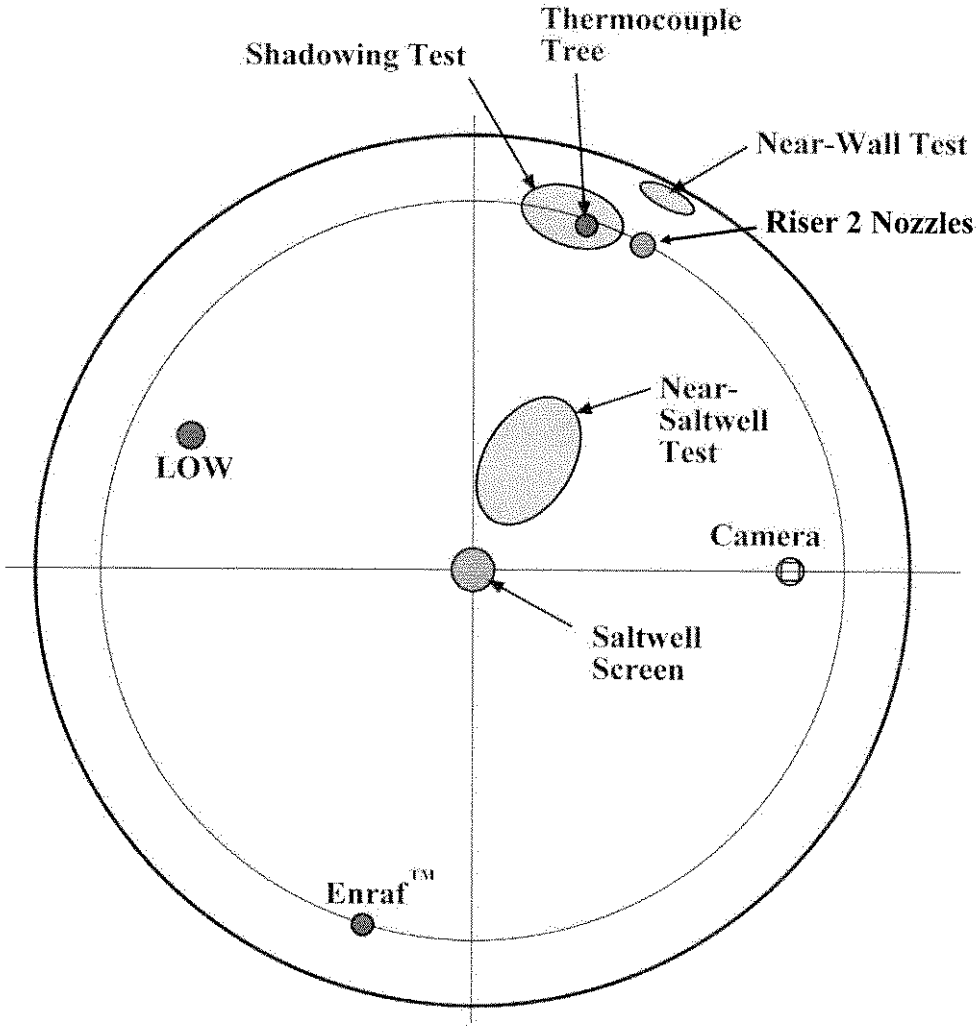


Table 2-3. Nozzle and Sprinkler Summary.

Sprinkler or Nozzle Area (Riser)	Approx. Area (ft^2)	Elevation (ft)	Angle	Flow Rate (gpm)	Water Flux (gpm/ ft^2)
Nelson Impact Large-area (Riser 7)	1728	~6.0	12° up toward center	~6.5	0.0038
BEX 1/4 FP2540 25° Flat Near-wall (Riser 2)	**38**	**~4.5**	**60° down**	**~3**	**0.079**
BETE MP156NN 30° Cone Near-saltwell (Riser 2)	**75**	**~8.5**	**horizontal**	**~4**	**0.053**
BEX 1/2 S16 55° Cone Shadowing (Riser 2)	**88**	**~4.5**	**45° down**	**~2.5**	**0.028**
Fury Tank Washer (Riser 2)	675	~4.0	n/a	~10	0.015

2.2 TIMELINE OF DESIGN AND DEPLOYMENT

The U-107 proof-of-concept saltcake dissolution demonstration was designed to evaluate the process as a retrieval method. The technical approach was to combine a simple water distribution system using in-tank spray nozzles in conjunction with the saltwell pumping system to dissolve and remove soluble wastes.

- March 2001: Operations Directive received to initiate a proof-of-concept demonstration for saltcake dissolution.
- March 2001: Conceptual design completed.
- March 2001: Developmental Control Plan for fabrication issued.
- April 2001: Process Control Plan issued.
- May 2001: Data Quality Objectives issued.
- June 2001: Criticality Safety Evaluation Report issued.
- June 2001: Tank Sampling and Analysis Plan issued.
- August 2001: Hazard Evaluation issued.
- August 2001: Final design completed.
- August 2001: Acceptance testing completed.
- September 2001: Dissolution equipment installation completed.

- September-October 2001: Saltwell pumping initiated and shutdown because of restricted transfer pipeline.
- October-May 2002: Resolution of restricted transfer pipeline.
- June-September 2002: Interim Stabilization Consent Decree priorities delay dissolution operations.
- September 2002: Operations Directive received to start up dissolution operations.
- October 2002: Replaced failed saltwell pump.
- November 2002: Restarted saltwell pumping.
- December-February 2002: Initiated dissolution operations.
- February 2003: Dissolution operations terminated because of transfer line restrictions and planned chemical cleaning to remove the blockage.

3.0 TANK STATUS BEFORE DISSOLUTION

The proof-of-concept operations in tank U-107 were preceded and followed by saltwell pumping. The first stage of pumping began on September 30, 2001 and lasted until November 4, 2001; pumping was stopped because a pre-existing blockage in the transfer line greatly reduced flow through the line. After pressurized line flushes, pumping was restarted on June 23, 2002 and continued intermittently up though December 2, 2002, the day before proof-of-concept operations began. Proof-of-concept demonstration started on December 3, 2002 and continued through February 8, 2003, at which time it was suspended because of restricted transfer line flow. Interim stabilization resumed on February 22, 2003 despite severe flow limitations in the transfer line.

This section describes the tank conditions and observations before saltwell pumping was initiated (Section 3.1) and during saltwell pumping (Section 3.2) to establish the baseline condition of the tank at the start of proof-of-concept operations.

3.1 TANK WASTE BEFORE SALTWELL PUMPING

Appendix B of the U-107 Process Control Plan provides an extensive characterization of the waste in tank U-107 before saltwell pumping. Only a brief summary of that information is given here to provide the baseline configuration of the waste and its liquid and retained gas content.

Prior to saltwell pumping, the waste level in tank U-107 was 157 in., which was believed to include 1 to 2 ft. of supernatant liquid. The saltcake waste was concentrated enough to be classified as double-shell slurry feed, and contained no sludge.

Photographs taken in 1988 showed the entire waste surface to be covered with liquid with numerous small clumps of apparently floating material. Neutron logs taken in 2001 showed that (at the near-wall location of the LOW) the waste was all liquid down to about 130 in. elevation, indicating a 27 in. supernatant layer. A much drier region, probably containing significant retained gas, was found between 130 and 100 in. elevation, with wetter waste below that.

When saltwell pumping began, the waste level in tank U-107 had been rising very gradually (about 0.1 in. per year) since 1990. Fourteen small spontaneous gas release events had been recorded by the tank's SHMS since March 1995. During the six years of SHMS monitoring the maximum hydrogen concentration was 1,900 ppm and the average was 840 ppm. The best estimate of the retained gas volume, 180 ± 60 cubic meters (6,400 ± 2,000 standard cubic feet [scf]) was taken as the average of the barometric pressure effect (BPE) calculation and neutron log integration (Hedengren et al. 2001). The waste level had risen 6 inches since 1981 (Whitney 1995), which would indicate a gas accumulation of 75 cubic meters at 1 atm assuming an *in situ* pressure of 1.2 atm.

The retained gas composition in tank U-107 has not been measured. However, Retained Gas Sampler data for tanks 241-U-103 and 241-U-109 showed 23 percent and 25 percent hydrogen, respectively (Mahoney 2000). Although there is considerable uncertainty, tank U-107 might be expected to have a similar hydrogen fraction because of their similar compositions. Based on data for tanks 241-U-103 and 241-U-109, 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.

At the thermocouple tree (near the wall), the waste temperature up to 118 in. was fairly uniform, varying between 73 and 78 °F. However, because the thermocouple tree is out at about the 32-ft radius, the temperatures in the central region could be somewhat different. Higher temperatures at the tank center were considered possible because during the annual cycle, the headspace temperature exceeded the temperature at the 22-in.-elevation thermocouple.

3.2 SALTWELL PUMPING OBSERVATIONS

The subject of this section is the set of observations made during the stabilization activities that preceded the proof-of-concept demonstration. The post-demonstration saltwell pumping observations are deferred to a later section.

3.2.1 Waste Transfer and Level Changes

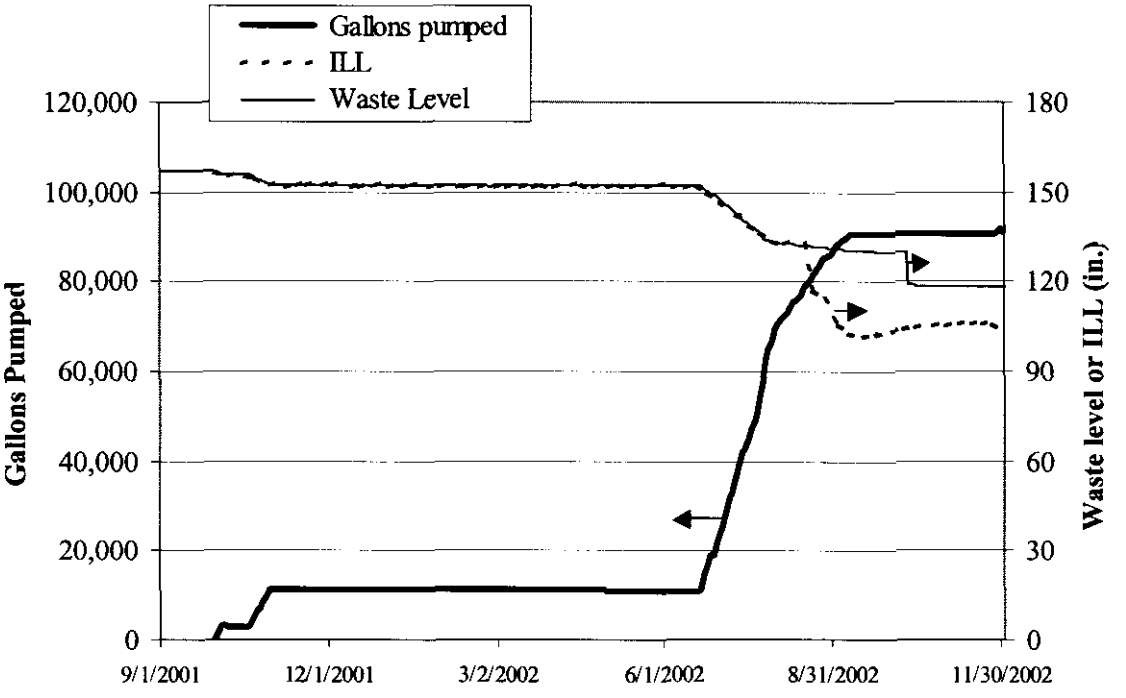
Figure 3-1 shows the cumulative transfer volume as a function of time during the saltwell pumping campaign. The figure also plots the waste surface level and the ILL.

As the divergence between waste level and ILL shows, the supernatant liquid was removed from the near-wall region represented by both the ENRAF and the LOW on about August 17, 2002. At this time the waste level was about 132 inches. Pumping rates above 0.5 gpm were maintained through August 26, removing another 5 or 6 kgal and suggesting that the supernatant was deeper and more available near the center of the tank than near the wall. 85 kgal of waste liquid had been removed by August 26. Saltwell pumping broke off on September 14 because of pump failure. After the pump was replaced, pumping resumed briefly draining additional liquid from November 27 through December 2, in preparation for the proof-of-concept demonstration. A total of 6.5 kgal of interstitial liquid was pumped after supernatant removal and before the demonstration; the PCP had expected approximately 10 kgal of interstitial liquid to be pumped before the demonstration in order to drain the topmost foot of waste.

During the September-to-November pumping hiatus, the ILL rose a few inches, probably because liquid from further out in the tank recharged the region around the LOW. The reason for the abrupt decrease in waste surface level from 129 to 118 in. on October 10 is unknown. No system water additions were recorded; also, the ILL that was located at nearly the same radius, but 90 degrees away, showed no change. A tank-wide waste collapse of this magnitude could, in theory, explain both the level drop and the increase in the ILL, but is not a likely explanation because the pumped fraction of the waste

matrix was too small to cause a collapse of nearly a foot. The in-tank camera showed a local depression near the ENRAF, so the apparent decrease was probably the result of the ENRAF's measuring a slightly different spot on the waste surface.

Figure 3-1. Transfer Volume and Level Changes for Pumping Before Proof-of-Concept Demonstration.



3.2.2 Liquid Content Changes Caused by Pumping

Figure 3-2 shows neutron logs in the LOW before and after the two main phases of saltwell pumping that preceded the proof-of-concept demonstration. An artificial sideways offset of 100 counts per minute has been introduced between scans to make them easier to distinguish. Note that these measurements were located some distance from the areas being sprayed and were not directly affected by water addition.

The first phase of pumping, from September 30 to November 4, 2001, removed part of the supernatant liquid. This is seen in the lowered elevation of the high-liquid, high-count region at the top of the waste, the only change in the plot on the left. The second phase, between June 23 and September 13, 2002, finished removing the supernatant and accomplished some drainage of the bulk waste between 110 and 130 in. elevation, as shown in the plot on the right. The September 17 and November 25 logs indicate that after pumping stopped there was some refilling of the bulk waste between about 100 and 108 in.

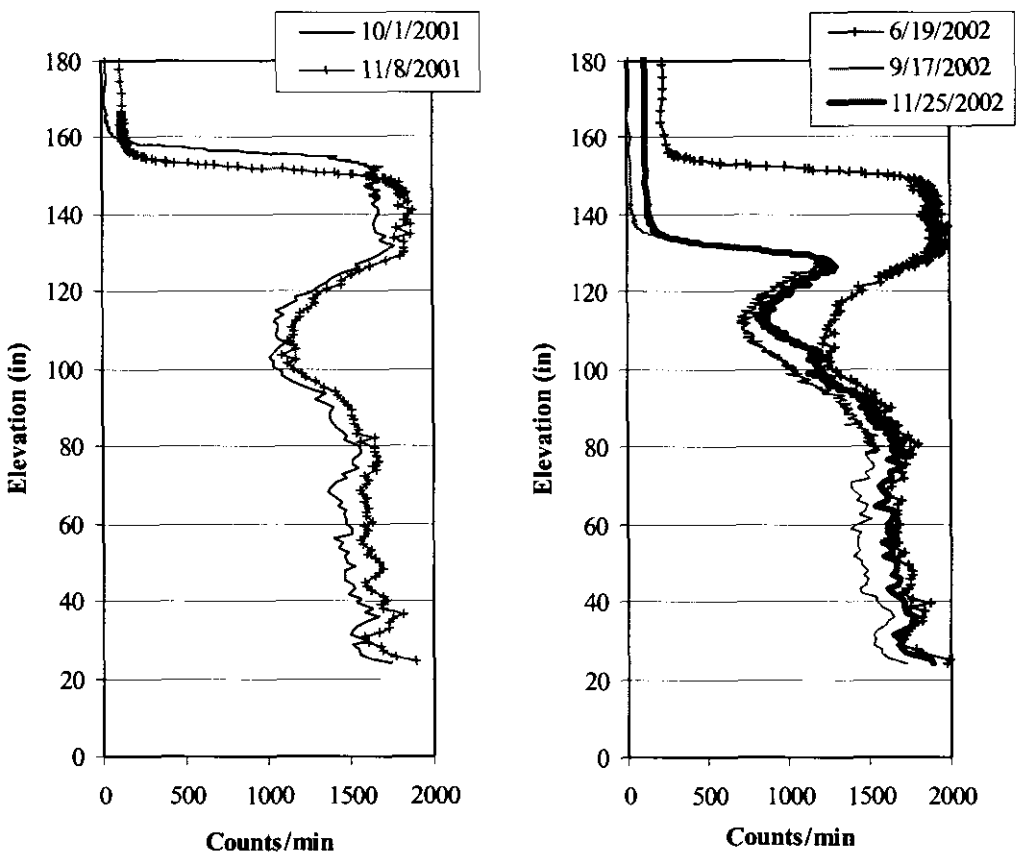
The ILL estimated from the log taken November 25, 2002, was 105.6 in. The waste surface level indicated by the same neutron scan was about 130 in., which matched the

ENRAF readings before the decrease on October 10. The LOW is located some distance from the ENRAF, so the concurrence of the neutron log with the ENRAF reading before the sudden drop that was measured only by ENRAF (Section 3.2.1) provides further evidence that the level drop measured by ENRAF was not a tank-wide event. Assuming this to be the case, the proof-of-concept demonstration began with an approximate 2-ft depth of hydrologically unsaturated waste near the 30-ft radius where the ENRAF and LOW were located. The corresponding depth near the saltwell is unknown, but at the time the demonstration began the uncorrected weight factor in the saltwell was about 100 in. H_2O, indicating 67 in. of liquid at the saltwell screen.

3.2.3 Temperature Behavior During Pumping

The waste temperature behavior during saltwell pumping was consistent with removing the supernatant and was generally unremarkable, except for a sharp headspace temperature rise at the beginning of each period of pumping. To illustrate this phenomenon, Figure 3-3 shows temperature variations in the tank U-107 waste and headspace during the period covering both phases of saltwell pumping. It also includes temperatures at the same thermocouples for an equivalent time span two years previous to demonstrate the temperature increases produced by saltwell pumping.

Figure 3-2. Neutron Logs Before and After Saltwell Pumping.



The thermocouples shown are #5 (below the supernatant or at the waste surface all through this pumping episode) and #6 (which began in the supernatant layer and moved into the headspace in mid-July 2002). Thermocouples #7 and #10, which were in the headspace throughout pumping, showed temperature trends much like those of #6 but with temperature changes that were smaller by 2 to 4 °F. The temperatures in the headspace and in the supernatant layer responded promptly to pumping, increasing by as much as 5 to 7 °F over normal, while the temperature just beneath the supernatant layer showed a lag in its increase. At the time when the supernatant was removed, the temperatures at the four thermocouples all became equal and gradually returned to normal values.

This behavior indicates that saltwell pumping exposed both the headspace and the waste surface near the tank wall (the thermocouple tree location) to higher-temperature waste. One possibility is that waste at the center of the U-107 tank is significantly hotter than waste near the tank wall. According to this theory, the liquid near the tank center contained a higher concentration of dissolved solids and was denser than the liquid in the supernatant layer. This density gradient would have inhibited natural convection while the tank was quiescent, preventing temperature equalization in the supernatant/saltwell liquid. Then saltwell pumping removed the hot, dense saltwell liquid and allowed the cooler, less concentrated supernatant to flow into the saltwell. If it took up heat more rapidly than it did solute, its density would have decreased as it was heated and natural convection would have mixed the heated liquid with the still-remaining supernatant, causing the observed rise in both the headspace and waste surface temperatures. In time the high-temperature liquid dissolved enough solids to increase its density, once again inhibiting natural convection.

As a test, the U-107 tank waste was modeled with Environmental Simulation Program (ESP) (a chemical thermodynamic simulation package). ESP predicted that the density of the liquid in contact with the waste solids was 1.465 g/cc at 25 °C and would be 1.496 g/cc at 50 °C.[(4)] (Note that the temperature of 50 °C was chosen only to bracket a temperature range; there is no reason to expect the temperature at the center of tank U-107 to be this high.) The model's density prediction is in accord with the hypothesis that elevated temperature could lead to suppression, rather than enhancement, of natural convection mixing.

The possibility that the tank waste is significantly hotter near the center of the tank than at the walls should be kept in mind. It implies that the potential for solids precipitation from the liquid, when cooled during transfer, may be greater than expected based on temperatures measured near the wall.

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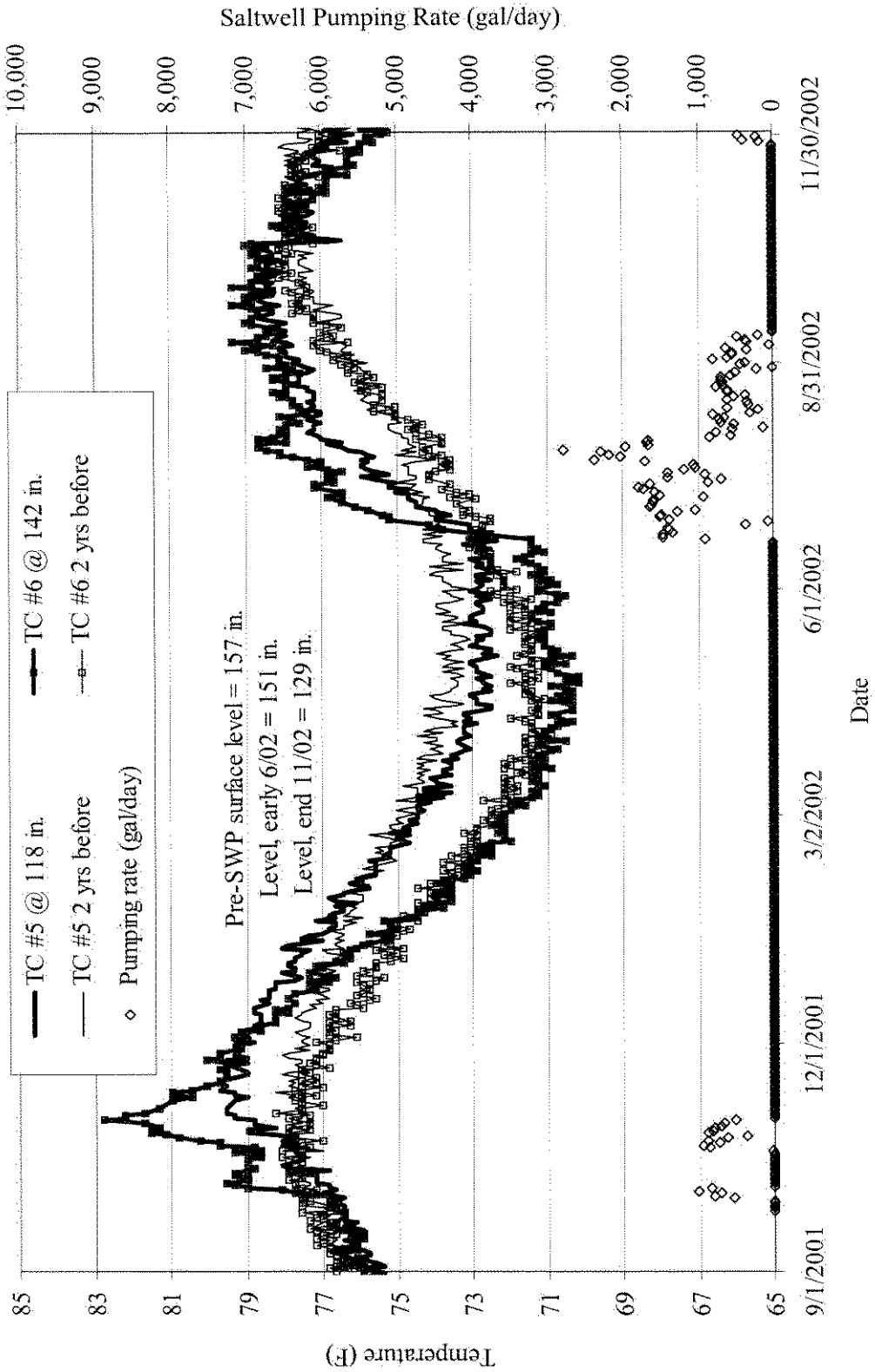
[4] The waste composition that was modeled using ESP, and the other modeling assumptions, were described by Mahoney, L. A., 2002, *U-107 ESP Model Predictions for Saltcake Dissolution by Water*, Letter report TWS02-067, Pacific Northwest National Laboratory, Richland, Washington.

Figure 3-3. Temperature Behavior During Pumping Before Proof-of-Concept Demonstration.



3.2.4 Headspace Hydrogen Concentration During Pumping

Figure 3-4 plots the hydrogen concentrations measured by the SHMS in the tank U-107 headspace during saltwell pumping and the year before, together with the cumulative transfer volume. Both the low-range and high-range instrument readings are plotted.

Both sensors show strong re-occurring negative trends. If the sensor drift is assumed to be linear from October 1, 2001, to October 15, 2002, then the adjusted data indicate that gas releases occurred during both periods of pumping. The hydrogen concentration history from October 1, 2001 to October 15, 2002 is shown in Figure 3-5 along with the measured waste level and equivalent pumped level (assuming supernatant was pumped). The drift of the SHMS sensors is assumed to be a linear decrease as indicated by the dash line labeled "Baseline Hydrogen Trend." The actual hydrogen concentration is calculated as the difference between the measured value and the baseline. When reduced in this way, the data indicate that gas releases occurred during both periods of pumping and persisted for some time afterward. This is shown by the shaded areas in Figure 3-5.

Using this assumption, the hydrogen volume released during saltwell pumping (up through October 15, 2002) has been calculated to be 432 scf, based on the low-range sensor.[5] If the hydrogen fraction in the released gas is 0.25 (0.23 and 0.25 measured in tanks 241-U-103 and 241-U-109, [Hedengren et al. 2001]), the total gas release for both periods is about 1,730 scf. This is approximately 24 percent of the 6,400 scf of gas estimated to have been initially stored in tank U-107 (Hedengren et al. 2001). Though the uncertainty in this calculation is probably on the order of ± 50 percent, it clearly shows that a large fraction of the initial gas inventory remained in the waste at the start of the dissolution testing in December 2002.

[5] Stewart, C. W., 2002, *Assessment of Gas Releases at High Retrieval Rates in Tank 241-U-107*, TWS03.009, Pacific Northwest National Laboratory, Richland, Washington.

Figure 3-4. SHMS Hydrogen Readings During Pumping Before Proof-of-Concept Demonstration.

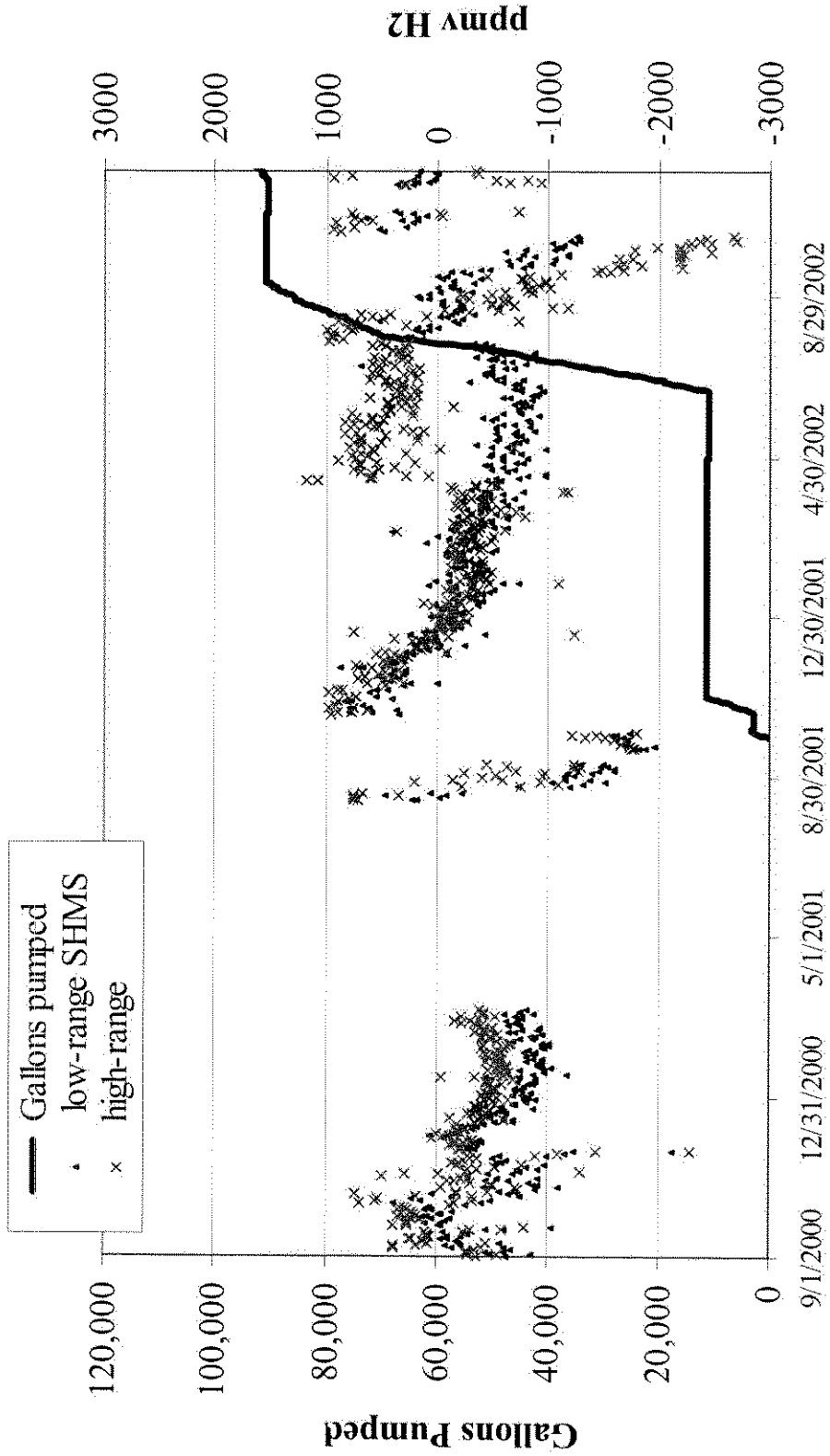
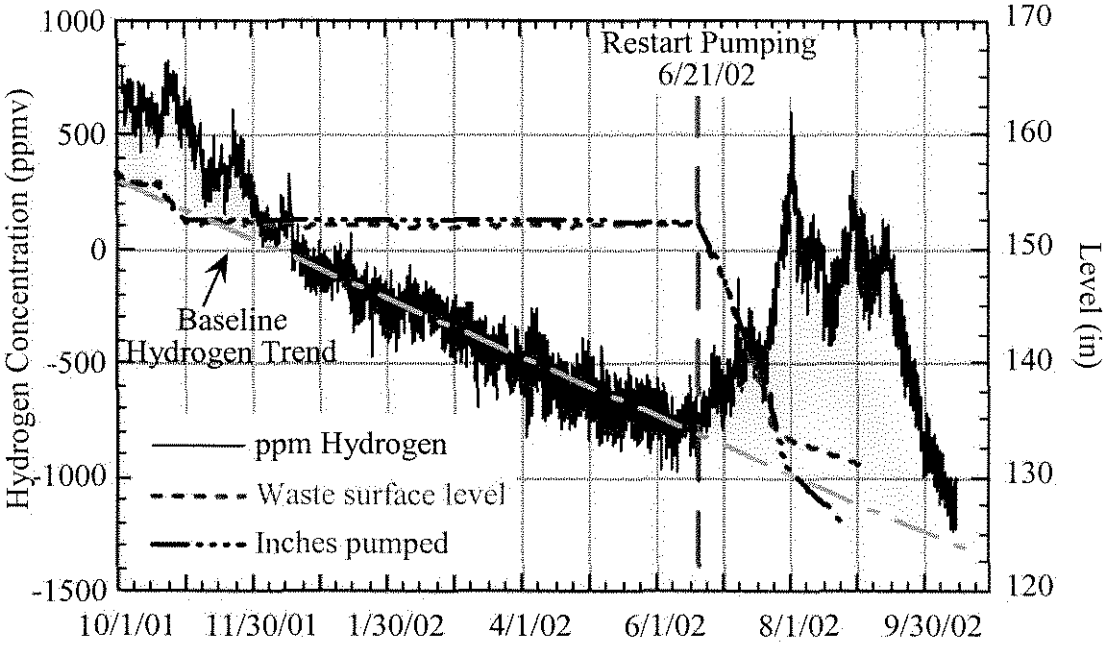


Figure 3-5. Adjusted SHMS Hydrogen Readings During Pumping.



3.2.5 Baseline Saltwell Liquid Grab Sample

The composition of the tank liquid before the proof-of-concept was defined by taking grab samples from the saltwell on November 20, 2002, two weeks before the demonstration and more than two months after the previous saltwell pumping. Two samples were taken near the top of the saltwell liquid and two near the bottom. Each pair of samples was combined to give a single composite sample from each elevation. Table 3-1 shows the composition of the grab samples.[6] As the table shows, the two saltwell samples are essentially identical.

The grab sample composition was compared to the compositions of drainable liquids from core samples (which had been taken from three different risers and a variety of elevations). The drainable liquid composition in tank U-107 core samples varied strongly with depth, with supernatant and upper core segment liquids being lower in Al and OH, and higher in total inorganic carbon (TIC) and total organic carbon (TOC), than the deep liquid. (Many minor constituents also vary.) The grab sample liquid was less similar to the supernatant samples than to the deep liquid samples, those in segment 4 and below, probably because the supernatant had been removed much earlier, and the liquid in the saltwell at that time was seepage from the surrounding waste. The deep samples represent liquid from less than 100 in. elevation.

[6] Baker, H. L., 2003, "Tank U-107 Grab Samples in Support of Salt Cake Dissolution Proof-of-Concept Analytical Results for the Final Report,"(letter FH-0301585 to G. A. Stanton, CH2M HILL, May 2), Fluor Hanford, Richland, Washington.

Aluminum may be supersaturated in the grab sample liquid, based on a comparison of the Al/OH ratio in the grabs and in drainable liquid samples. In supernatant liquid, Al was typically between 21,000 and 24,000 μg/mL and OH between 25,000 and 34,000 μg/mL. In deep liquid, Al was 40,000 to 45,000 μg/mL and OH (in a single composite measurement) was 46,000 μg/mL. By contrast, the grab samples contained about 41,000 μg/mL of Al and only 31,000 μg/mL of OH. Since the solubility of aluminum depends on hydroxide, the higher Al/OH ratio in the saltwell liquid could indicate supersaturation (or perhaps colloid formation), with implications for potential transfer line plugging.

An estimate of the pre-water-addition waste liquid specific gravity is important as a baseline against which to compare the measured saltwell specific gravities. Table 3-2 lists the available specific gravity data for drainable liquid from tank U-107 core samples, taken from the tank characterization database (TCD) via the Tank Waste Information Network System (TWINS). The database also contained "liquid density" data, but these were considered less accurate than specific gravity measurements and were omitted. ("Liquid density" is not directly measured but is a calculated property, liquid mass divided by a liquid volume that was measured with low resolution.)

The average of the core drainable-liquid specific gravity values in Table 3-2 is 1.423, in good agreement with the grab sample values in Table 3-2. However, the possibility that the measured densities were underestimates because the samples were diluted with hydrostatic head fluid (HHF) that is used in the core-sampling drill string during sample acquisition must be considered. Since HHF is an aqueous solution of LiBr – in this sampling event, it was 21,745 μg/mL LiBr – the analyte Br is generally used to determine the extent of HHF dilution of samples. Table 3-2 shows that, with two exceptions, there was no measurable HHF in the samples, and the detection limit was 3 to 6 percent HHF.

It should be noted that dilution of the samples would not necessarily have led to a decrease in liquid density. If the liquid in the samples were in contact with soluble solids (and in most cases the core samples did include solids as well as liquid), then sodium nitrate and other salts would have dissolved in the diluent and maintained the specific gravity. In support of this point is the fact that no consistent relations are seen between the specific gravity and the amount of HHF in the two samples in which HHF was detected.

The liquid specific gravities were measured at laboratory temperature (25 to 30 °C) and so might have been slightly lower than the in-tank specific gravity. This is expected to be a small effect, as suggested by the ESP predictions alluded to in Section 3.2.3.

Table 3-1. Composition of Baseline Saltwell Grab Samples from Tank 241-U-107.

	Grab Samples		Typical Core Drainable Liquid		The most similar core-sample drainable liquid (obtained from TWINS)
	7U-02-01A and B (top)	7U-02-01C and D (bottom)	Core 129 Seg. 1	Core 245 Seg. 6R	
Al, μg/mL	40,300	41,600	24,400	40,500	Core 245 Seg. 6R (40,500)
Cl, μg/mL	11,100	10,200	7,260	12,900	Core 245 Seg. 7R (11,000)
Cr, μg/mL	62.1	64.8	813	173	Core 245 Seg. 5R (44.0)
F, μg/mL	< 155	< 306	454	248	Most segments 1 through 4
P, μg/mL	1,300	1,350	1,270	1,070	Nearly all segments' liquids have similar P
Na, μg/mL	206,000	203,000	228,000	231,000	Core 242R Seg. 2 (208,000)
NO_2, μg/mL	134,000	121,000	88,800	142,000	Core 242R Seg. 4 (120,000)
NO_3, μg/mL	146,000	138,000	206,000	156,000	Core 245 Seg. 7R (140,000)
S, μg/mL	1,420	1,490	2,490	1,610	Core 245 Seg. 5R (1,370)
OH, μg/mL	30,600	32,000	28,300	45,700	Core 245 Segs 5R and 6R Composite (6,210)
TIC, μg/mL	2,880	3,550	4,720	3,170	Core 245 Segs 5R and 6R Composite (3,170)
TOC, μg/mL	6,470	6,080	3,120	6,210	Core 245 Segs 5R and 6R Composite (6,210)
C_2O_4, μg/mL	< 1,390	< 2,750	626	<1,070	Nearly all segments' liquids have similar low C_2O_4
SpG, g/mL	1.435	1.42	1.38	1.47	Similar to most segments
C-14, μCi/mL	0.00078	0.00117			
Se-79, μCi/mL	0.00148	0.00149			
Sr-89/90, μCi/mL	0.453	0.459		0.474	Core 245 Segs 5R and 6R Composite (0.474)
Tc-99, μCi/mL	0.358	0.332			
I-129, μCi/mL	0.00029	0.000299			
Cs-137, μCi/mL	344	355		457	Core 242 Segs 1-4 Composite (306)

Notes: Seg. = segment
Segs. = segments
SpG = Specific gravity

Table 3-2. Specific Gravities of Baseline Core Drainable Liquid from Tank 241-U-107.

Core Sample	HHF Dilution	Specific Gravity
Core 129 Seg. 1	<2.4%	1.38
Core 129 Seg. 2; Riser 9	<2.4%	1.44
Core 134 Seg. 5B; Riser 7	19%	1.43
Core 135 Seg. 1; Riser 2	<2.4%	1.43
Core 135 Seg. 1R; Riser 2	<2.4%	1.44
Core 135 Seg. 2A; Riser 2	16%	1.37
Core 242 Seg. 1; Riser 2	<3.0%	1.43
Core 242 Seg. 2; Riser 2	<5.9%	1.31
Core 242 Seg. 2A; Riser 2	<5.9%	1.34
Core 242R Seg. 1; Riser 2	<3.0%	1.26
Core 242R Seg. 2; Riser 2	<3.0%	1.39
Core 242R Seg. 3; Riser 2	<3.0%	1.41
Core 242R Seg. 4; Riser 2	<3.0%	1.41
Core 242R Seg. 5; Riser 2	<3.0%	1.36
Core 245 Seg. 1; Riser 7	<5.9%	1.41
Core 245 Seg. 2R; Riser 7	<3.0%	1.41
Core 245 Seg. 5R; Riser 7	<5.9%	1.47
Core 245 Seg. 6R; Riser 7	<5.9%	1.47
Core 245 Seg. 7R; Riser 7	<3.0%	1.45

4.0 PROOF-OF-CONCEPT NARRATIVE AND TIMELINE

As originally planned (Estey 2001), the proof-of-concept demonstration was to include water additions through several different nozzles and at several different locations, which are described in Table 4-1. Figure 2-3 (taken from the same reference, with some instrumentation notes added) shows the area that each water addition was expected to cover. Of the eight planned additions, the first five were completed (although in some cases, less water was used than had been planned, as detailed in Table 4-1). The relatively forceful spray of the Fury tank washer was not used, so its possible ability to erode saltcake was not evaluated. The Nelson impact sprinkler, which would have added water at a rate and over an area consistent with full-scale retrieval operation, also was not evaluated.

For the purposes of this report, the demonstration that was carried out will be considered as two phases, the first including the completed "initial" and "channeling" tests and the second including the partial large volume test. Section 4.1 contains the narrative for the first phase, while the second phase is covered in Section 4.2. Detailed timelines for both phases are given in Appendix A.

Table 4-1. Water Addition Area and Volume.

Pattern/Test	Area (ft^2)	Water Volume (gal)	
		Planned	Actual
Near Saltwell - Initial	19	400	400
Shadowing - Initial	20	500	400
Near Wall - Initial	2	400	300
Near Saltwell - Channeling	150	2000	2000
Near Wall - Large Volume	1105	8000	7501
Fury - Large Volume	1105	3000	--
Large Area A	2000	8000	--
Large Area B	2000	8000	--
TOTAL		**30300**	**10601**

4.1 INITIAL AND CHANNELING PHASE OF TEST (FIRST PHASE)

The water additions in this phase of the proof-of-concept were intended to accomplish the following:

- Near-saltwell (initial) test – initial observations and assessment of the results of water addition.

- Shadowing (initial) test – establish whether a spray directed at an obstacle (the nearby 3.5-in. thermocouple tree) was effective at dissolving waste behind the obstacle.

- Near-wall (initial) test – establish whether water added at the wall would reach the saltwell by migrating under the surface or channeling, or whether it would pool.

- Near-saltwell (channeling) test – observation of the dilute runoff expected to result from a high spray rate in a small area near the saltwell. Channeling is perceived as an undesirable short-circuit of water through channels or ditches eroded or dissolved into the waste by excess water runoff.

Table A-1 in Appendix A shows the detailed sequence of events associated with the first phase of the test. An estimate of the waste removal by dissolution, based on saltwell liquid properties, water addition, and pumping, is given in Section 5.0.

All of the water-addition events in this section are described with plots of four measurements:

- Temperature at 118 in., measured by thermocouple 5 of the thermocouple tree located near the near-wall spray area;

- Gamma concentration in the transferred liquid (including in-line dilution);

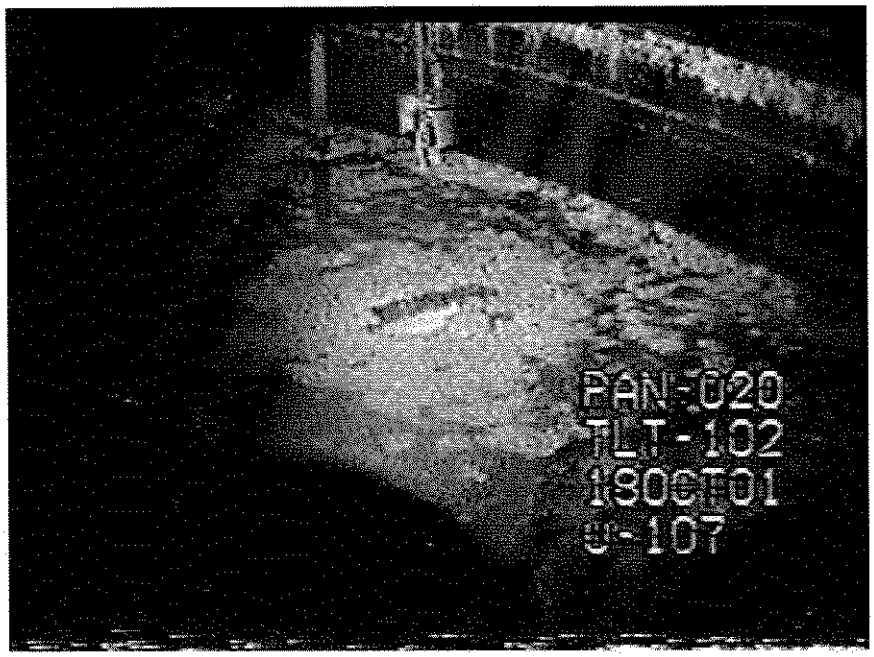
- Weight factor in the saltwell, a measure of liquid depth (measured by dip tubes and not corrected for specific gravity (SpG), hence stated in the measured units of in. H_2O); and

- Specific gravity (SpG) in the saltwell (measured by the dip tubes near the bottom of the well). When the liquid depth is low enough to expose the SpG dip tube, specific gravity measurements are meaningless. This should occur at about 10 in. liquid (an uncorrected WFT of 15 in. H_2O), but in tank U-107, it actually occurs at a WFT of about 30 in. H_2O. Accordingly, SpG measurements for periods in which the WFT was less than 30 have been deleted from the data.

Figure 4-1 is a photograph taken from an in-tank video filmed on October 18, 2002. It shows the baseline appearance of the waste. The waste surface is flat, and the thermocouple tree can be seen at the top-left of center.

The first water addition, of 400 gal near the saltwell, began at 2:30 p.m. on December 3, 2002, and ended at 4:30 p.m. This addition of water toward the saltwell screen (Figure 2-3) was expected to cause surface runoff of unsaturated brine into the saltwell screen. At issue was whether this would cause surface runoff, and if so, whether the runoff liquid would become saturated via contact with the saltcake before reaching the pump.

Figure 4-1. Baseline Image of Near-Wall Waste.



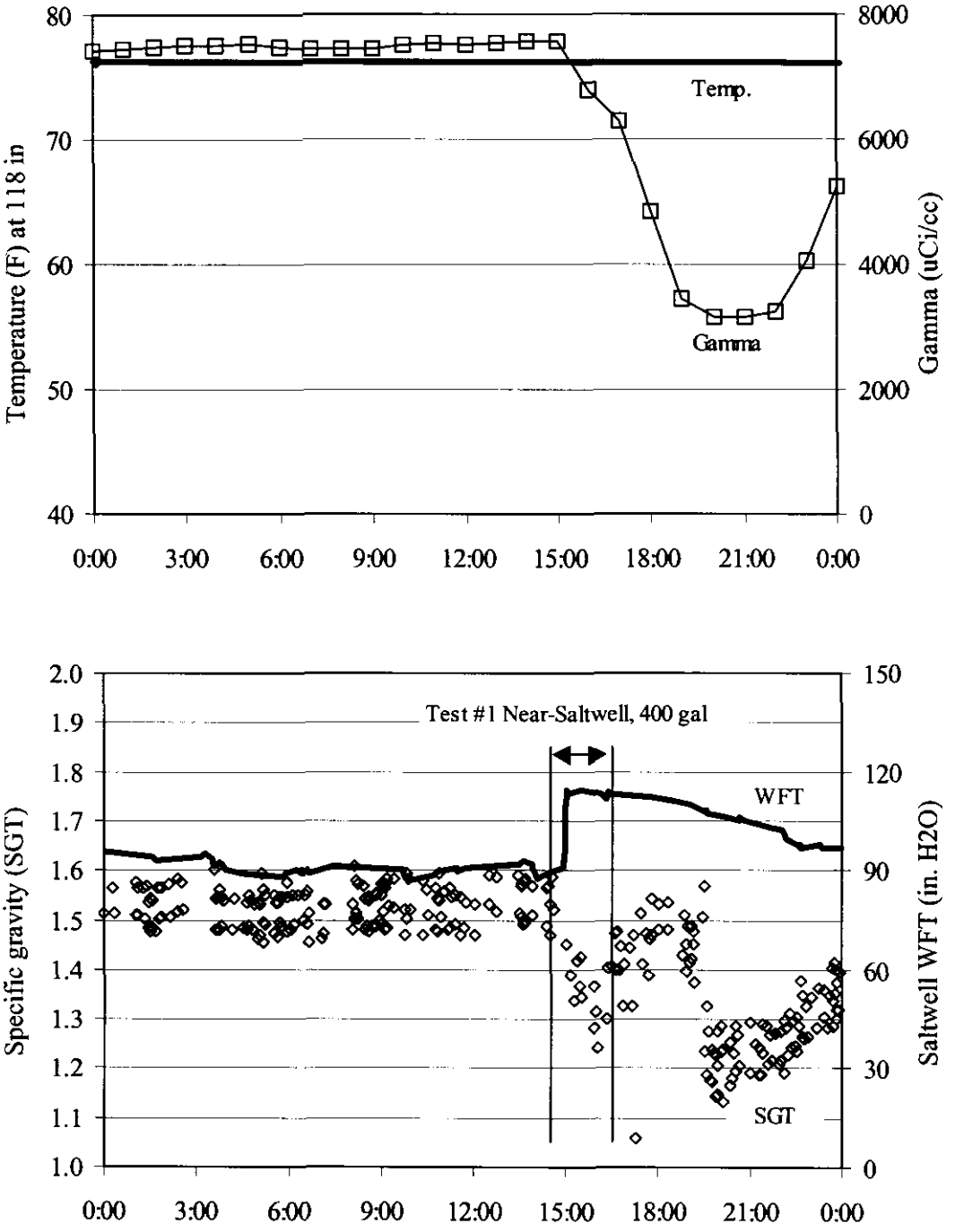
The saltwell liquid level at the start of water application was estimated to be 60 in. above the bottom of the weight factor dip tube, and the saltwell pump was removing liquid from the saltwell screen at approximately 0.3 gpm. The water application rate was 3.7 gpm during the first hour, and 2.9 gpm during the second hour. Specific gravity data indicated that surface runoff of unsaturated brine did in fact occur, and that the runoff was relatively dilute. This is illustrated in Figure 4-2, where the specific gravity measurements have been plotted for the time period of interest. As is typical, the specific gravity data show substantial scatter.

The brine apparently required about 0.5 hours to reach the saltwell, as indicated by the drop in specific gravity at about 3:00 p.m. The observed drop in liquid specific gravity was expected. The cause of the second drop in specific gravity, starting around 7:30 p.m., is not well established. It may be associated with a sudden release of unsaturated brine into the saltwell, or with changes in the pumping, dilution water additions, or mixing behavior of the saltwell. The trends in the gamma concentration data include the first drop in specific gravity, but not the second.

The pre-water-addition gamma concentration measurements averaged to about 7400 μCi/cc. This is much higher than the total of about 350 μCi/cc measured in the saltwell grab samples, and even higher than the concentration to be expected at the in-line dilution of 1 part water per 4 parts waste that was used. Some discrepancy was expected because the absolute gamma measurement requires calibration against a standard to be accurate, but the magnitude of the difference indicated that excess background radiation was affecting the sensor.

As expected, the near-saltwell water addition had no effect on the temperatures measured at the thermocouple tree (located near the wall).

Figure 4-2. First Near-Saltwell Water Addition (12/3/2002).



The "shadowing" water addition was also 400 gal, a decrease from the planned 500 gal (Table 4-1). This test was intended to examine the effects of an obstacle in the spray pattern. The water addition lasted from 12:08 p.m. to 3:00 p.m. on December 4. Water was applied at a rate of about 2.8 gpm for 82 minutes (12:08 a.m. to 1:30 p.m.), then reduced to about 1.9 gpm for the second half of the test. The water had no immediate effect on the saltwell liquid SpG or level or on the gamma of the pumped liquid, as is shown in Figure 4-3, indicating that there was no significant surface runoff from the test. Given the relatively small volume of the water applied, the distance from the saltwell screen to the target area, and that liquids in the upper few inches of waste had been drained before the test, no surface runoff was expected.

The test did cause two separate sharp drops in temperature at the thermocouple tree (the obstacle which was the target of the spray), as depicted in Figure 4-3. The temperature drops are evidently due to the spray water temperature, indicated to be about 60 °F by thermocouples 6 and 7, which were above the waste and in the water spray, and to the endothermic dissolution of sodium nitrate and other sodium salts, as indicated by thermocouple 5 located at 118 in., just below the waste surface. Temperature observations are discussed in greater detail in Section 5.2.

The first in-tank video that was taken after the shadowing test was on December 10, 2002. That video shows no shadow of waste behind the thermocouple tree. The high water application rate for this relatively small region of waste may have caused a small pool to form around the thermocouple tree, which would have effectively dissolved the waste in the shadow. Lower water application rates would not necessarily have the same favorable result. Also, by the time of the video was taken, near-wall tests had also been conducted and might also have changed the waste surface around the thermocouple tree.

The initial near-wall water application test, which sprayed about 300 gal at the waste near the wall, was conducted between 10:06 a.m. to 11:46 a.m. on December 5. The spray rate was about 3 gpm. Originally intended to spray only the waste surface, some of the water was actually directed at the wall above the waste because the waste surface was lower than had been expected. Coincident with the start of water application, thermocouple 5 on the nearby thermocouple tree registered a drop in temperature (Figure 4-4). Specific gravity measurements in the saltwell were not available for December 5, but gamma concentration did not drop after the near wall test.

On the same day, December 5, the first 549 gal of a water addition eventually totaling 2,000 gal was applied near the saltwell in an attempt to cause channeling with resulting dilute runoff. This water addition lasted from 12:11 p.m. to 3:00 p.m., with a spray rate between 3 and 3.5 gpm. As mentioned above, saltwell specific gravity data were unavailable for December 5. Though specific gravity data from December 6 indicate the saltwell liquid to be unsaturated (shown in Figure 4-4), the continued low specific gravity is due at least in part to 40 gal of system flush water added on December 6, as confirmed by the simultaneous drop in gamma.

Figure 4-3. "Shadowing" Water Addition (12/4/2002).

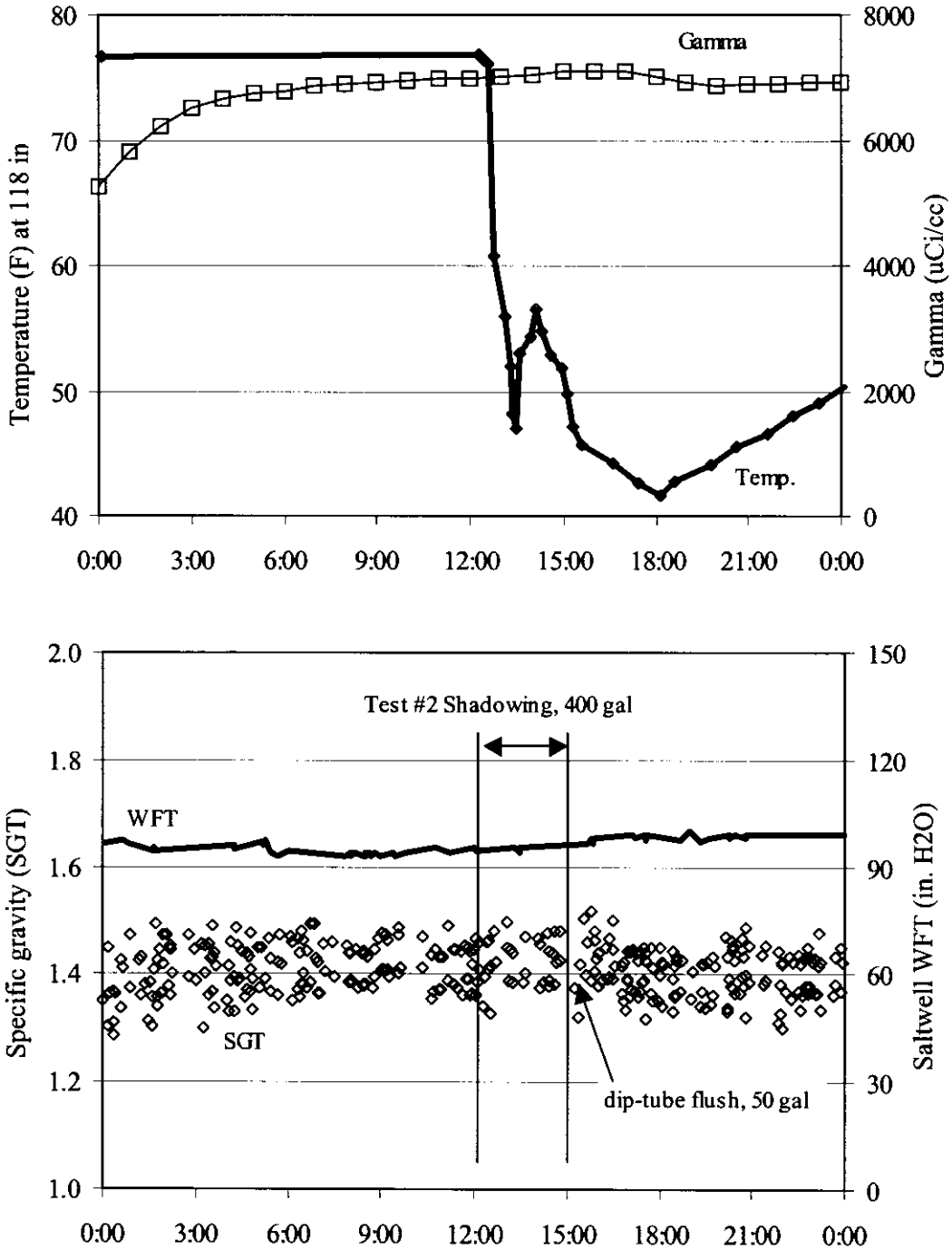
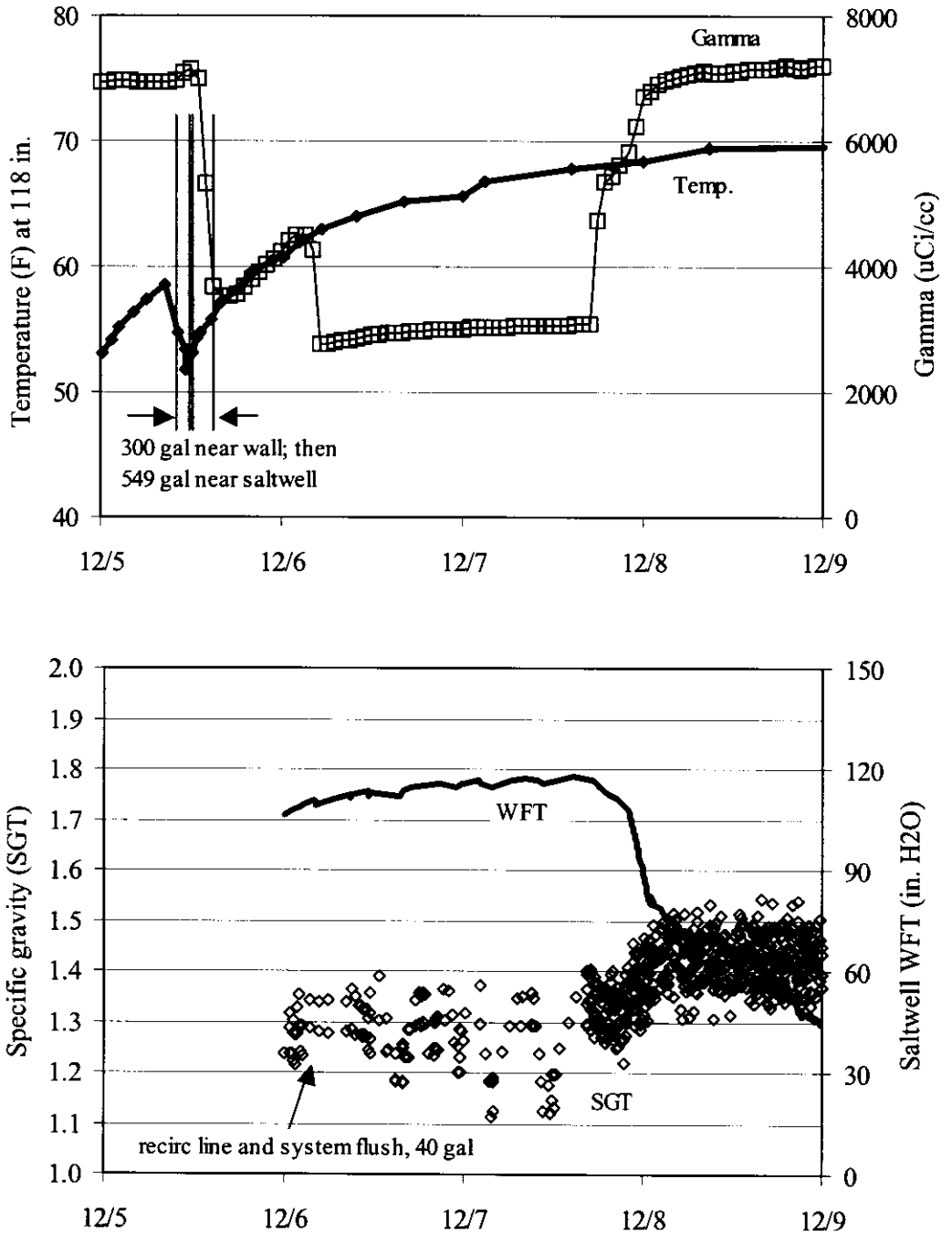


Figure 4-4. Near-Wall and Near-Saltwell Water Additions (12/5-8/2002).



Because of external constraints on pumping, no further water was applied until December 14, 2002, when the near-saltwell channeling test that had begun on December 5 was continued (Figure 4-5). Spray rates ranged from 3.1 to 3.6 gpm over a period from 7:45 a.m. to 2:58 p.m. A total of 1,451 gal of water were added on this day, completing the planned 2,000 gal.

Dilute brine reached the saltwell about 15 minutes after the start of water application, as evidenced by the rapid rise in saltwell liquid level (see Figure 4-5). Prior to this rise, the saltwell liquid was too low to allow specific gravity measurements (the liquid level was below the bottom of the specific gravity dip tube), but had indicated a specific gravity of about 1.4 the previous evening (before the liquid level had been dropped). The high gamma concentration before the liquid level rise is consistent with nearly undiluted saltwell liquid. The reason for the drop in specific gravity and gamma concentration on the afternoon of December 15 is unknown.

During the seven hours of specific gravity measurements before the water application was stopped, the average specific gravity in the saltwell was only about 1.1. Assuming that the low specific gravity was that of the dissolution brine, rather than being the effect of in-line dilution water mixing with the liquid in the saltwell screen, there are two possible interpretations of low brine density. First, the water could have been in contact with waste that was still predominantly sodium nitrate, but not reaching dissolution equilibrium with it because of mass-transfer limitations. Second, the water could have been in contact with waste that contained only less-soluble salts such as sodium phosphate, owing to leaching of nitrate by earlier water applications. In this case, low specific gravity could be consistent with complete saturation in the salts that were available.

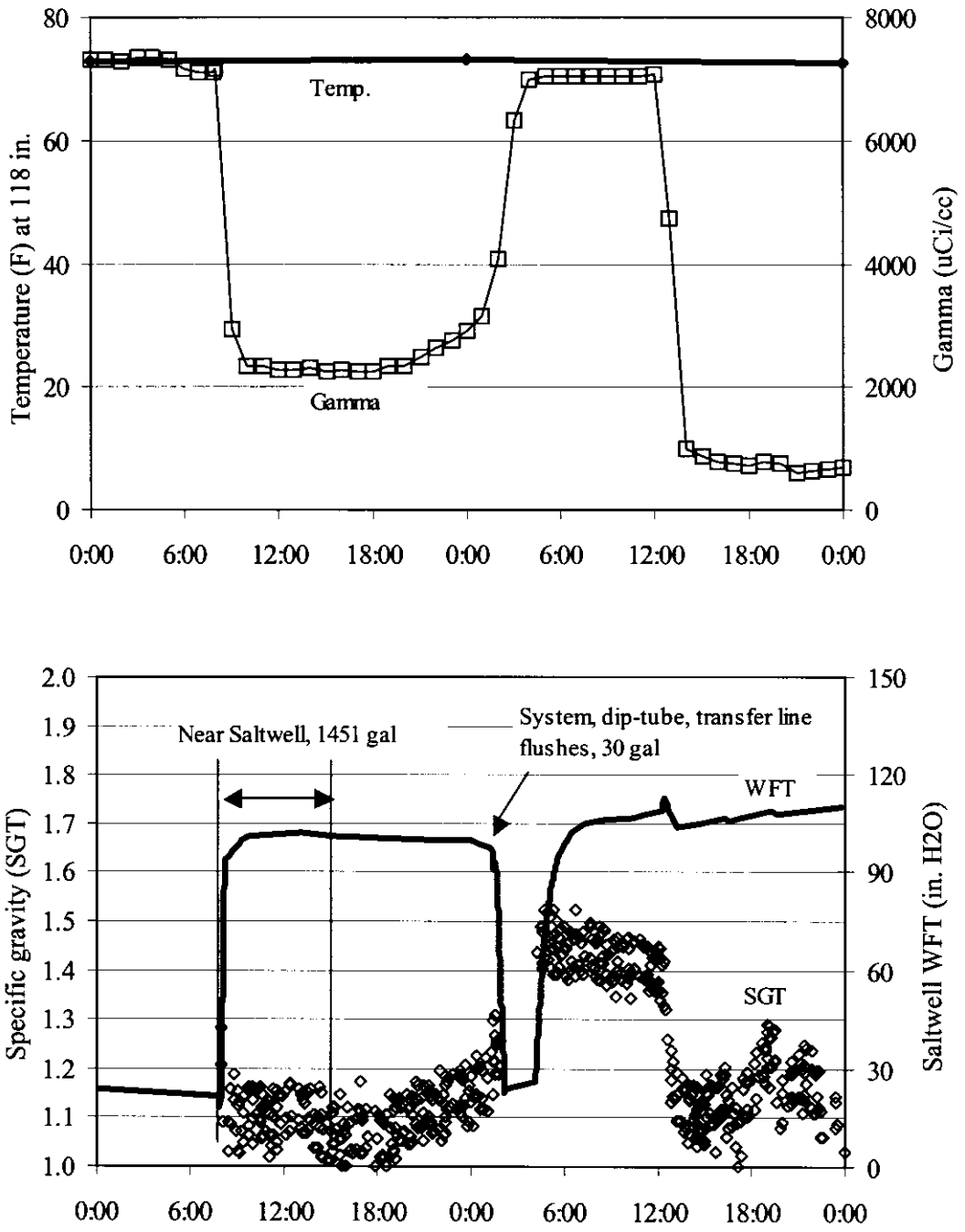
As in the initial near-saltwell test and as was expected given the thermocouple tree location, the thermocouple tree measurements were unaffected by this near-saltwell water application.

4.2 LARGE-VOLUME NEAR-WALL TEST (SECOND PHASE)

In the second phase of the proof-of-concept test, 7,501 gal (of a planned 8,000 gal) of water were added near the tank wall. This test was intended to determine whether spraying far from the saltwell would cause brine to reach the saltwell by surface runoff (with possible channeling), whether it would pool, or whether it would migrate under the surface.

The large-volume near-wall test was begun at 11:45 a.m. on December 17, 2002, with the addition of 600 gal of water at a nearly constant rate of 2.6 gpm. Water addition was ended at 3:30 p.m., at the shift change. Although constant water addition had been planned, the pumping rate limitations imposed by the transfer-line and by interim stabilization of other U-Farm tanks (241-U-108 and 241-U-111) often made it necessary to pump for up to five days after each water addition to remove the added volume.

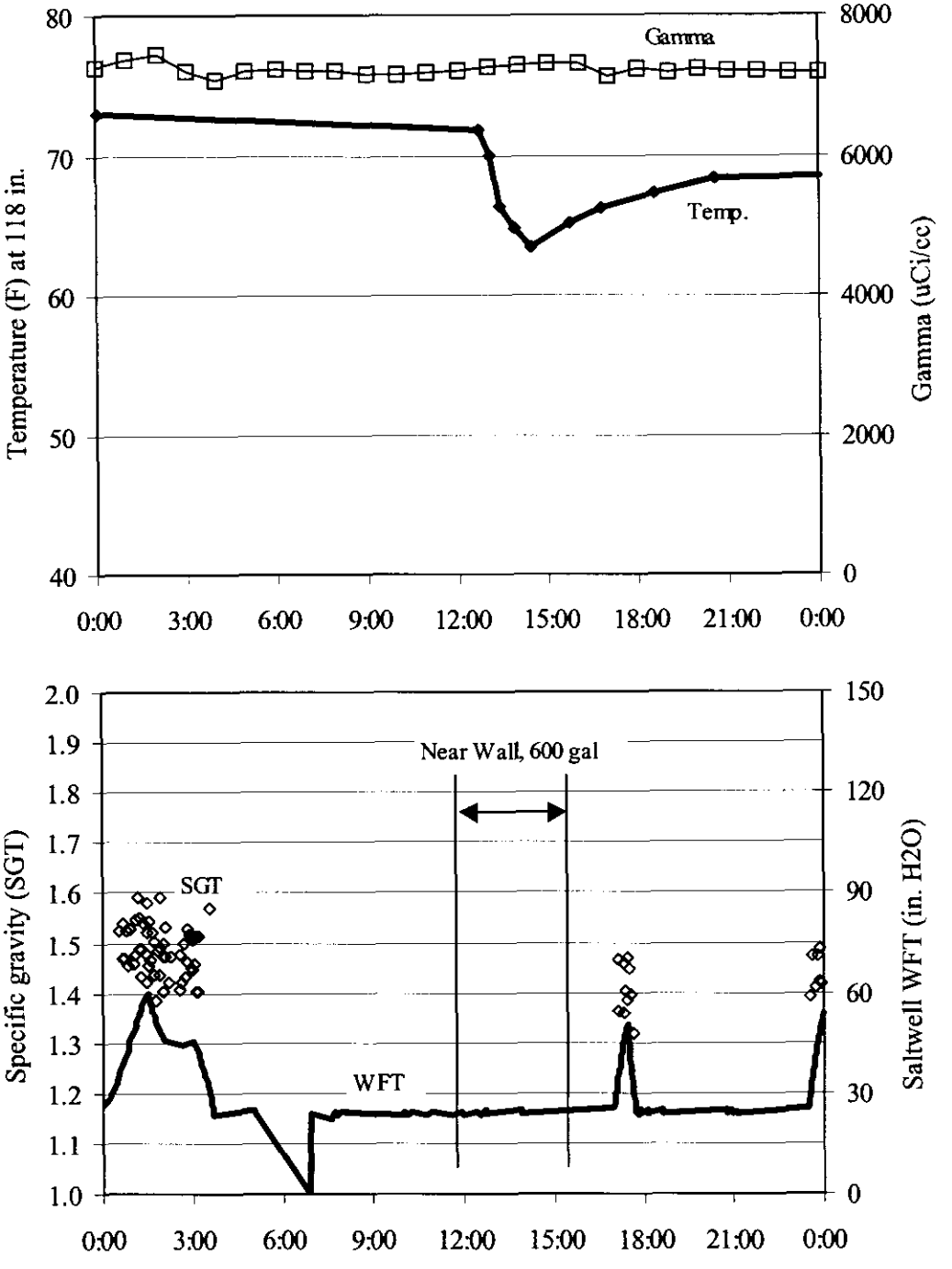
Figure 4-5. Continued Near-Saltwell Water Addition (12/14-15/2002).



Neither the saltwell liquid level, the saltwell liquid specific gravity, nor the gamma concentration in the pumped liquid responded to the 600-gal addition of water on December 17, as is shown in Figure 4-6. The rise in liquid surface level starting at about 5:00 p.m. is associated with a temporary stoppage of the pump. The temperature at the

thermocouple tree dropped gradually during the water application. The tree is near to (and potentially downstream of) the near-wall spray area.

Figure 4-6. Continued Near-Saltwell Water Addition (12/17/2002).

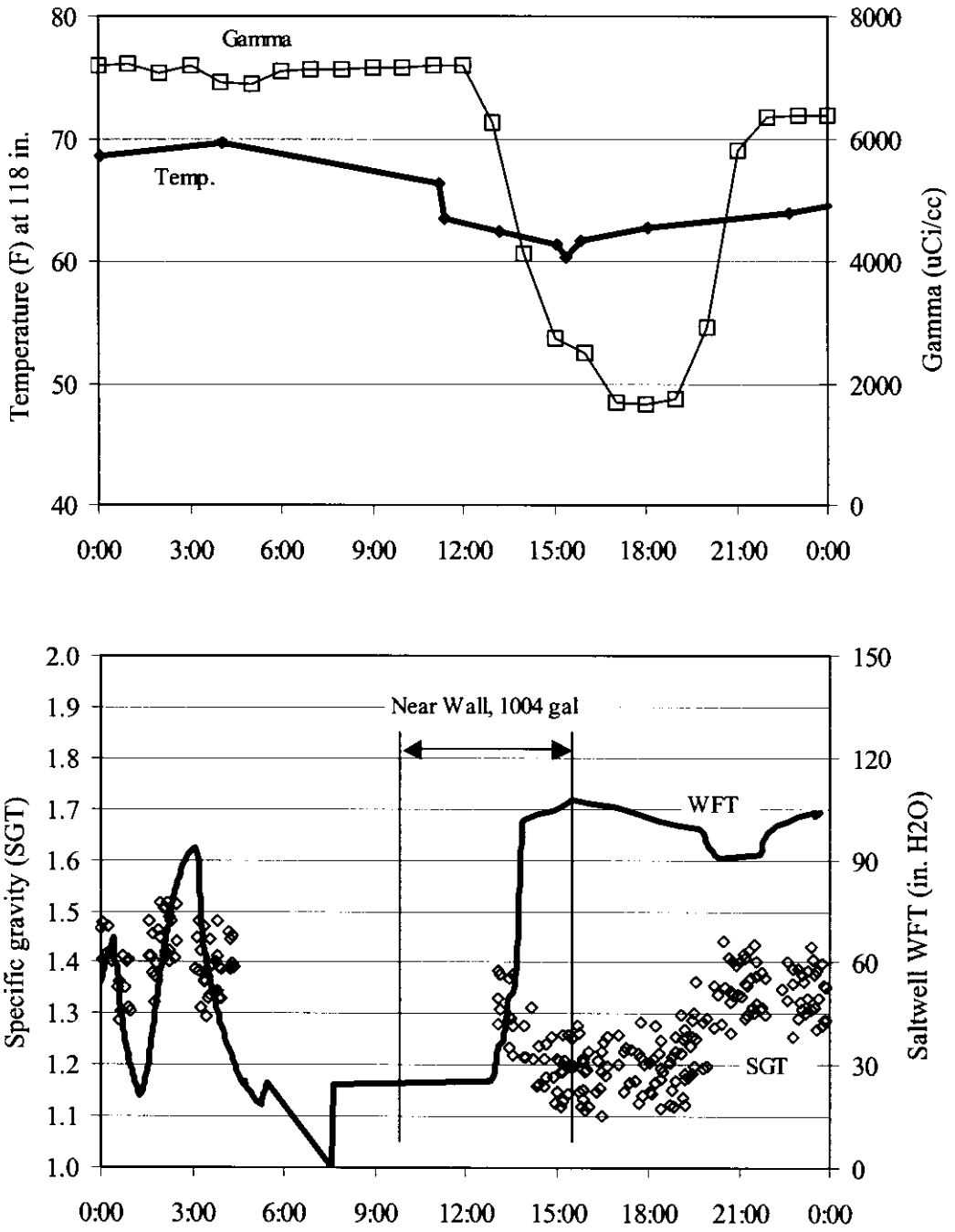


Near-wall spraying continued the next day, December 18, with an additional 1,004 gal of water added between 9:50 a.m. and 3:30 p.m. (Figure 4-7) at a rate of about 3 gpm. On this day, the near-wall water addition appeared to have made a short-circuit to the saltwell; the saltwell liquid level rose sharply and the specific gravity dropped several hours after the spraying began. The spray had little effect at the thermocouple tree.

An in-tank video was taken on December 18 between 1:00 p.m. and 1:16 p.m. Comparison of this video with one taken on October 18 showed that a triangular depression seemed to have formed along the wall, and might have been 4 to 6 in. deep. At this point, 1,604 gal of water had been sprayed near the tank wall by this test, in addition to the 300 gal that had been applied during the initial near-wall test.

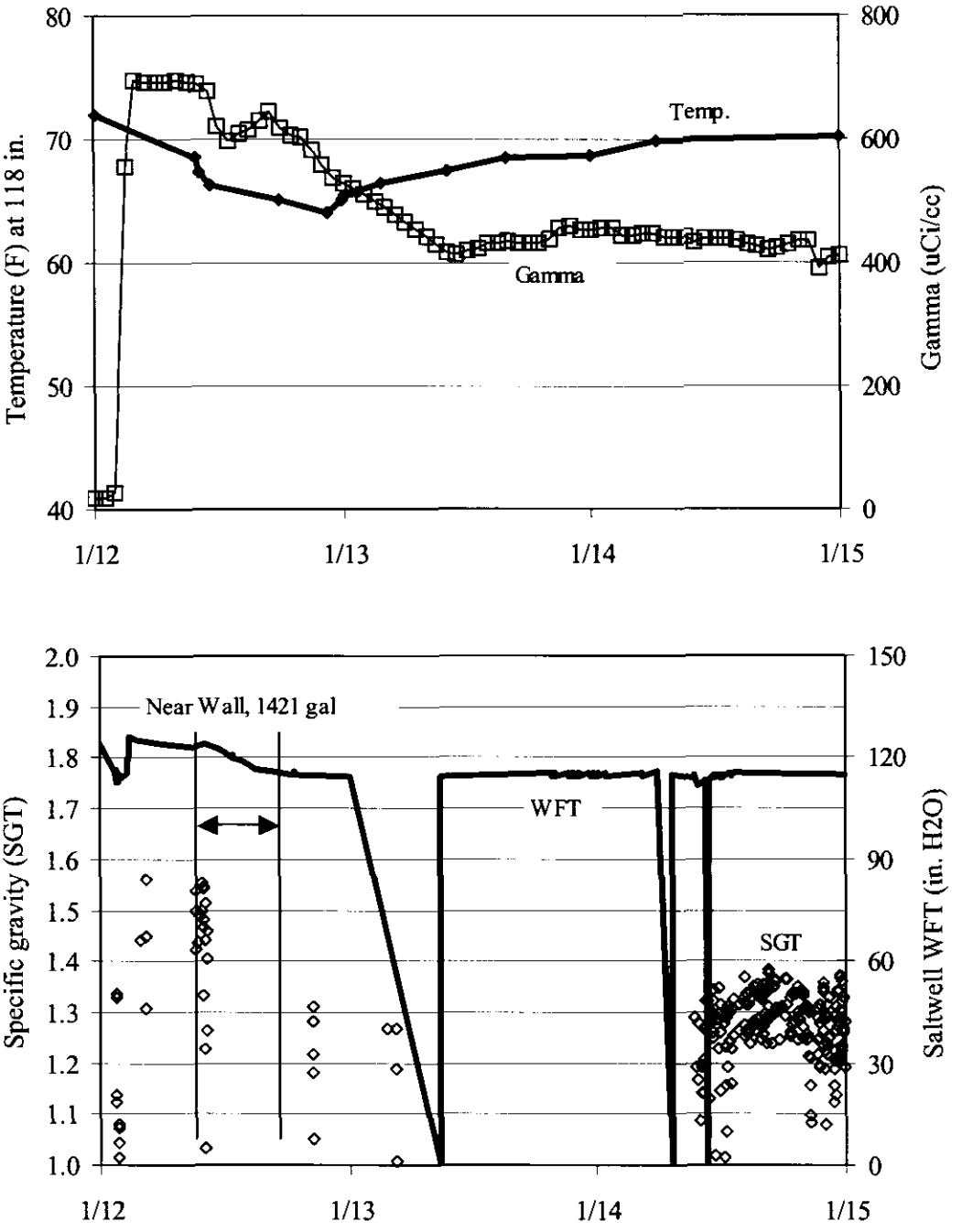
Near-wall spraying was shut down for more than three weeks at this point and began again on January 12, 2003. Between 9:15 a.m. and 5:15 p.m. 1,451 gal of water were added at a rate varying from 2.8 to 3.1 gpm. Figure 4-8 shows monitoring data from the day of the water addition and the two days following. Sparse saltwell liquid specific gravity measurements during the water addition and for about two days afterwards make interpretation of this event difficult. A gradual decrease in the weight factor during the water addition suggests no surface runoff occurred, but scattered specific gravity readings suggest the specific gravity may have declined during the same period. A decrease in gamma concentrations corroborates the decrease in specific gravity and shows the decrease began very soon after the water addition began. Only a small, very gradual drop in temperature was seen at the thermocouple tree.

Figure 4-7. Continued Near-Saltwell Water Addition (12/18/2002).



Another in-tank video was taken on January 14 between 1:16 p.m. and 1:31 p.m. A distinct depression had been formed in the saltcake near the wall by January 14. No channel from the hole to the saltwell was evident in this video. At this time, a total of 3,355 gal of water had been added in the near-wall area.

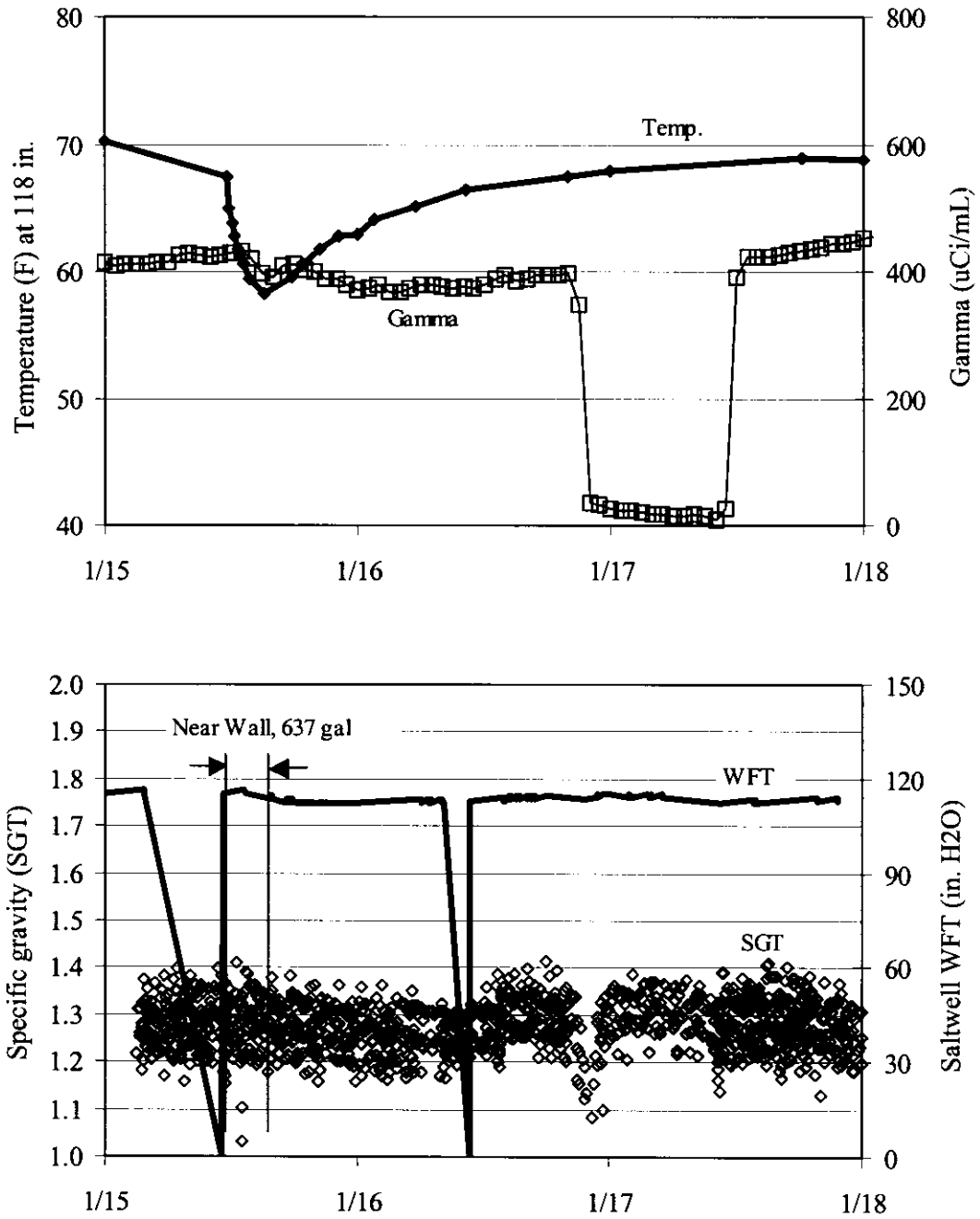
Figure 4-8. Continued Near-Saltwell Water Addition (1/12-14/2003).



After two days without water addition, 637 gal of water were sprayed near the wall between 11:30 a.m. and 3:30 p.m. on January 15, 2003. The spray rate was about 3 gpm. Figure 4-9 shows that neither the weight factor nor the specific gravity readings changed

significantly during or immediately after this relatively small water addition, indicating that surface runoff of unsaturated brine was not significant. This water addition, though smaller than the two previous ones, produced a larger temperature decrease at the thermocouple tree.

Figure 4-9. Continued Near-Saltwell Water Addition (1/15-17/2003).

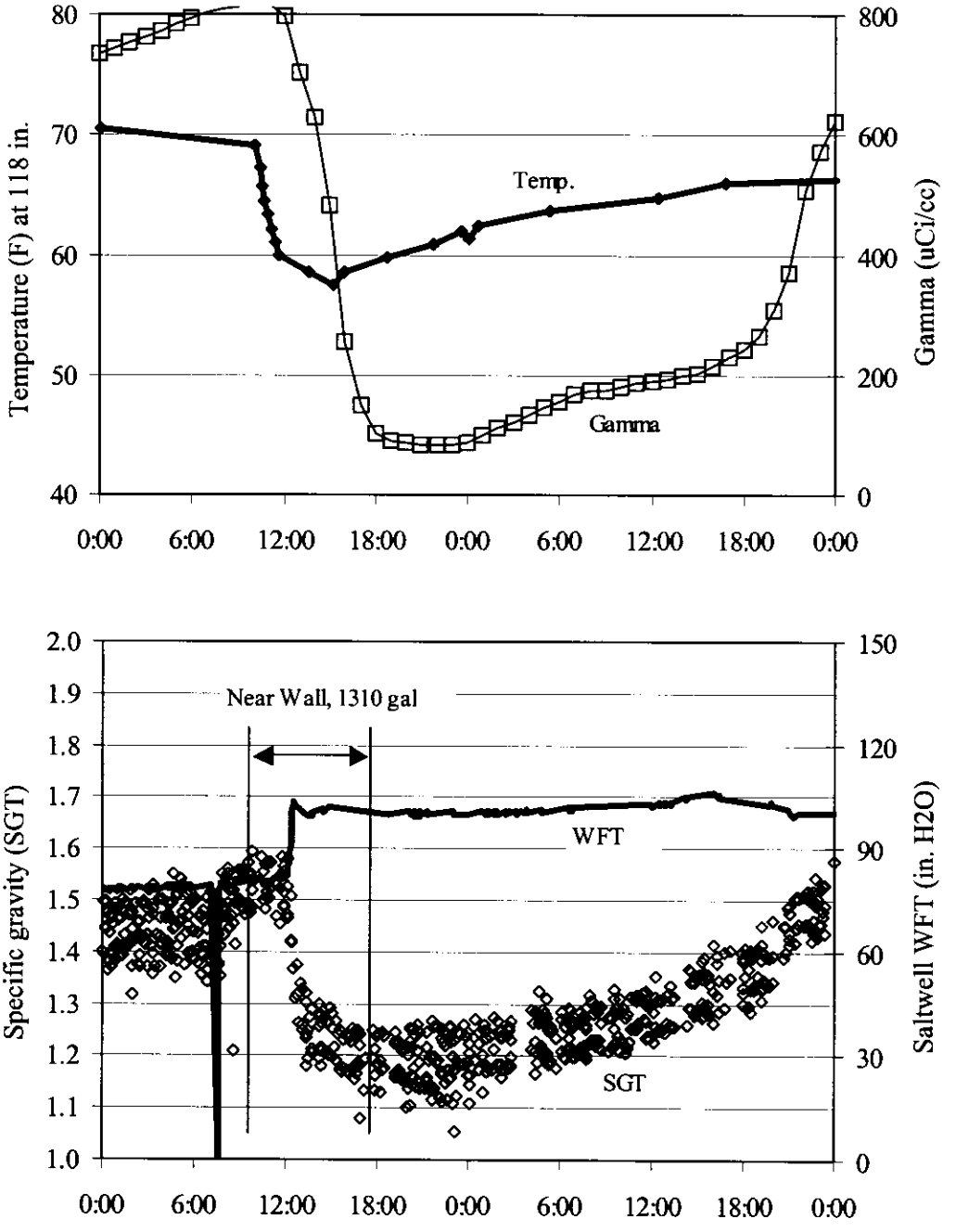


The relatively low measurements of saltwell liquid specific gravity and gamma concentration that were observed between January 14 and 18 (Figures 4-8 and 4-9) are not well understood. The low values may be due to mixing of the dilution water with the drained interstitial liquid at the bottom of the saltwell. The possibility exists that unsaturated brine was being transported via subsurface seepage to the saltwell, but that is inconsistent with the expectation that the intimate contact of water and salts within the saltcake cause saturation of the water within minutes or at most tens of minutes.

The next near-wall water addition was on January 27, 2003, and consisted of 1,310 gal of water sprayed between 9:30 a.m. and 5:30 p.m. The spray rate was 2.8 gpm. Figure 4-10 shows the results on that day and the day following. A fairly sharp temperature decrease was observed soon after water addition began. About 2 hours into the test the gamma concentration and saltwell liquid specific gravity began to drop and the liquid level to rise, indicating clearly that a significant amount of dilute brine was arriving at the saltwell. The recovery of the specific gravity from this incursion required about 36 hours. Given that the level of liquid in the saltwell remained consistently high during this period (see Figure 4-9) and the pumping rate was in the 0.2 to 0.3 gpm range, it seems unlikely that the increase in specific gravity during this period was due simply to the removal of all unsaturated liquid and the influx of saturated interstitial liquid. Instead, the increase in specific gravity is more reasonably associated with the dissolution of salt at the wall of the saltwell and the accumulation of this saturated brine and liberated interstitial liquid in the region of the SpG and weight factor dip tubes.

After four days without spraying, 1,757 gal of water were added near the wall between 7:45 p.m. February 1, 2003 and 5:30 a.m. February 2, 2003. The water addition rate was 2.8 to 3.3 gpm. Figure 4-11 shows the results for February 1 through February 4. After the spray rate was increased, the gamma, specific gravity, and weight factor data indicate dilute brine reached the saltwell. The specific gravity took more than 48 hours to recover. The temperature drop at the thermocouple tree preceded the saltwell brine incursion by several hours.

Figure 4-10. Continued Near-Saltwell Water Addition (1/27-28/2003).



An in-tank video taken on February 3, 2003 showed that the near-wall triangular depression seen in earlier videos had become larger. Its volume had approximately doubled or tripled since the video on January 14. What appeared to be a channel leading from the depression was visible in the video, with the implication that this was formed by surface runoff. At this time, a total of 7,029 gal of water had been added in the near-wall area.

Figure 4-11. Continued Near-Saltwell Water Addition (2/1-4/2003).

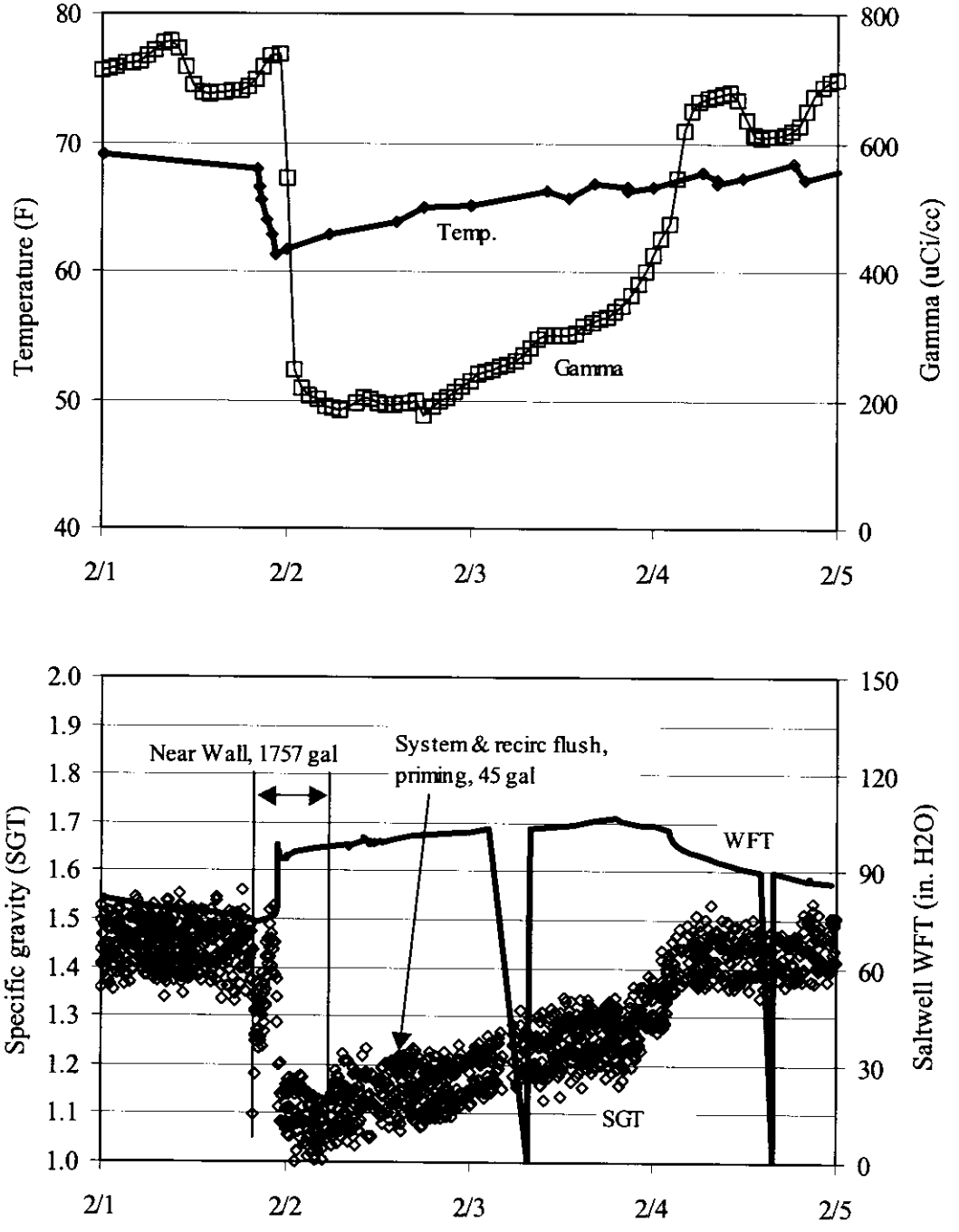


Figure 4-12 is a photograph taken from the video. Two of the tank stiffener rings are visible, and the distance between them is roughly 1 m. Using this distance for scaling, the hole can be approximated as a triangle about 1.7 m long along the wall, 1 m long

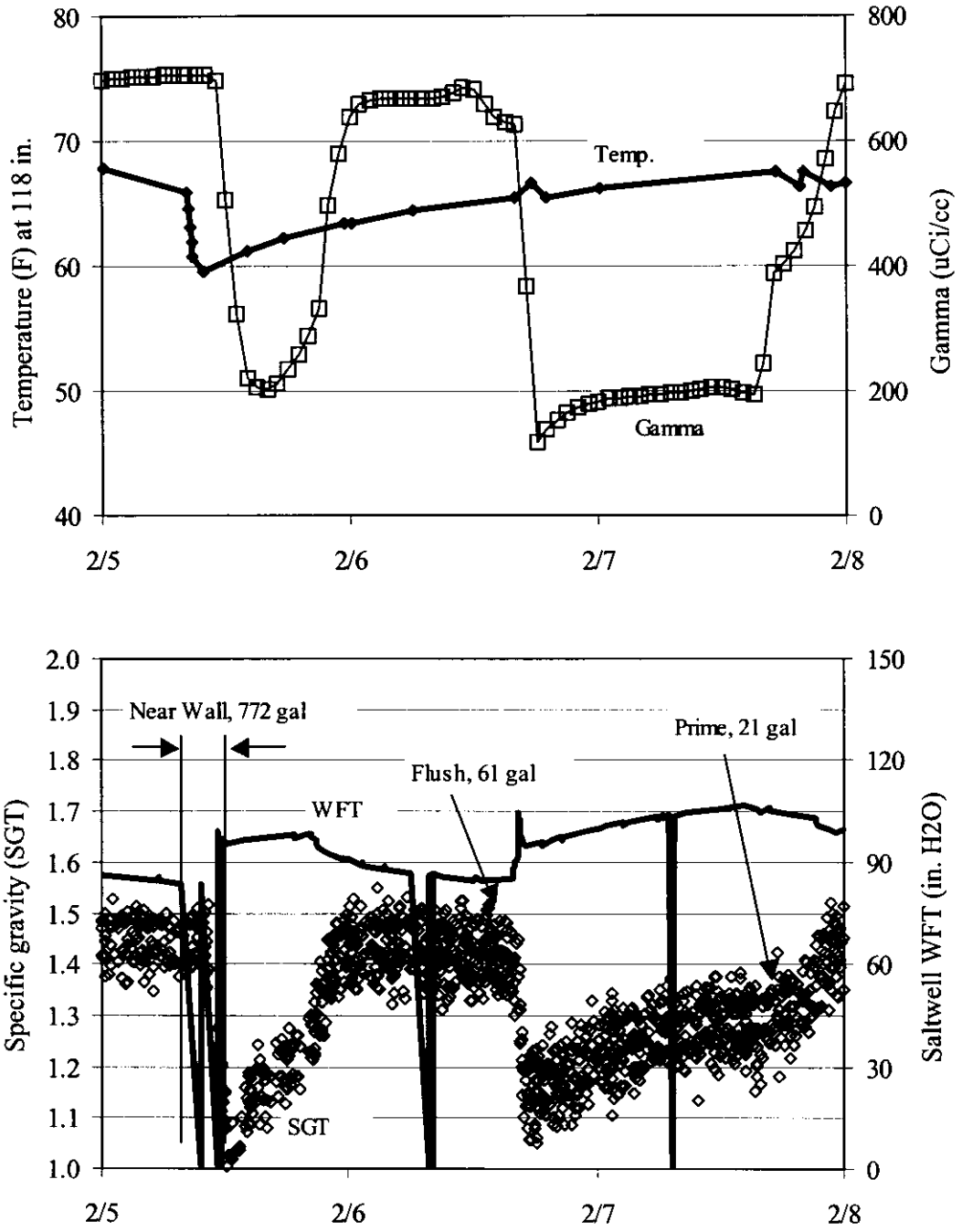
away from the wall, and 0.3 m deep. Its volume is about 0.5 m^3, or 130 gal. Considering the irregular depressions around the hole, and the volume of the channel, the total visible affected volume is estimated to be about 200 gal.

Figure 4-12. Hole Produced by Near-Wall Spraying (February 3, 2003).

The final near-wall water addition of 772 gal took place between 7:37 a.m. and 12:00 p.m. on February 5, 2003. Monitoring data for this event are shown in Figure 4-13. The spraying rate was about 3 gpm. Dilute brine flowed into the saltwell about 3 hours after the spraying began. By contrast, when a similar volume of water had been added on January 15, no immediate effect was apparent at the saltwell. This may be due to the differences in thickness of the unsaturated saltcake layer present at the start of the January 15 and February 5 events. Dissolution of the upper saltcake and accumulation of liquids in this region of the waste would have given the waste less capacity to absorb water on February 5, and resulted in surface runoff. There is also the consideration that surface runoff is more likely once a channel has been formed from previous surface runoff events.

The specific gravity and gamma concentration recovered in about 13 hours after the February 5 water application was stopped. The temperature decrease matched the pattern shown in the two previous water additions, being relatively sharp but not so large as to prove that unhindered, rapid endothermic dissolution was occurring.

Figure 4-13. Final Near-Saltwell Water Addition (2/5-7/2003).



5.0 TANK 241-U-107 DISSOLUTION DATA ANALYSIS

Data recorded during the tank U-107 saltcake dissolution proof-of-concept operations provide the means to assess the effectiveness and safety of the operations. They also provide insight into chemical and physical effects of the dissolution process. The effectiveness of the saltcake dissolution process is evaluated in Section 5.1 by evaluating the amount of original waste removed from the tank. Temperature effects of the dissolution water additions are discussed in Section 5.2. In Section 5.3, interstitial liquid drainage is considered. In Section 5.4, gas release histories during the dissolution are presented, and a qualitative discussion of process leak detection is in Section 5.5.

5.1 WASTE REMOVED BY DISSOLUTION

In saltcake dissolution waste retrieval, water-soluble waste salts are mobilized by dissolution and removed from the tank by saltwell pumping. Specific data recorded during the dissolution process allow the amount of original waste removed from the tank to be determined. The effectiveness of the process is measured by comparing the volume of solid waste retrieved to the volume of solid waste that would be dissolved if the applied water were completely saturated.

5.1.1 Waste Removal Model

The parameters for the original waste transfer model are listed below. All parameters refer to material that flows into the saltwell screen and is removed from the tank, as depicted in Figure 5-1. The parameters measured by the process instrumentation (Section 2.1) are denoted as such, and additional data sources are noted:

- V_B Bulk volume of saltcake in which soluble solids are dissolved;
- V_{SW} Volume of original interstitial liquid, brine produced by dissolution water, and in-line dilution water and system water;
- V_{IL} Volume of original interstitial liquid;
- V_{BR} Volume of brine produced by dissolution water;
- V_H Volume of dissolution water in brine;
- V_S Volume that the dissolved solids in the brine occupied prior to dissolution;
- V_M Volume of original interstitial liquid and brine produced by dissolution water;
- V_T Total volume of liquid removed from the tank (includes in-line dilution water and system water, measured by saltwell pumping system flow totalizer);
- V_D Volume of in-line dilution water (measured by saltwell pumping system dilution flow totalizer);
- V_{SH} Volume of system water (pump priming, dip tube flushes, saltwell system flushes, etc.; measured by appropriate instrumentation depending on water application);
- V_{DS} Volume of dissolved solids in the brine;

M_{DS} Mass of dissolved solids in the brine;

M_{SDS} Mass of dissolved solids in the brine at saturation ($\rho_{BR} = \rho_{IL}$);

ρ_{IL} Density of original interstitial liquid (core sample measurements, modeling);

ρ_{SW} Density of mixture of original interstitial liquid, brine produced by dissolution water, and in-line dilution water and system water (measured by saltwell dip tubes);

ρ_{BR} Density of brine produced by dissolution water;

ρ_H Density of water (assumed to be 997 kg/m^3);

ρ_S Density of soluble solids in their undissolved state;

ρ_{DS} Density of soluble solids in their dissolved state;

χ_{BR} Mass fraction of water in brine produced by dissolution water (function of ρ_{BR} based on core sample measurements, modeling);

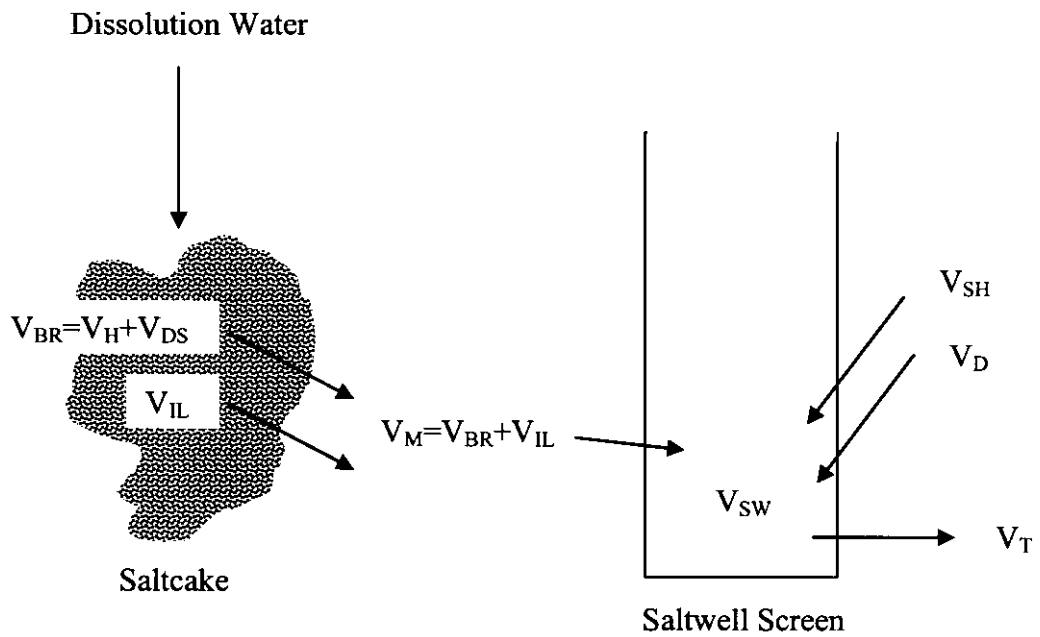
χ_{IL} Mass fraction of water in original interstitial liquid (function of ρ_{IL} based on core sample measurements, modeling);

α Gas volume fraction in the bulk waste;

ϕ_S Undissolved solids volume fraction of the bulk degassed waste; and

F_{SS} Volume fraction of solids that is soluble.

Figure 5-1. Schematic of Saltwell Screen Waste Parameters.



For this analysis, it is assumed that all liquid volumes are additive when mixed. The system water is assumed to have essentially the same effect on specific gravity measurements as the in-line dilution water, and the combination of the two is henceforth referred to as dilution water. The effect of the dilution water on the density of the liquid in the saltwell is unknown, and could not be clarified by examination of the dilution

additions and saltwell density histories. The potential effect of the dilution water on the saltwell density is therefore accounted for by defining the volume fraction of the dilution water that mixes into the saltwell screen (as opposed to being directly introduced into the transfer pump) to the volume of dilution water added as

$$\varepsilon = \frac{(V_D + V_{SH})_{SW}}{V_D + V_H}. \tag{5.1}$$

With ε, the saltwell and mixture volumes can be written in terms of the dilution and transfer volumes as

$$V_{SW} = V_T - (V_D + V_{SH})(1 - \varepsilon), \tag{5.2}$$

and

$$V_M = V_{SW} - (V_D + V_{SH})\varepsilon = V_T - (V_D + V_{SH}), \tag{5.3}$$

respectively. The mass of liquid in the saltwell screen is comprised of the mixture (brine produced by dissolution and original interstitial liquid) and the water added from the dilution water. From this mass, the mixture density is simply

$$\rho_M = \frac{\rho_{SW} V_{SW} - \rho_H (V_D + V_{SH})\varepsilon}{V_M}, \tag{5.4}$$

where V_{SW} and V_M are given by Equations 5.2 and 5.3, respectively.

If the volume fraction of the original interstitial liquid in the mixture of original interstitial liquid and brine produced by the dissolution water is defined as

$$\eta = \frac{V_{IL}}{V_M}, \tag{5.5}$$

then, from a mass balance on the mixture, η may be computed as

$$\eta = \frac{\rho_{SW} - \rho_{BR}}{\rho_{IL} - \rho_{BR}}. \tag{5.6}$$

The volume of original interstitial liquid and volume of brine from dissolution water are then given by

$$V_{IL} = \eta V_M, \tag{5.7}$$

and

$$V_{BR} = (1-\eta)V_M, \tag{5.8}$$

respectively.

In previous analyses for Hanford Site double- and single-shell tanks, correlations have been developed which relate the density to the mass fraction of water of a brine (e.g., Rassat et al. 2000, Estey et al. 2003, Hanson 2003). For this analysis, a mass balance on the brine is used to define the mass fraction of water in the brine:

$$\chi_{BR} = \frac{\frac{\rho_{DS}}{\rho_{BR}} - 1}{\frac{\rho_{DS}}{\rho_H} - 1} \tag{5.9}$$

Data from TWINS[7], Herting[8], and Environmental Simulation Program (ESP) results for dissolution of U-107 waste[9] were analyzed. A least squares analysis provided the fit shown in Figure 5-2; the error in the fit was minimized for ρ_{DS} = 2.607 kg/L. This value was therefore used in all model calculations.

The volume of water in the brine produced by the dissolution water is then given by

$$V_H = V_{BR}\chi_{BR}\frac{\rho_{BR}}{\rho_H}. \tag{5.10}$$

The mass of the dissolved solids in the brine, or

$$M_{DS} = \rho_{BR}V_{BR}(1-\chi_{BR}), \tag{5.11}$$

is used to determine the volume of the solids in their pre-dissolution state as

$$V_S = \frac{M_{DS}}{\rho_S} = \frac{\rho_{BR}}{\rho_S}V_{BR}(1-\chi_{BR}). \tag{5.12}$$

The bulk volume of saltcake dissolved to provide V_S is given by

$$V_B = \frac{V_S}{\phi_S F_{SS}(1-\alpha)}. \tag{5.13}$$

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[7] TWINS: Tank Waste Information System, http://twins.pnl.gov/twins3/twins.htm

[8] Herting, D. L., 2001, "Saltcake Dissolution Volume Results, Tank 241-U-107," (letter FH-0100932 to D. G. Baide, CH2M HILL, February 12), Fluor Hanford, Richland, Washington.

[9] Mahoney, L. A., 2002, *U-107 ESP Model Predictions for Saltcake Dissolution by Water*, Letter report TWS02-067, Pacific Northwest National Laboratory, Richland, Washington.

If it is assumed that saturated brine is equivalent in specific gravity and water fraction to the original, saturated interstitial liquid, Equation 5.11 can be written as the dissolved solids mass in the brine at saturation, or

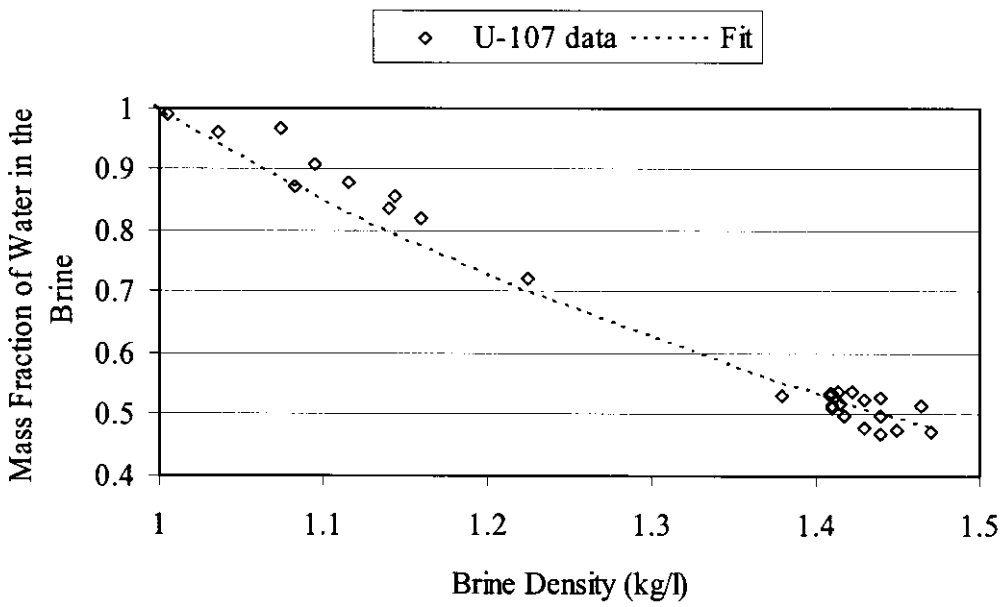
$$M_{SDS} = \rho_{IL}(1-\eta)V_{SW}(1-\chi_{BR}). \tag{5.14}$$

The level of saturation in the brine removed from the tank is then expressed as

$$S = \frac{M_{DS}}{M_{SDS}}. \tag{5.15}$$

The assumption that saturated dissolution brine is equivalent to interstitial liquid implies the assumption that the brine was in contact with waste that was predominantly sodium nitrate, as was the case for the interstitial liquid. If, because of earlier water additions, the brine contacted only low-nitrate high-phosphate waste, then the dissolution brine could have been saturated and nevertheless had a specific gravity much lower than that of the interstitial liquid. This possibility could not be evaluated with the data that were gathered, and was excluded from the analysis.

Figure 5-2. Mass Fraction of Water in the Brine as a Function of the Brine Density for Tank 241-U-107.



5.1.2 Waste Removal Results

A model was developed, based on the equations of Section 5.1.1, to evaluate the saltcake dissolution operation in tank U-107. The time period of the dissolution operation, December 3, 2002 to February 8, 2003, with a follow-up period to February 28, 2003,

was divided into half-day segments, and calculations were conducted for those periods during which transfers out of tank U-107 occurred.

In Equations 5.7 and 5.8, η is computed from Equation 5.6 and in Equations 5.10 and 5.12, χ_{BR} is determined from Equations 5.9. As specified, V_T, V_D, V_{SH}, and ρ_{SW} are measured by the process instrumentation.

The validity of the saltwell density measurements is not always clear. As discussed in Section 4, variation in the saltwell density is qualitatively associated with dissolution water additions. However, when these data are evaluated in terms of the volume of water addition and the estimated liquid volume in the saltwell, the measured saltwell densities are lower than expected. Additionally, some saltwell densities lower than water and above that expected for a maximum interstitial liquid density were recorded.

Saltwell density data are generally recorded at three-minute intervals. The density data below 0.985 kg/L were filtered out, as well as those readings that were made when the weight factor reading at the same time stamp was less than 30 in H_2O (see Section 4.1). Half-day averages were then taken. No attempt was made to further quantify uncertainties in the measured saltwell density values.

The interstitial liquid and soluble solids densities, volume fraction of gas in the bulk waste, undissolved solids volume fraction in the degassed waste, and the fraction of the solids that is soluble have been determined from core samples and modeling and have quantifiable uncertainties (Estey et al. 2003). The fraction of the dilution water that mixes into the saltwell liquid and the density of the brine are unknown. A Monte Carlo simulation approach (with 14,000 realizations) was used to determine the range of possible results for the volume of original tank U-107 waste removed from the tank and associated parameters (volume of interstitial liquid removed, etc.), given the parameter uncertainties.

The fraction of the dilution water that mixes into the saltwell screen (ε) was allowed to vary uniformly between zero (i.e., no dilution water mixes into the saltwell screen) to the maximum dictated by setting ρ_{SW} in Equation 5.4 to ρ_{IL} and solving for ε. A different ε is selected for each half-day time step in the model.

The dissolution brine density was constrained to be between the density of water and that of the saltwell by

$$\rho_{BR} = \rho_H + (\rho_{SW} - \rho_H)B, \tag{5.16}$$

where B is assigned a uniform distribution from zero to unity. A different B is selected for each half-day time step in the model. The brine density was constrained to be equal to or less than that of the interstitial liquid. This is supported by ESP simulation results

for stepwise dissolution of tank U-107 waste.[10] With this constraint, the saltwell liquid must be less than or equal to the interstitial liquid density. In the Monte Carlo simulation, this constraint could be violated to varying degrees depending on the interstitial liquid density selected for that specific simulation. To account for this, the half-day averages of the saltwell density in excess of the interstitial liquid density were set to 0.001 kg/L below the interstitial liquid density.

The input parameter distributions are summarized in Table 5-1. Uncertainties in the total transfer, in-line dilution water, and system water volumes were considered negligible and are not accounted for.

Table 5-1. Input Parameter Distributions.

Parameter (units)	Symbol	Value (range) Distribution
Interstitial Liquid Density (kg/m^3)	ρ_{IL}	1440 (1380 to 1500)* normal
Dry Soluble Solids Density (kg/m^3)	ρ_S	2210 (2000 to 2260) triangular
Volume Fraction of Gas in the Bulk Waste	α	0.17 (0.08 to 0.26) uniform
Dry Solids Volume Fraction in the Degassed Waste	ϕ_S	0.37 (0.30 to 0.45) skewed normal
Fraction of Dry Solids that is Soluble	F_{SS}	0.84 (0.60 to 0.90) skewed normal
Brine Density Factor	B	0 to 1 uniform
Dilution Water Mixing Fraction	ε	0 to ε_{max}** uniform

Notes:

* Truncated to a minimum of 1420

** As defined by Equation 5.4 with $\rho_{SW}=\rho_{IL}$

The Monte Carlo simulation results for the summation of the bulk volume of saltcake in which the soluble solids were dissolved [Equation 5.13] and removed over the duration of the saltcake dissolution operation are shown in Figure 5-3. The bulk waste volume includes interstitial liquid, soluble and insoluble solids, and gas (void). The median values are shown as well as the upper and lower bounds of the 95% confidence interval (U95 and L95, respectively).

Results for the test-phase totals as well as over the entire period considered are presented in Table 5-2. For the first phase of the dissolution test, the median volume of bulk saltcake is 540 gal. In the second phase, the median is 1,060 gal, while the median over the entire period evaluated (December 3, 2002 to February 28, 2003) is 1,780 gal. Note

[10] Mahoney, L. A., 2002, *U-107 ESP Model Predictions for Saltcake Dissolution by Water*, Letter report TWS02-067, Pacific Northwest National Laboratory, Richland, Washington.

that when interim stabilization pumping re-commenced in late February, the removal of waste that had been dissolved during the demonstration continued.

The median total dissolution of bulk saltcake is 0.17 gal of saltcake per gallon of water added. The 95% confidence interval is 0.10 to 0.28 gal/gal (Table 5-2).

Figure 5-3. Bulk Saltcake Volume in which Soluble Solids were Dissolved During Saltcake Dissolution Operation.

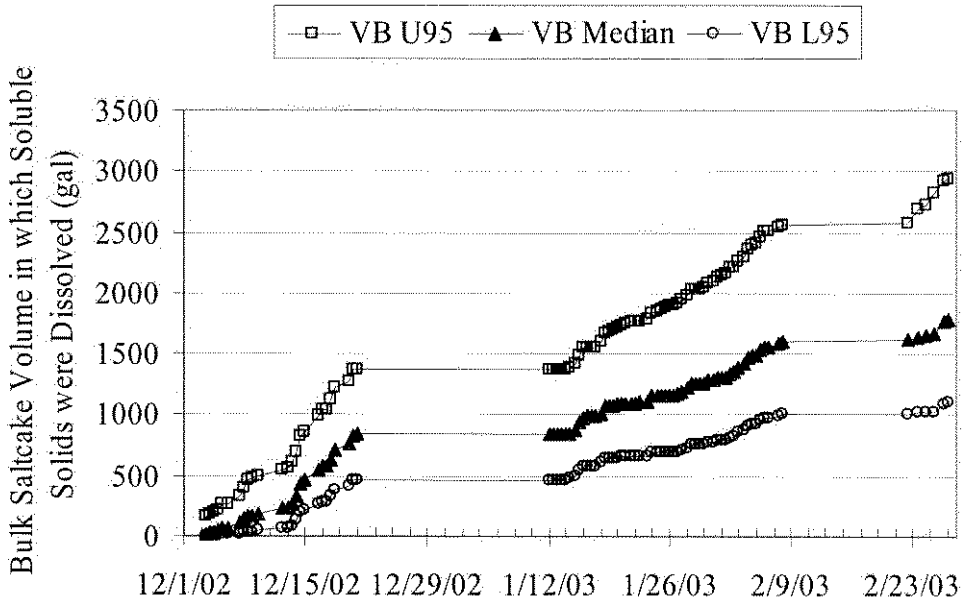


Table 5-2. Monte Carlo Simulation Results.

Parameter (Eq. #)	First Phase (12/3/02 to 12/16/02)			Second Phase (12/17/02 to 2/8/03)			Total (12/3/02 to 2/28/03)		
	U95	Median	L95	U95	Median	L95	U95	Median	L95
V_B (5.13)	980[a]	540	260	1,580	1,060	750	2,940	1,780	1,100
V_B*[b]	0.32	0.17	0.08	0.24	0.14	0.08	0.28	0.17	0.10
V_S (5.12)	240	140	70	380	270	200	710	450	290
V_{iL} (5.7)	3,010	2,700	2,310	8,540	8,200	7,600	13,950	13,180	11,960
V_{BR} (5.8)	2,060	1,660	1,360	2,890	2,280	1,950	5,490	4,260	3,500
V_H (5.10)	1,870	1,550	1,290	2,580	2,060	1,790	4,910	3,890	3,260
S[c] (5.15)	0.80	0.40	0.02	0.89	0.45	0.02	0.87	0.45	0.02

Notes:

(a) All results for volumes are in gallons.
(b) V_B per unit volume of dissolution water added.
(c) Saturation values are reported as the median of the U95, median and L95 values respectively for the given time period.
Eq. = Equation

The dissolved solids were removed in the brine volume shown in Figure 5-4. As listed in Table 5-2, the median volume of brine removed for the first and second phases of the test

was 1,660 gal and 2,280 gal, respectively. The median brine volume removed from December 3, 2002, to February 28, 2003 is 4,260 gal.

The total median original interstitial liquid volume removed is 13,180 gal (Table 5-2). The volume of original interstitial liquid removed from the tank over the duration of the dissolution operation is shown in Figure 5-5.

Figure 5-4. Brine Produced by Dissolution Water Removed During Saltcake Dissolution Operation.

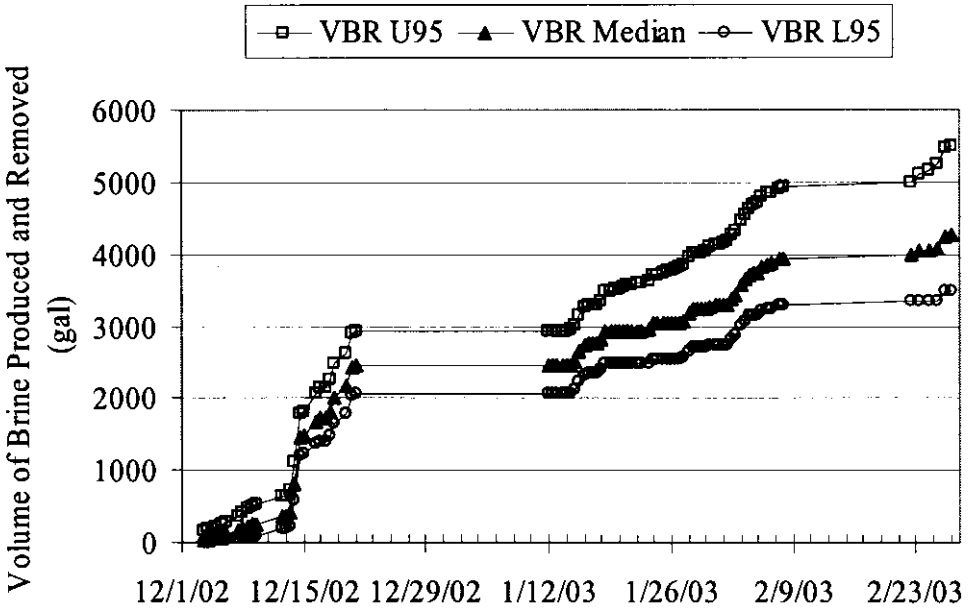
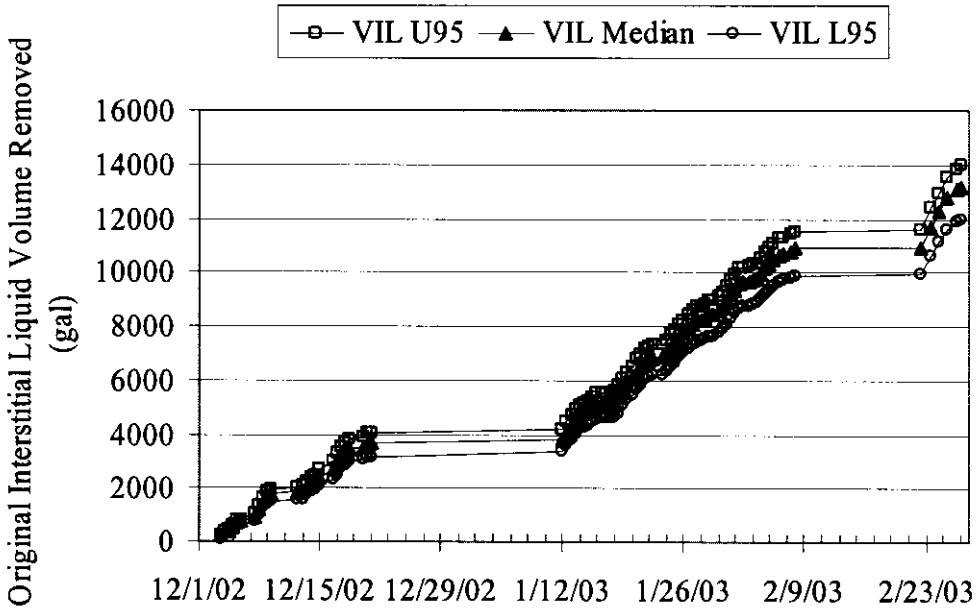


Figure 5-5. Original Interstitial Liquid Removed During Saltcake Dissolution Operation.



The volume of dissolution water removed is shown in Figure 5-6. The total dissolution water addition was 10,601 gal (Section 4.0), of which 3,890 gal (median value) was removed by February 28, 2003 (Table 5-2). If the dissolution water remaining in the tank after the 28th is assumed to become fully saturated, the soluble solids would be dissolved in an additional 12,240 gallons (median value) of bulk saltcake (15,360 gal to 9,990 gal in the 95% confidence interval).

The median (median of the medians at each time step) saturation of the brine was 0.45, and the brine saturation with time is shown in Figure 5-7. These results indicate that the brine produced by the dissolution water added during the saltcake dissolution operation removed 45 percent of its potential soluble solid removal.

Figure 5-6. Dissolution Water Removed During Saltcake Dissolution Operation.

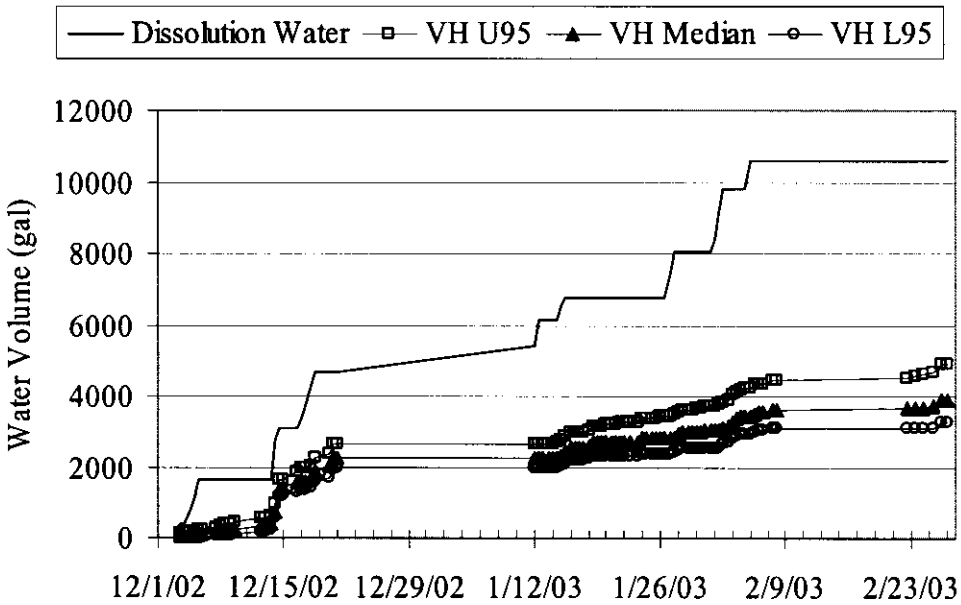
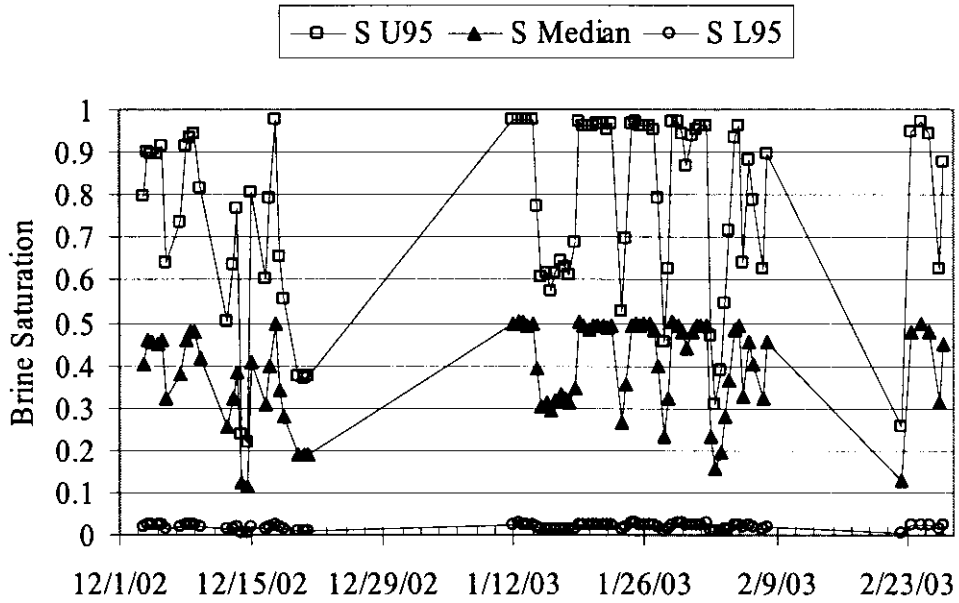


Figure 5-7. Saturation of Brine Removed During Saltcake Dissolution Operation.



5.1 TEMPERATURE CHANGES DURING DISSOLUTION

Sections 4.1 and 4.2 described the temperature decreases that occurred when spray water reached the thermocouple tree. To some extent the decreases were caused by the low temperature of the spray water, which was taken from the river through pipes that lay below the frost level. The strongly endothermic dissolution of $NaNO_3$ (and some other sodium salts, to a much lesser extent) also contributed to the temperature decreases. Significant temperature decreases were predicted by ESP modeling of stepwise dissolution of tank U-107 waste.[11]

Figures 5-8, 5-9, and 5-10 show the temperatures recorded near the waste surface, above the waste surface, and below the waste surface, respectively, during the proof-of-concept test. The greatest temperature changes were observed for thermocouple 5, which is near the waste surface at an elevation of 118 in. This thermocouple was located less than a foot below the pre-water-addition surface level. The temperature as recorded by thermocouple 5 dropped by 34 °F (19 °C) during the shadowing test conducted on December 4, 2003 (Section 4.1), in which the water spray was aimed at the thermocouple tree. Subsequent temperature decreases during the application of water to waste near the tank wall were less pronounced.

Figure 5-9 focuses on the thermocouples that were above the waste surface during the proof-of-concept test. Both thermocouples 6 and 7 (the lowest thermocouples in the headspace) dropped to a temperature of about 60 °F during the shadowing test. These thermocouples are believed to have been directly in the water spray, and their readings

[11] Mahoney, L. A., 2002, *Effect of Using Unheated Water to Dissolve Waste in Tank 241-U-107*, Letter report TWS03.020, Pacific Northwest National Laboratory, Richland, Washington.

indicate that the spray water temperature was about 60 °F. These temperature minima preceded the thermocouple 5 minimum by 2 to 3 hours.

As Figure 5-10 shows, the thermocouples that were well below the waste surface indicated the temperature in this region was affected less by the water, as would be expected. Thermocouple 4 was about 3 ft below the waste surface; at this point, the temperature decrease was less than 20 percent of the decrease at thermocouple 5. There was no immediate short-term temperature decrease at thermocouple 3, 5 ft below the surface.

A closer examination of the data shows that the minimum temperature at thermocouple 4 was 19 hours later than the minimum at thermocouple 5. This time scale is considerably shorter than that associated with the slow recovery of temperature at thermocouple 4 between water applications, suggesting that waste cooling could have been caused by a different mechanism than the slow conduction that caused the re-warming.

The temperature at thermocouple 5 dropped about 10 °C (18 °F) below the spray water temperature during the shadowing test. This additional temperature drop is apparently the result of endothermic dissolution of sodium salts, primarily sodium nitrate. The ESP model was applied to estimate how much $NaNO_3$, assumed to be 10 °C above water temperature, would have to dissolve in water to drop the resulting brine temperature to 10 °C below the water temperature. A concentration of 94 grams $NaNO_3$ per liter of water was predicted assuming adiabatic mixing and dissolution. The ESP-modeled saturation concentration of $NaNO_3$ at 25 °C was 666 grams per liter of water. Assuming adiabatic conditions, the observed temperature decrease represents about 14 percent saturation in sodium nitrate. This is the minimum saturation at the time of the temperature minimum, since conditions were not adiabatic. More sodium nitrate than calculated was probably dissolved and its cooling offset by heat flowing into the dissolution zone from nearby waste.

Figure 5-8. Temperature Changes Near Surface During Proof-of-Concept.

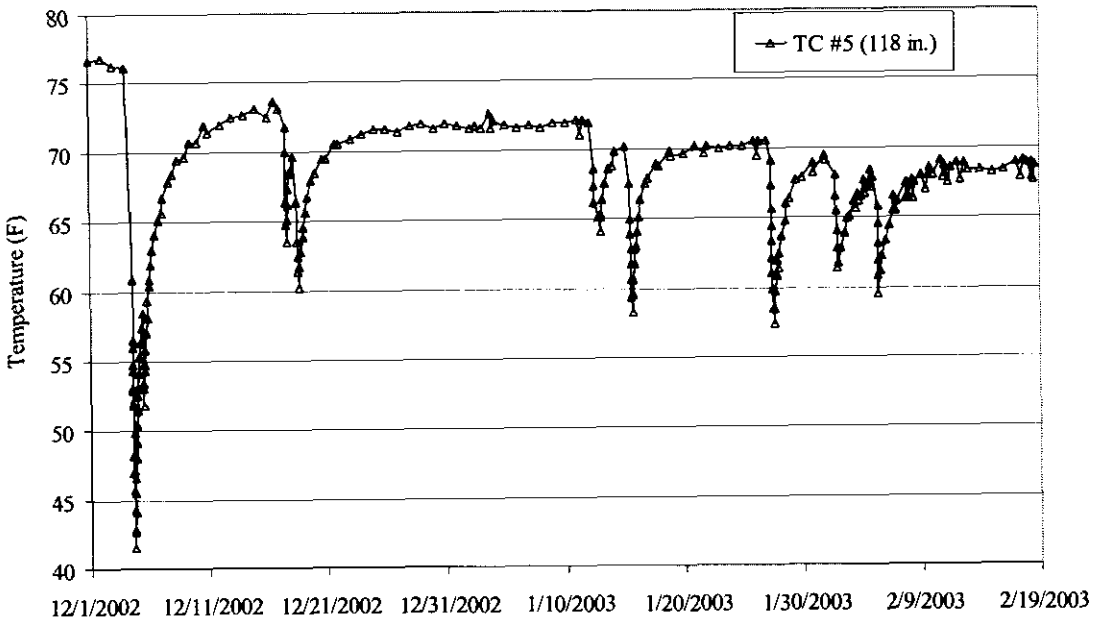


Figure 5-9. Temperature Changes Above Surface During Proof-of-Concept.

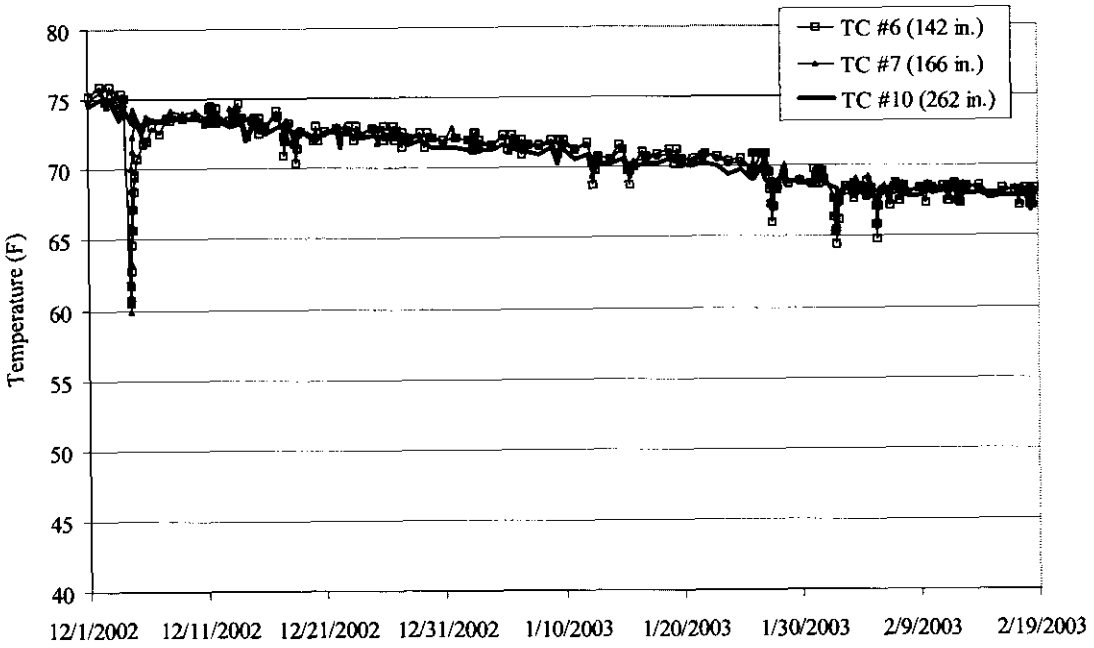
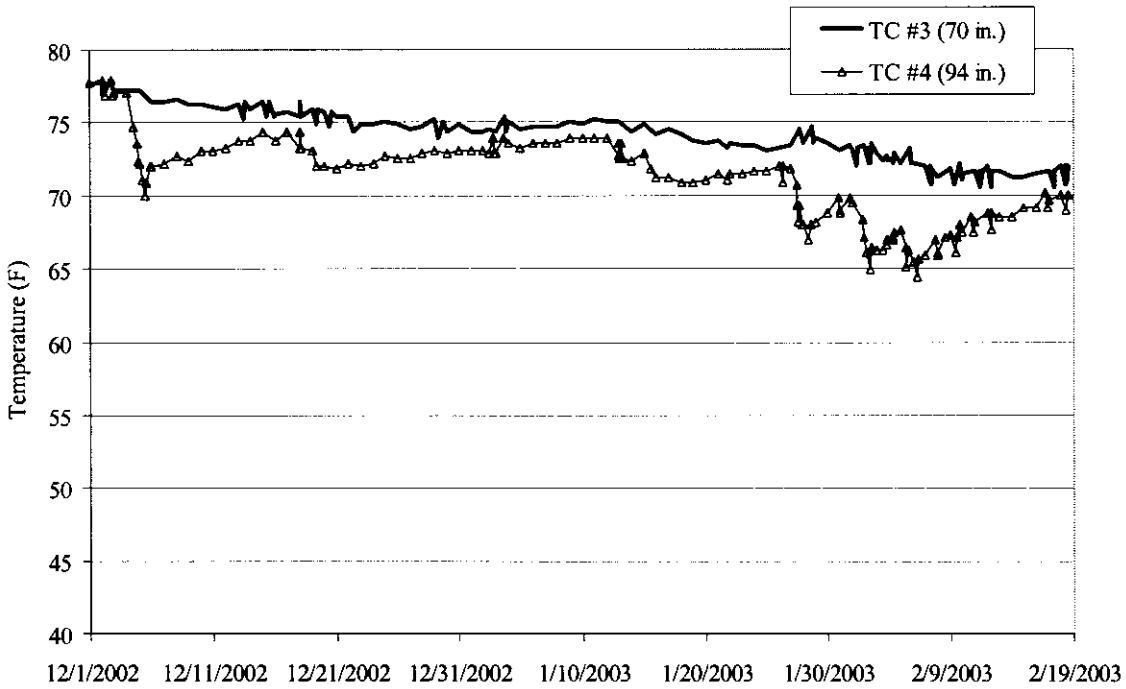


Figure 5-10. Temperature Changes Below Surface During Proof-of-Concept.



5.2 INTERSTITIAL LIQUID DRAINAGE DURING AND AFTER DISSOLUTION

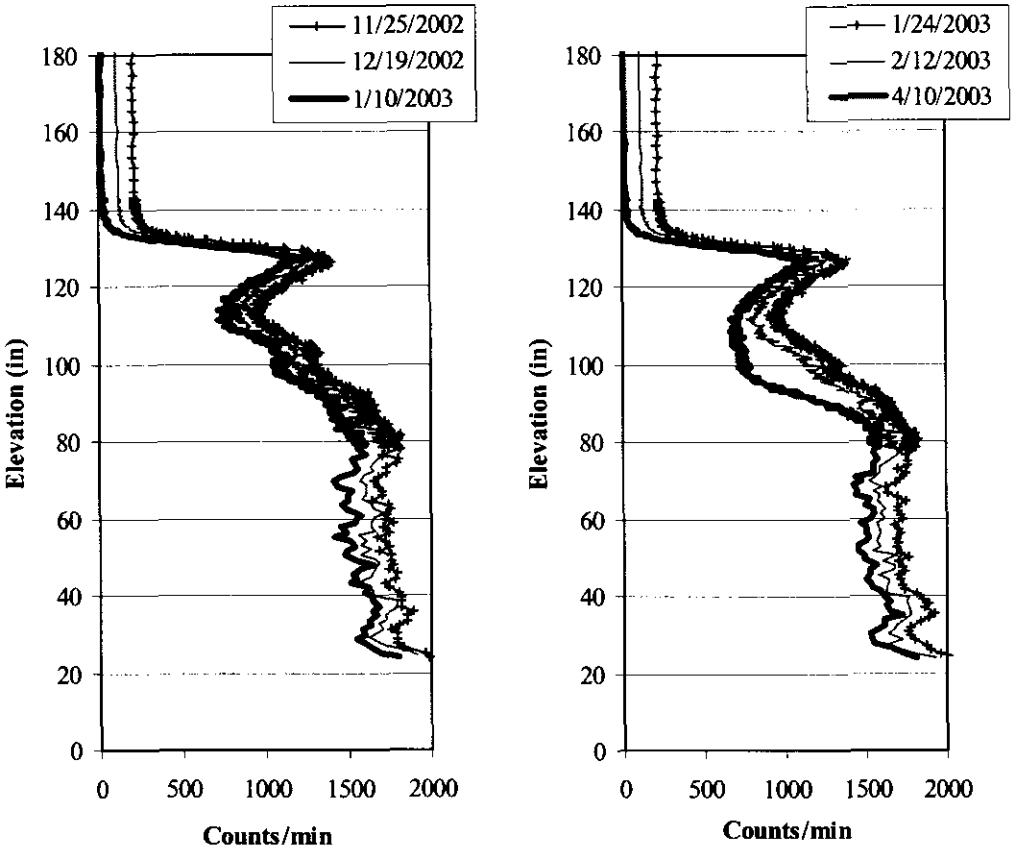
The LOW used to measure interstitial liquid level was located in a different quadrant of the tank than the water additions, and so was not expected to observe the liquid accumulation that might result from water additions. However, because the probe was distant from the sprayed area, it was a useful instrument for tracking interstitial liquid changes from drainage alone.

The neutron logs taken over the course of the proof-of-concept tests are given in Figure 5-11. They show that the original interstitial liquid continued to drain from the waste during the dissolution tests. (An artificial sideways offset of 100 counts per minute has been introduced between scans to make them easier to distinguish.)

There was no significant change in the profile at the LOW between November 25, 2002 and January 24, 2003. However, between January 24 and February 12, there was a decrease in the liquid fraction between about 95 and 110 in. elevation, apparently due to drainage allowed by the lower level of liquid in the saltwell.

Pumping was continued in the subsequent two months, with a total of 6,820 gal of waste plus in-line dilution transferred between February 12 and April 10. As of April 10, the waste between 110 and 95 in. was drained much more completely than it had been on February 12, and the drained region extended further down, to 85 in.

Figure 5-11. Neutron Log Changes During and After Proof-of-Concept.



5.3 HYDROGEN RELEASE DURING DISSOLUTION

The hydrogen sensor drift that took place before and during saltwell pumping, as described in Section 3.2.4, continued and worsened during the proof-of-concept. The instrument was considered to have failed as of January 12, and after that date, industrial hygiene technicians took supplementary twice-daily readings with a combustible gas meter (CGM) calibrated with iso-pentane.

The CGM indicated flammable gas concentrations to be below its minimum detection level of 1 percent of the lower flammability limit (LFL), through almost the entire period of interest. The exceptions were readings of 2 percent LFL at 7:30 p.m. on January 26, 2 percent LFL at 7:30 p.m. on January 27, and 3 percent LFL at 7:30 p.m. on January 28. These three minor increases in headspace flammability may not have been associated with the water additions, since the first occurred about nine days after the most recent water addition.

Because of the SHMS instrument problems, and secondarily because CGM readings were taken at times outside the water addition intervals, no attempt was made to estimate the retained gas releases caused by dissolution during or after the proof-of-concept test. A recent analysis gave a median estimate of 5,315 ft^3 at headspace conditions for the retained gas inventory in tank U-107, based on an *in situ* void fraction of 15.2 percent and an average *in situ* retained gas pressure of 1.158 atm (Huckaby and Wells 2003). The cited reference also gave a headspace volume of 71,977 ft^3 for tank U-107 and estimated that the retained gas was 46 percent flammable, with an LFL of 4.2 percent in air. Under these assumptions, a CGM measurement of 2 percent LFL in the headspace corresponds to a gas release of about 130 scf. This is equivalent to all of the gas in 5,600 gal of waste. Releases of this magnitude were more likely to have been the result of interstitial liquid drainage than of the relatively small amount of waste dissolution.

5.4 LEAK DETECTION DURING SALTCAKE DISSOLUTION OPERATION

Leak detection technology available for the U-107 dissolution operation included the use of a mass balance on the tank contents and existing drywells that surround the tank to watch for potential leakage plumes. The in-tank methodology, mass balance on the tank contents, is limited in its application and by its accuracy. The drywell or ex-tank monitoring provides definitive results for the regions sampled, but is limited in its application because of the minimal coverage of the sample sites.

5.4.1 In-Tank Leak Detection

The in-tank leak detection method is a mass balance on the tank contents. Evaluation of the tank mass (from volume and density) before, during, and after retrieval operations is required. This method, therefore, works well in tanks with free liquid surfaces across the entire tank (ease of volume measurement, homogeneity, etc.). However, for tanks without a free liquid surface, the uncertainty associated with this approach is quite large (Hanson 2003).

The waste surface in tank U-107 is exposed saltcake, and the dissolution operation had limited effect on the waste volume (Sections 4.2 and 5.1). As hardware issues affected operation of the TMS, the quantification of the limited local change in waste volume removed by the dissolution operation has significant uncertainties, as indicated by the Monte Carlo analysis described in Section 5.

5.4.2 Ex-Tank Leak Detection

Only seven boreholes are located in the vicinity of tank U-107, which has a circumference of almost 240 ft. The possibility of a leak from the tank sidewall or bottom therefore cannot be disproved based solely on geophysical logging.

Comparison of the radionuclide assessment system (RAS) and spectral gamma logging system (SGLS) logs and neutron moisture logs from before and after the dissolution operation indicate no changes in either gamma activity or soil moisture content that would be indicative of a leak or spill associated with the saltcake dissolution tests.[12] Plots showing SGLS and RAS data for total gamma activity and neutron log data for the seven boreholes are presented in Figures 5-12 through 5-18. The observed increase in soil moisture in the upper 10 ft of the vadose zone (Figures 5-13, 5-14, 5-16, and 5-18) appears to be related to infiltration of precipitation from an unusually wet winter.

[12]McCain, R., (to be published) 2003, *Evaluation of Log Data in the Vicinity of Tank U-107*, GJO-2003-427-TAC, S.M. Stoller Corp., Grand Junction Office, Grand Junction, Colorado. This reference is the source of Figures 5.12 though 5.18.

Figure 5-12. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-07-01.

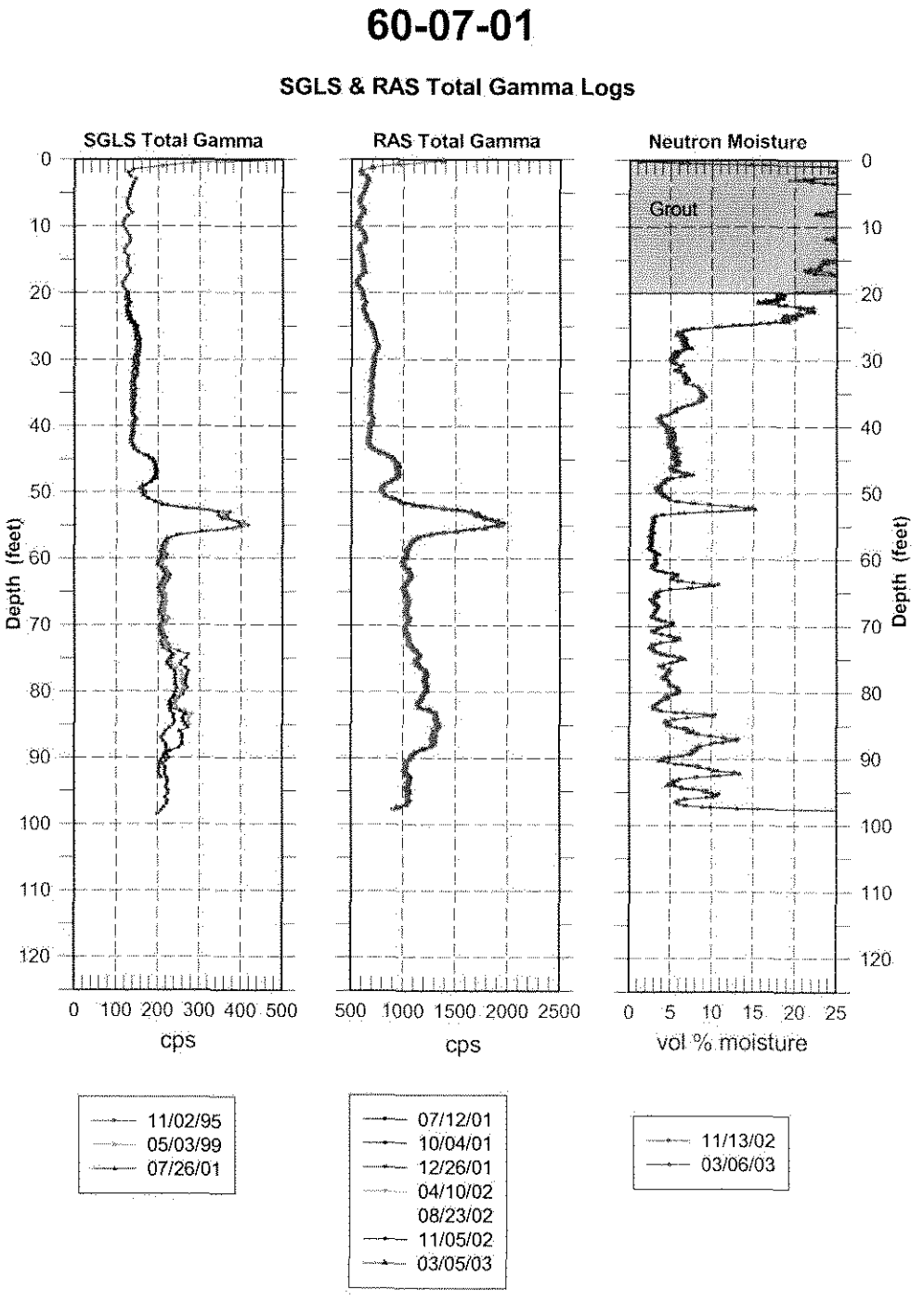


Figure 5-13. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-07-02.

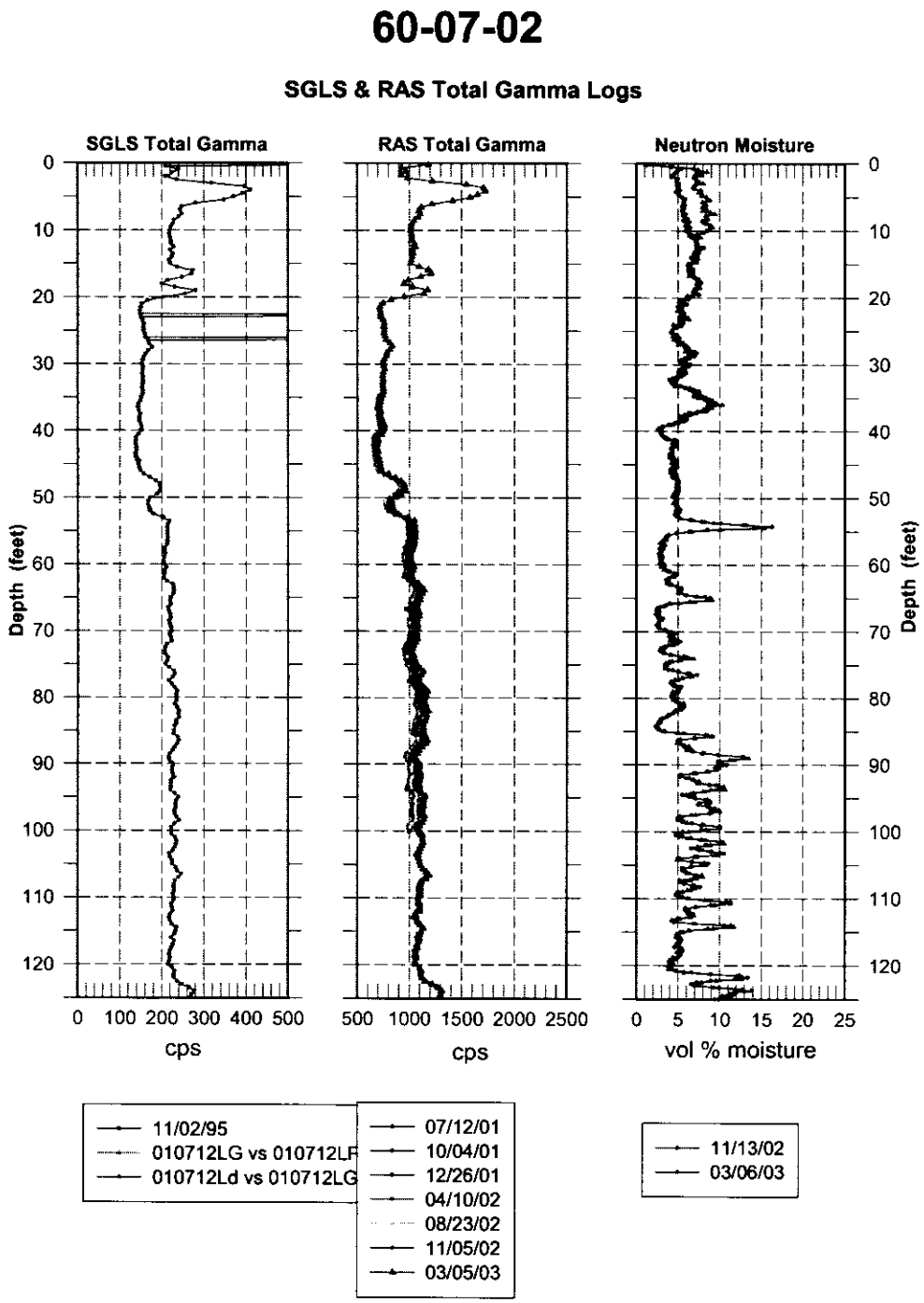


Figure 5-14. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-10-01.

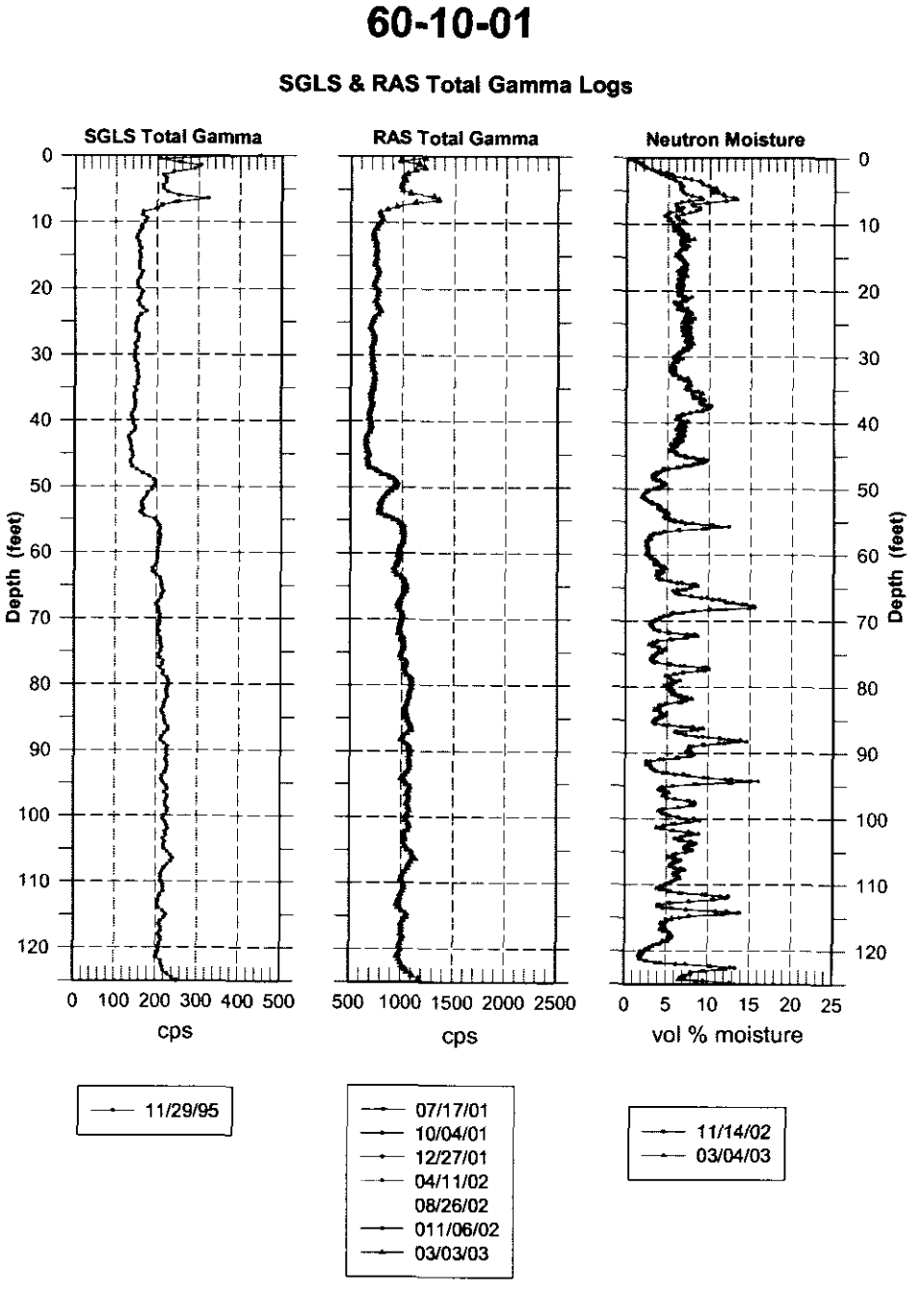


Figure 5-15. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-10-11.

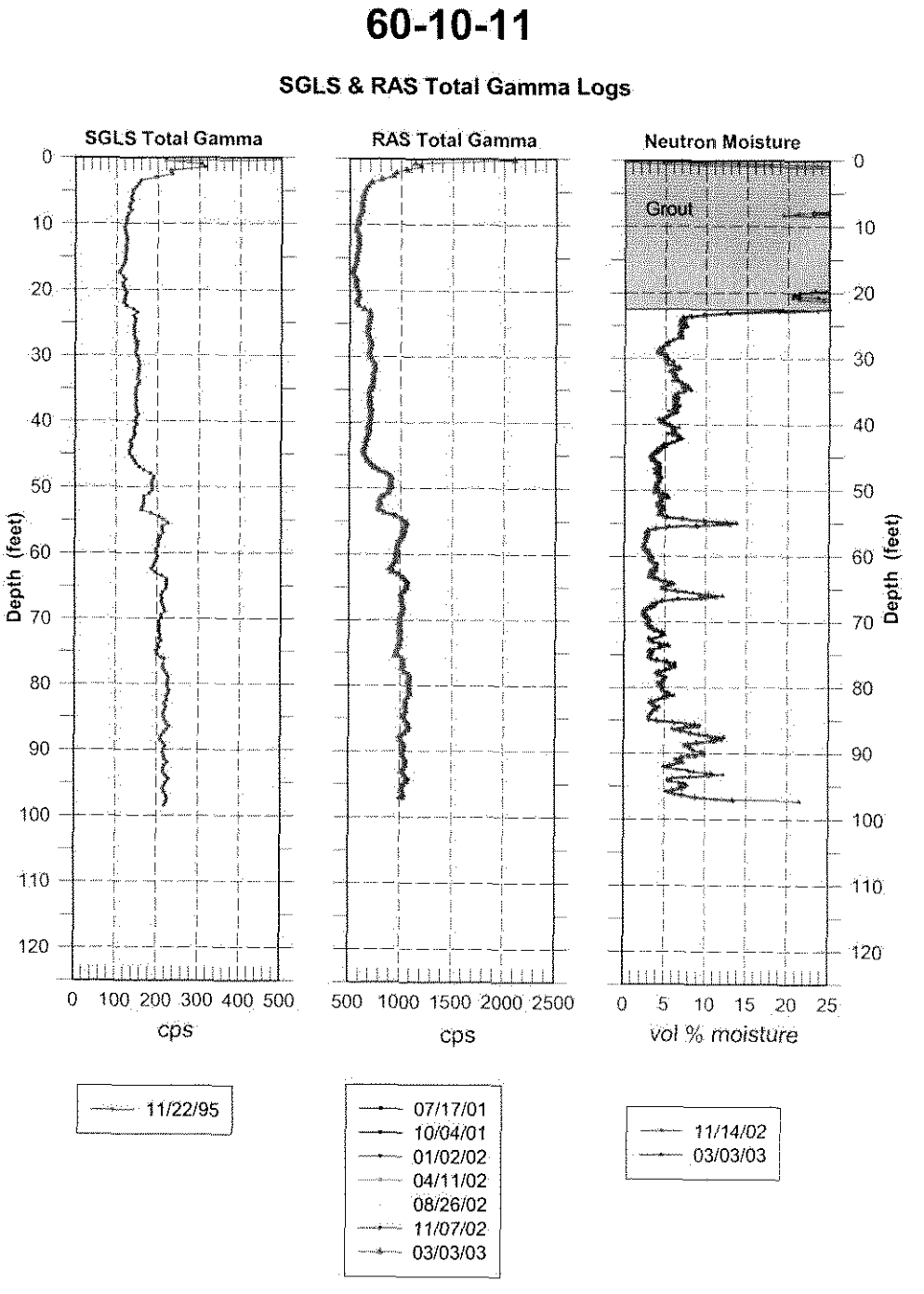


Figure 5-16. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-08-04.

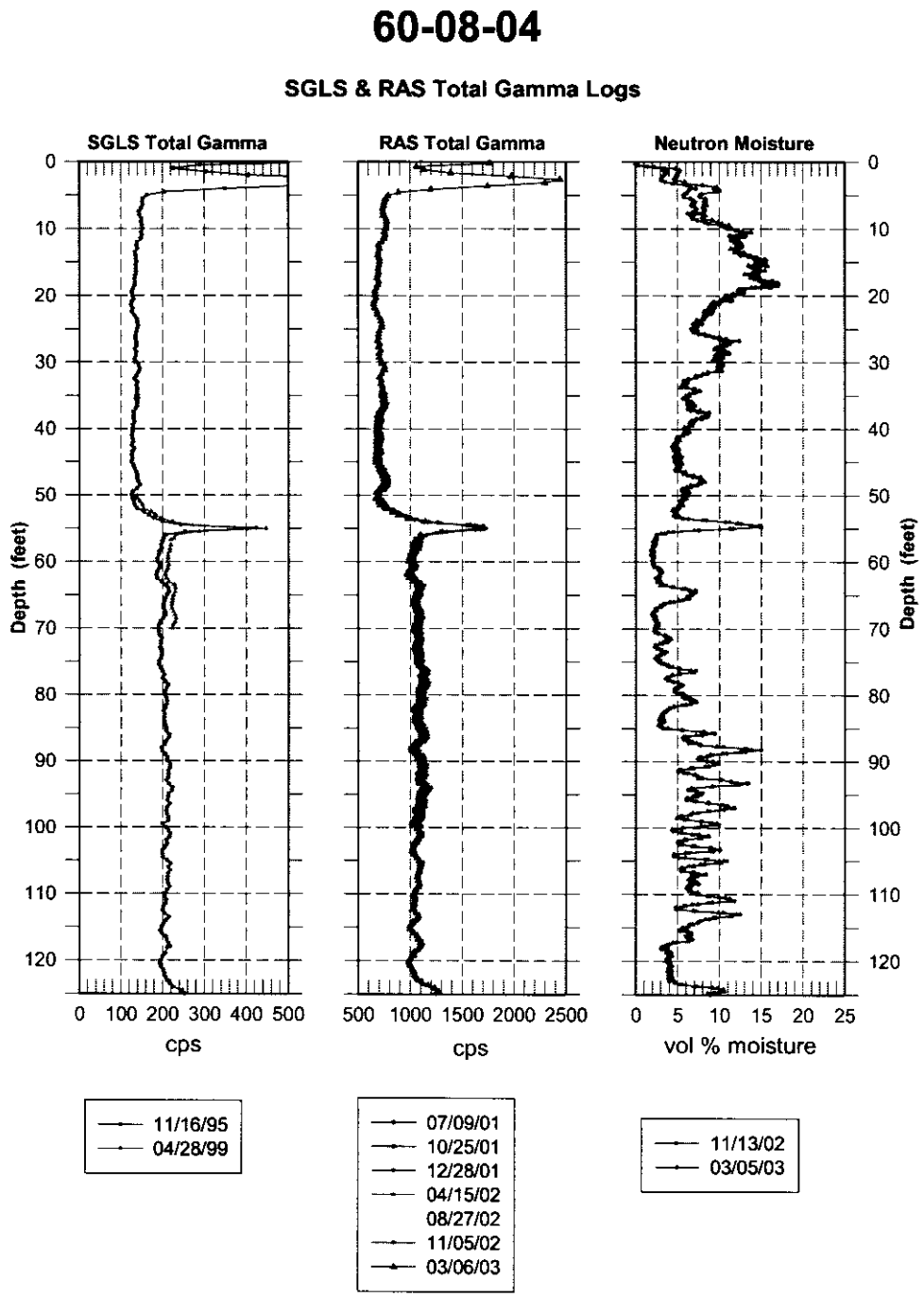


Figure 5-17. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-07-10.

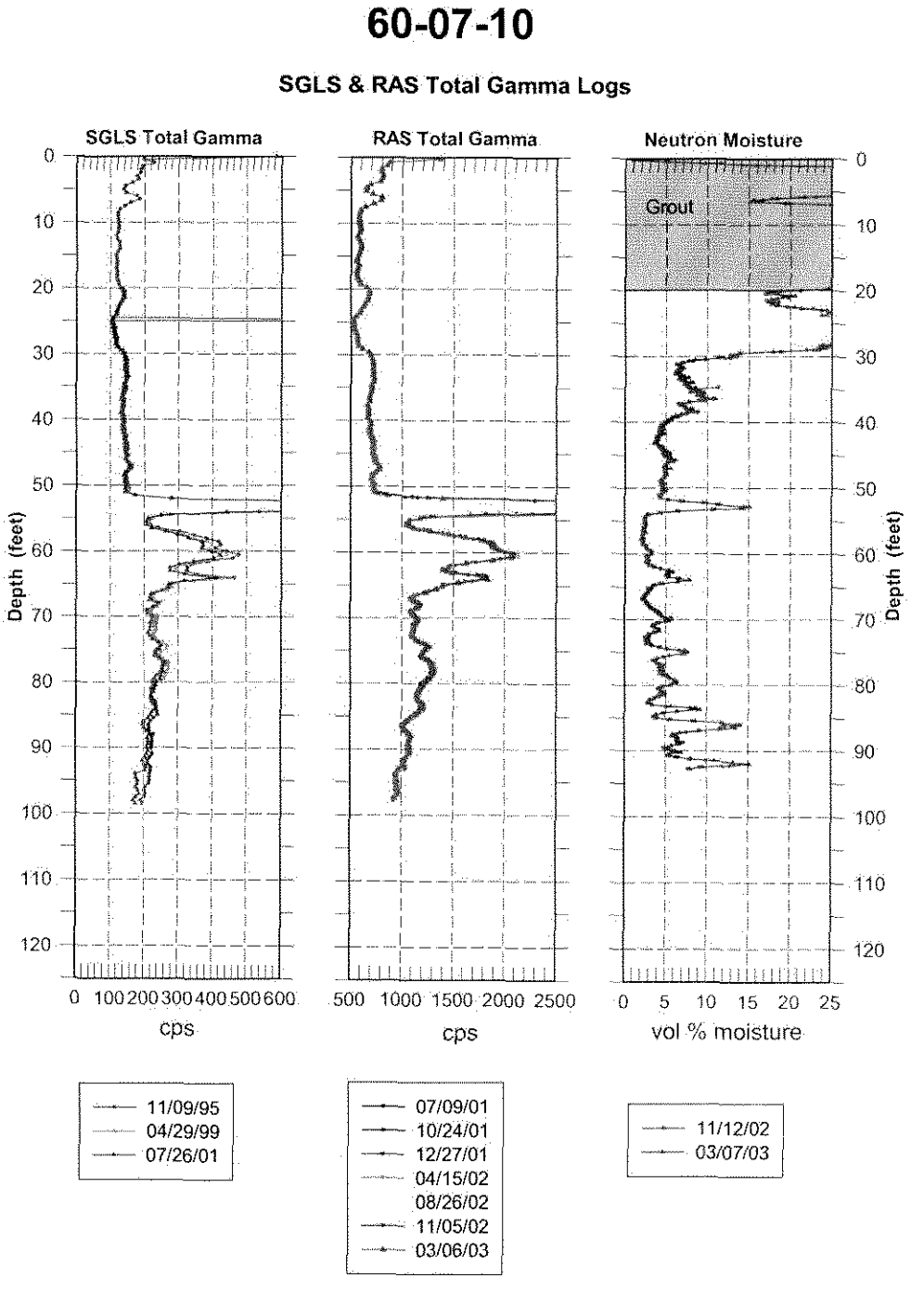
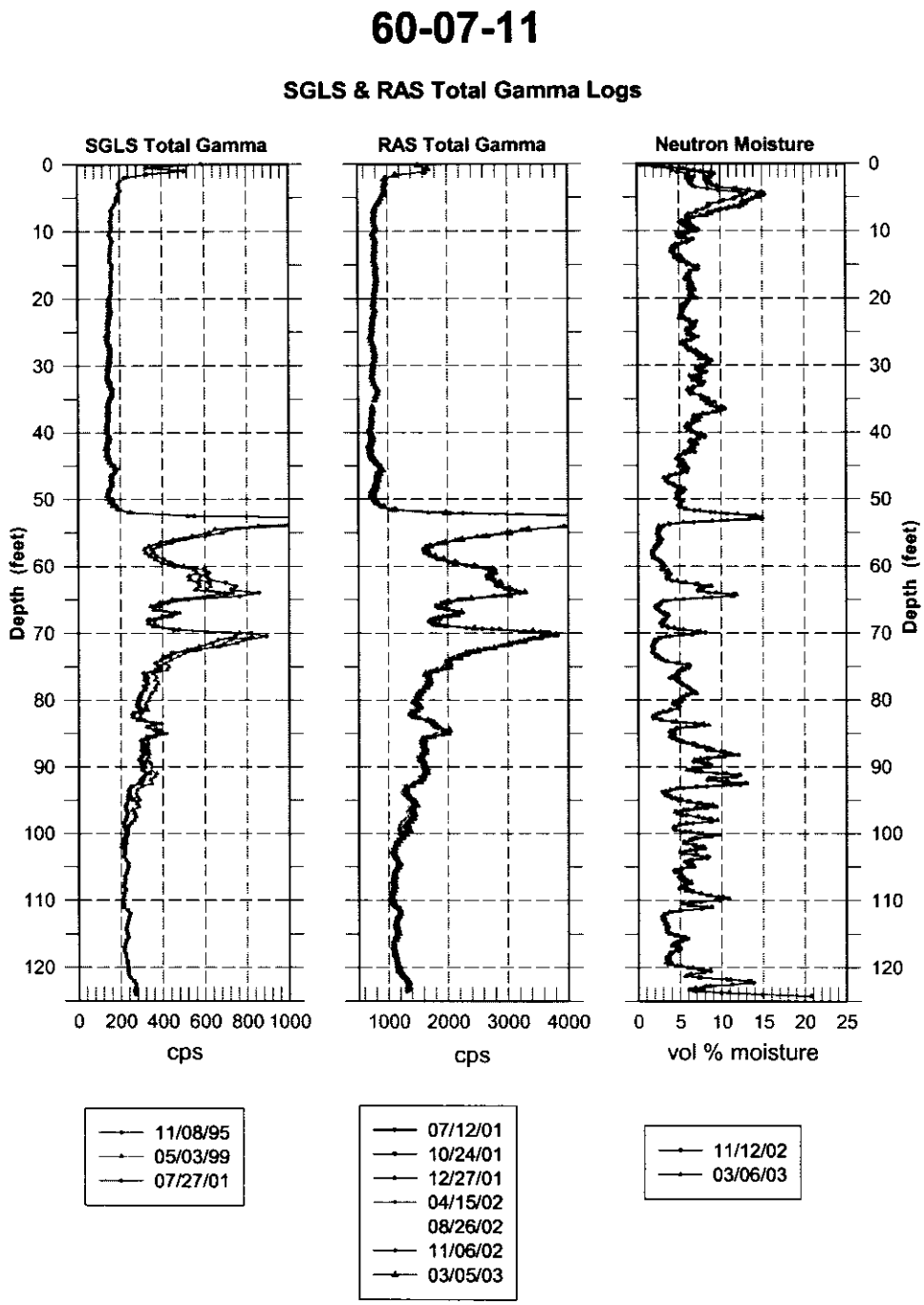


Figure 5-18. SGLS and RAS Total Gamma Logs and Neutron Logs for Borehole 60-07-11.



6.0 RESULTS AND CONCLUSIONS

In this section the sequence of events and results of the dissolution tests are compared to the plan set forth in the Process Control Plan (PCP). The results of the U-107 dissolution proof-of-concept test are also summarized and conclusions are presented. The conclusions pertain to the overall efficacy of the test, in terms of how close the amount of solids dissolved per water addition came to the theoretical value, and to the extent to which the demonstration addressed the technical uncertainties of the dissolution process. Appendix B contains a list of "Lessons Learned" from the demonstration and supplements this section.

6.1 COMPARISON TO PLAN

Because of operational constraints, the dissolution demonstration did not strictly follow the PCP in many regards. These changes are listed below, roughly in order of decreasing importance:

- The demonstration was terminated before the Fury and Nelson nozzles were used. These nozzles had the smallest ratios of spray water to waste surface area, and were, therefore, the least likely to cause surface runoff. The only nozzles tested were those for which runoff had been expected.

- Because of low pumping rates, it is probable that the "in-line" dilution water introduced to the saltwell mixed with the liquid in the saltwell and reduced the liquid specific gravity (SpG) reading, adding uncertainty to the identification and quantification of runoff and the evaluation of dissolution efficacy.

- On several occasions, the liquid level in the saltwell was pumped down so low that the SpG dip tube was exposed, making the specific gravity data for that period meaningless.

- No grab samples were taken after the baseline set. Chemical composition data would have allowed the degree of saturation and removal rate to be estimated for each salt. The long periods during which saltwell liquid was unsaturated would have made it possible to collect meaningful samples. Grab samples also might have indicated whether solids had settled or re-precipitated within the saltwell screen.

- Water additions did not occur according to the planned schedule because of the low pumping rates (due to transfer line restrictions) and the need to avoid accumulation of liquids in the tank. The schedule of some tests was also affected by whether trained operators were available on the shift. Overall, the operating efficiency of water addition was 17 percent (one day of dissolution followed by five days of pumping).

- The Topographic Mapping System (TMS), which had been tested successfully before installation, failed after installation and could not be used as planned to estimate the bulk volume removed from the surface of the waste. The in-tank videos provided qualitative information about waste surface changes, but were frequently unclear and difficult to interpret.

- The Standard Hydrogen Monitoring System (SHMS) was not operating properly; as a result the only hydrogen measurements were the twice-daily combustible-gas "sniff tests" performed by industrial hygiene technicians. These measurements were not usually made during test periods.

- The gamma monitor on the transferred liquid was not included in the PCP. Though uncalibrated, the gamma concentration data provided a useful qualitative supplement for periods when SpG data were unavailable.

The reductions in nozzle usage and continuity of water application make it difficult to apply the results of the demonstration to evaluating the application techniques that would be used in a full tank waste retrieval. The difficulties and ambiguities in the dip-tube measurement of specific gravity added substantial uncertainty to the estimate of waste removal. Chemical composition data could have made it clearer whether runoff had already leached nitrate out of the waste at the surface, creating a dissolution-resistant top layer, or whether nitrate was still available to the flow but dissolving slowly. The TMS would have provided useful supplementary information about changes in the waste surface, allowing comparison with other estimates of waste removal.

The criteria for success of the demonstration were listed in Section 1.2. They are repeated here for convenience, with an assessment of each.

Determination of the volume of waste dissolved per unit volume of water added:

- As described in Section 5.1, the volume of bulk saltcake in which soluble solids were dissolved was evaluated using a Monte Carlo simulation approach. A significant uncertainty in the analysis was the extent to which in-line dilution water affected the saltwell liquid SpG. The median estimated bulk waste volume dissolved per volume of water added over the period evaluated (December 3, 2002 to February 28, 2003) is 0.17 gal/gal. The 95% confidence interval is 0.10 to 0.28 gal/gal. If there had been supplementary measurements that showed that in-line dilution water had more effect on the SpG in the well, a higher dissolved waste volume would have been estimated. The standard interim stabilization instruments do not allow the in-well effect of dilution water to be assessed.

Observation of the overall qualitative behavior of saltcake in response to surface water addition:

- Only the high water-to-surface-area tests were completed, but results from these were consistent with expectations and strengthen current understanding of saltcake dissolution behavior.

- It was observed that water could be applied at relatively high rates to small waste surface areas without causing immediate runoff of the applied water. The water was apparently readily absorbed by the porous saltcake at the surface.

- After extended periods of spraying water during the near-wall test, evidence of dilute runoff was observed. This suggests that the saltcake being sprayed with water had become saturated with liquids, and that water applied after the saltcake is saturated with liquid is ineffective at dissolving the surface of saltcake.

- The diminished pumping capacity caused the water application schedule of the near-wall test to be expanded to include several days of pumping between each large water addition. The observation that dilute runoff did not immediately resume with application of water after each delay for pumping suggests that significant drainage of the saltcake being sprayed had occurred during the pumping. Whether the drainage rate of this region of the waste had been enhanced or diminished by the absorption of water was not evident.

- Video images of the region taken after completion of the near-wall tests indicate a distinct channel was formed between the near-wall region of water application and the saltwell. This suggests that runoff from the region being sprayed did seep into and dissolve saltcake as it ran toward the saltwell.

- The formation of this channel combined with the evidence that very dilute brine did reach the saltwell suggests that the saltcake forming the channel also became saturated with liquid, and that water traveling down the channel was ineffective at dissolving saltcake (i.e., it reached the saltwell without becoming saturated with dissolved salts).

For the applied water to become saturated brine it is evidently necessary for the water to seep into the saltcake; water flowing over the saltcake surface did not become saturated even after traveling from near the wall to the saltwell.

The data and observations from the shadowing and near-wall tests suggest that relatively large volumes of water can be applied to small areas of the waste surface for short periods, and therefore broad-area water application is not necessary to prevent immediate runoff of dilute brine. However, except for the formation of a channel running between the region sprayed and the saltwell, there was no evidence that the applied water was affecting any region of waste beyond the area sprayed. It is not known whether this means the effects of the water sprays were strictly localized or that the test durations and/or data were insufficient to observe such effects.

Assessment of the effectiveness of the leak-detection developmental strategy and approach:

- There is significant uncertainty in the pre-demonstration solid and liquid waste inventories, as well as in the estimates of the quantities of dissolved waste and added water that were removed from the tank, making in-tank leak detection infeasible in this case. Ex-tank moisture detection, using existing wells near tank U-107, showed no indication of a leak during the demonstration. In addition, a saltwell system material balance was performed per procedures TO-430-102 and TO-505-107 and showed no leaks in the pumping and transfer system.

Understanding of the cause(s) of adverse behavior such as dilute liquid in the saltwell screen, excessively nonuniform dissolution, excessive runoff, or solids accumulation in the saltwell screen:

- The presence of dilute runoff was evident, but the extent to which it was caused by dissolution chemistry (endothermic reaction, buildup of an insolubles layer, etc.) could not be established because analyses of the saltwell liquid were lacking.

Determination that no unmanageable safety concerns exist with the full-scale demonstration in tank S-112:

- The demonstration was limited to high water-to-surface-area tests; there was no evidence of safety concerns under those conditions.

Demonstration that the saltcake dissolution retrieval method is fundamentally unworkable or impractical for reasons that cannot be alleviated by adjusting the process:

- The saltcake dissolution retrieval method is technically viable; however, production (rate) issues may make it less desirable than other retrieval methods. The high-water-to-area application of water is significantly below theoretical efficiency in dissolving waste. The tests that were not run would have applied water at a rate likelier to permit it to percolate into the waste rather than run off. The efficacy of those application methods cannot be assessed from the tests that were performed.

The demonstration is considered successful, within the limits set by its early termination. If the remaining tests were performed, their usefulness would be enhanced by modifying the test to include the following (1) allowing continuous pumping; (2) adding in-line monitoring of density to remove the uncertainties of saltwell SpG measurement; and (3) providing for some form of chemical analysis, with in-line monitoring being preferred but regular sampling being adequate for test purposes.

6.2 DISSOLUTION EFFICACY

The total water addition during the proof-of-concept demonstration, December 3, 2002, to February 5, 2003, was 11,600 gal; this figure includes system flushes that were directed into the tank as well as the 10,601 gal of water that were sprayed on the waste. The total waste transfer volume during the same period was 15,800 gal (not including in-line dilution).

As discussed in Section 5.1, the median Monte Carlo simulation result for the bulk volume of saltcake in which the soluble solids were removed by dissolution is 1,780 gal over the entire period evaluated (December 3, 2002 to February 28, 2003). The 95% confidence interval is 1,100 to 2,940 gal. By comparison, the bulk waste removal apparent from the in-tank video was on the order of 200 gal. The large discrepancy between median calculated and apparent bulk waste volumes removed suggests that water seeping into the saltcake is increasing the waste porosity (i.e., enlarging the pores) and/or a cavity was being formed below the surface.

The Monte Carlo analysis also estimated that 4,260 gal of dissolution brine had been removed in the same period, with a 95% confidence interval of 3,500 to 5,490 gal. Much of the removal by dissolution was not apparent in the video. The TMS could have clarified how much waste loss occurred over the waste surface, allowing a check of the calculated waste removal and possibly providing evidence for or against subsurface cavern formation.

An analysis that assumed complete saturation of the dissolution brine[13] was conducted before the proof-of-concept demonstration began and is reproduced in Appendix C. It predicted that the first five tests of the demonstration would add 11,300 gal of water, produce 28,100 gal of total brine (after in-line dilution of 1 part water to 5 parts waste), and remove 20,300 gal of bulk waste (including void volume). Using the actual, slightly decreased water addition, the expected saturation-based results were the removal of 19,100 gal of bulk waste (including void volume) and the production of 20,000 gal of brine (not counting in-line dilution).

The median total dissolution water removed by the end of February 2003 was 3,890 gal out of the 10,601 gal added. Interim stabilization pumping was still removing dissolution water (and the waste dissolved in it) three weeks after the end of spraying. Over the whole demonstration, the portion of the dissolution water that was removed from the tank was 45 percent (median value) saturated with soluble salts. Therefore, the dissolution water removed 45 percent of the soluble salts it had theoretically been expected to remove. If it had been assumed that in-line dilution water had no effect on the SpG in the well, a much lower dissolved waste volume would have been estimated.

Because no saltwell liquid grab samples were taken during or after the demonstration, no conclusions can be drawn about the removal of constituents that were present in the waste

[13] Mahoney, L. A., 2002, *Dissolution Estimates*, letter report TWS03.011, Pacific Northwest National Laboratory, Richland, Washington.

solids. However, the estimates of interstitial liquid removal allow the rough estimation of removal of constituents that were present only or predominantly in dissolved form. Based on the median Monte Carlo estimate of 13,180 gal of removed interstitial liquid, the average grab-sample concentration of ^{99}Tc given in Table 3-2, and the assumption (based on a laboratory dissolution study [Herting 2001]) that the Tc in U-107 waste is predominantly found in the liquid, 17 Ci of ^{99}Tc were removed from the tank during the proof-of-concept test. The 450 gal of solids that were removed were associated with an equal volume of liquid, according to the ESP chemical simulator model. Therefore, the order-of-magnitude estimate can be made that 4 percent of the Tc removed, or 0.7 Ci, was removed because of dissolution alone. The rest was removed by waste drainage. The accuracy of this estimate would have been improved by the "reality check" provided by concurrent grab sampling.

Once water spraying had begun, the specific gravity of the liquid in the saltwell was almost always less than the values measured on December 1 and 2, 2002, just before spraying began. This overall observation, as well as specific observations made during individual water addition events, proved that solubility equilibrium was not being reached during full-scale dissolution at the relatively high water application flux rates that were employed. However, laboratory data (Herting 2002) had indicated rapid equilibration in dissolution. Apparently in-tank mass-transfer limitations prevented equilibration.

Rapid surface runoff was the likeliest reason for suppressed equilibration. A surface channel was visible in the last in-tank video. Some form of flow short-circuiting was demonstrated because dilute brine repeatedly arrived rapidly at the saltwell. Dissolution water additions of more than 700 gal at a time were sufficient to cause flow short-circuiting.

Dissolution may also have been hindered by cooling caused by the use of 60 °F river water and by the endothermicity of dissolution. (Laboratory-scale dissolution was essentially isothermal, with no perceptible cooling, because of the small sample size.) The most significant soluble sodium salt, sodium nitrate, is less soluble as the temperature decreases, and significant drops in temperature were observed repeatedly during the demonstration.

6.3 REMAINING TECHNICAL UNCERTAINTIES

The proof-of-concept demonstration was designed to gather information to reduce the uncertainties of retrieval by dissolution. These uncertainties were listed in Section 1.1 and will be discussed here in the same order as in that section.

6.3.1 Nonuniformities in Dissolution

Although channels and holes were formed in the waste by the intense local water application in the tests, the depth of the holes were rather uniform in level and appearance. The wall and the thermocouple tree were clean. The tests do not rule out the possibility of pits, caverns, or mounds being formed, but no such features were apparent.

6.3.2 Undersaturation of Dissolution Brine

Undersaturation of the brine formed was apparent during both the near-saltwell and near-wall tests, particularly in the last stages of the near-wall tests. This was an expected result, inasmuch as the saltcake had been only partially drained and the flux of water applied to the surface was expected to exceed the percolation capacity of the saltcake. Any extrapolation of this result to the broad area water application methods must consider the degree to which the saltcake has been drained and the water application rate. Completion of the demonstration is needed to affirm this.

6.3.3 Process Operations Control

Because transfer-line limitations forced most of the pumping to be carried out in the absence of water addition, the capacity for jointly controlling pumping and water addition has not been fully tested. Completing the demonstration would provide such a test to the extent that the transfer line could be cleared and the retrieval rate based on pump capacity instead of line capacity.

6.3.4 Leak Detection

The use of existing ex-tank wells in the immediate vicinity of the U-107 near-wall tests to monitor soil moisture levels provided strong indication that these tests did not result in a large leak of liquid from the tank. However, the more general use of such wells to monitor the retrieval of the entire contents of a tank was not tested or strengthened by the limited saltcake dissolution conducted. The reduced amounts of water applied and shortened duration of the demonstration also precluded significant use of a material balance to identify a hypothetical tank leak; uncertainties in the initial solid and liquid waste inventories are considered larger than the quantities of water added, liquids pumped out, and solids dissolved.

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APPENDIX A

DETAILED DISSOLUTION TIMELINES

Table A-1. Timeline for First Phase of Proof-of-Concept Test. (2 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
11/25/02 18:18	Neutron probe, ILL = 105.6 in.			
		12/3/02 12:00		
12/3/02 14:30	Start dissolution water spraying of 400 gal near saltwell (initial) from nozzle SALW-SD-QD-002			
12/3/02 16:30	End near-saltwell spraying			
			12/4/02 0:00	238.4 gal waste + 59.6 gal in-line dilution
		12/4/02 0:00		
			12/4/02 12:00	181.6 gal waste + 45.4 gal in-line dilution
		12/4/02 12:00		
12/4/02 12:08	Start dissolution water spraying of 400 gal for shadowing from nozzle SALW-SD-QD-003			
12/4/02 13:20	Temperature dropped to 55-60 °F at thermocouples #5, #6, #7			
12/4/02 15:00	End shadowing spraying			
12/4/02 15:15	50-gal dip tube flush			
12/4/02 15:37	Temperature dropped further to 41 °F at thermocouple #5			
12/4/02 19:19	Neutron probe, ILL = 103.0 in.			
			12/5/02 0:00	97.6 gal waste + 24.4 gal in-line dilution
		12/5/02 0:00		
12/5/02 10:06	Start dissolution water spraying of 300 gal near wall (initial) from nozzle SALW-SD-QD-001			
12/5/02 11:17	Temperature dropped to 52 °F at thermocouple #5			
12/5/02 11:46	End near-wall spraying			
			12/5/02 12:00	113.6 gal waste + 28.4 gal in-line dilution
		12/5/02 12:00		
12/5/02 12:11	Start dissolution water spraying of 549 gal near saltwell (channeling) from nozzle SALW-SD-QD-002			
12/5/02 15:00	End near-saltwell spraying			
			12/5/02 20:00	270 gal waste + 72 gal in-line dilution
		12/6/02 0:00		
			12/6/02 1:40	42.4 gal waste + 10.6 gal in-line dilution

Table A-1. Timeline for First Phase of Proof-of-Concept Test. (2 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
12/6/02 4:00	40-gal flush of recirc line and system			
		12/7/02 12:00	12/7/02 18:13	238.4 gal waste + 59.6 gal in-line dilution
		12/8/02 0:00	12/8/02 12:00	338.4 gal waste + 84.6 gal in-line dilution
		12/8/02 12:00	12/9/02 0:00	323.2 gal waste + 80.8 gal in-line dilution
		12/9/02 0:00	12/9/02 12:00	198.4 gal waste + 49.6 gal in-line dilution
		12/9/02 12:00	12/9/02 20:00	117.6 gal waste + 29.4 gal in-line dilution
12/9/02 20:00	20-gal saltwell flush			
12/12/02 15:30	10-gal jet pump startup	12/12/02 15:30	12/12/02 23:30	193.6 gal waste + 48.4 gal in-line dilution
		12/13/02 0:00	12/13/02 3:00	38.8 gal waste + 20.2 gal in-line dilution
12/13/02 1:50	12 gal, fill PIC skid			
		12/13/02 12:00	12/13/02 20:10	236.9 gal waste + 58.1 gal in-line dilution
12/14/02 7:45	Start dissolution water spraying of 1451 gal near saltwell (channeling) from nozzle SALW-SD-QD-002	12/14/02 0:00	12/14/02 12:00	446 gal waste + 112 gal in-line dilution
12/14/02 14:58	End near-saltwell spraying	12/14/02 12:00	12/15/02 0:00	756 gal waste + 189 gal in-line dilution
12/15/02 0:00	30-gal system, dip tubes, transfer line flush	12/15/02 0:00		
12/16/02 1:00	50-gal recirc system flush			
			12/15/02 4:40	216.8 gal waste + 54.2 gal in-line dilution
12/16/02 12:20	100-gal dip tube flush	12/16/02 12:00		
12/16/02 12:34	39-gal fill of PIC skid			
12/16/02 12:48	21-gal foot valve flush			
12/16/02 12:55	10-gal prime of saltwell			
			12/16/02 21:30	700 gal waste + 0 gal in-line dilution

Table A-2. Timeline for Second Phase of Proof-of-Concept Test. (5 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
		12/17/02 0:00		
12/17/02 11:45	Start dissolution water spraying of 600 gal near wall (large volume) from nozzle SALW-SD-QD-001			
			12/17/02 12:00	284.8 gal waste + 71.2 gal in-line dilution
		12/17/02 12:00		
12/17/02 15:30	End near-wall spraying			
			12/18/02 0:00	234.4 gal waste + 58.6 gal in-line dilution
		12/18/02 0:00		
12/18/02 9:50	Start dissolution water spraying of 1004 gal near wall (large volume) from nozzle SALW-SD-QD-001			
			12/18/02 12:00	221.4 gal waste + 55.6 gal in-line dilution
		12/18/02 12:00		
12/18/02 15:30	End near-wall spraying			
			12/18/02 20:49	361.6 gal waste + 90.4 gal in-line dilution
12/19/02 0:00	40-gal hot water flush of system/recirc/transfer line			
12/19/02 2:00	30-gal flush of saltwell system			
12/19/02 8:57	Neutron probe, ILL=105.6 in.			
		12/20/02 0:00		
			12/20/02 4:00	209.6 gal waste + 52.4 gal in-line dilution
		12/20/02 12:00		
			12/21/02 0:00	369.6 gal waste + 92.4 gal in-line dilution
		12/21/02 0:00		
			12/21/02 8:05	137.6 gal waste + 34.4 gal in-line dilution
12/21/02 8:30	30-gal flush of saltwell system (DOV)			
12/27/02 9:25	Neutron probe, ILL=105.0 in.			
12/31/02 8:53	Neutron probe, ILL=105.5 in.			
1/10/03 10:27	Neutron probe, ILL=105.6 in.			
		1/12/03 0:00		
1/12/03 0:00	20-gal flush			
1/12/03 9:15	Start dissolution water spraying of 1421 gal near wall (large volume) from nozzle SALW-SD-QD-001			
			1/12/03 10:30	213.6 gal waste + 53.4 gal in-line dilution
		1/12/03 12:00		
1/12/03 17:15	End near-wall spraying			
			1/13/03 0:00	232.8 gal waste + 58.2 gal in-line dilution
		1/13/03 0:00		
			1/13/03 12:00	233.2 gal waste + 45.8 gal in-line dilution
		1/13/03 12:00		
			1/14/03 0:00	251.2 gal waste + 62.8 gal in-line dilution

Table A-2. Timeline for Second Phase of Proof-of-Concept Test. (5 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
		1/14/03 0:00		
1/14/03 0:00	40-gal flush			
			1/14/03 10:30	211.2 gal waste + 52.8 gal in-line dilution
		1/14/03 12:00		
			1/14/03 14:00	54.4 gal waste + 13.6 gal in-line dilution
		1/15/03 0:00		
1/15/03 11:30	Start dissolution water spraying of 637 gal near wall (large volume) from nozzle SALW-SD-QD-001			
			1/15/03 12:00	121.6 gal waste + 30.4 gal in-line dilution
		1/15/03 12:00		
1/15/03 15:30	End near-wall spraying			
1/15/03 19:35	Neutron probe, ILL=106.3 in.			
			1/16/03 0:00	259.6 gal waste + 62.4 gal in-line dilution
		1/16/03 0:00		
1/16/03 0:00	40-gal flush			
			1/16/03 12:00	274.4 gal waste + 68.6 gal in-line dilution
		1/16/03 12:00		
			1/16/03 14:00	44 gal waste + 11 gal in-line dilution
		1/17/03 0:00		
			1/17/03 0:30	10.4 gal waste + 2.6 gal in-line dilution
1/17/03 11:30	10-gal flush			
1/17/03 12:00	27-gal flush	1/17/03 12:00		
			1/18/03 0:00	28.6 gal waste + 114.4 gal in-line dilution
		1/18/03 0:00		
			1/18/03 12:00	128 gal waste + 32 gal in-line dilution
		1/18/03 12:00		
			1/19/03 0:00	281.6 gal waste + 70.4 gal in-line dilution
		1/19/03 0:00		
			1/19/03 12:00	254.4 gal waste + 63.6 gal in-line dilution
		1/19/03 12:00		
			1/20/03 0:00	236.8 gal waste + 59.2 gal in-line dilution
		1/20/03 0:00		
			1/20/03 12:00	230.4 gal waste + 57.6 gal in-line dilution
		1/20/03 12:00		
			1/21/03 0:00	225.6 gal waste + 56.4 gal in-line dilution
		1/21/03 0:00		
1/21/03 0:00	42-gal fill of PIC skid			
			1/21/03 12:00	231.2 gal waste + 57.8 gal in-line dilution
		1/21/03 12:00		
			1/22/03 0:00	197.6 gal waste + 49.4 gal in-line dilution

Table A-2. Timeline for Second Phase of Proof-of-Concept Test. (5 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
		1/22/03 0:00		
1/22/03 0:00	40-gal system flush			
			1/22/03 12:00	119.2 gal waste + 29.8 gal in-line dilution
		1/22/03 12:00		
			1/22/03 20:00	71.6 gal waste + 19.4 gal in-line dilution
		1/23/03 12:00		
			1/23/03 13:46	49.6 gal waste + 12.4 gal in-line dilution
1/23/03 21:30	10-gal jet pump prime			
		1/24/03 0:00		
			1/24/03 12:00	217.6 gal waste + 55.4 gal in-line dilution
		1/24/03 12:00		
1/24/03 14:29	Neutron probe, ILL=103.1 in.			
			1/25/03 0:00	190.2 gal waste + 43.8 gal in-line dilution
		1/25/03 0:00		
			1/25/03 12:00	191.2 gal waste + 47.8 gal in-line dilution
		1/25/03 12:00		
			1/26/03 0:00	196 gal waste + 49 gal in-line dilution
		1/26/03 0:00		
			1/26/03 12:00	198.4 gal waste + 49.6 gal in-line dilution
		1/26/03 12:00		
			1/27/03 0:00	180 gal waste + 45 gal in-line dilution
		1/27/03 0:00		
1/27/03 9:30	Start dissolution water spraying of 1310 gal near wall (large volume) from nozzle SALW-SD-QD-001			
			1/27/03 12:00	153.6 gal waste + 38.4 gal in-line dilution
		1/27/03 12:00		
1/27/03 17:30	End near-wall spraying			
			1/28/03 0:00	140.8 gal waste + 35.2 gal in-line dilution
		1/28/03 0:00		
			1/28/03 12:00	145.6 gal waste + 36.4 gal in-line dilution
		1/28/03 12:00		
			1/28/03 22:05	135.2 gal waste + 33.8 gal in-line dilution
		1/29/03 0:00		
			1/29/03 12:00	88.8 gal waste + 22.2 gal in-line dilution
		1/29/03 12:00		
1/29/03 16:41	Neutron probe, ILL=102.8 in.			
1/29/03 21:10	50-gal fill of PIC Skid			
			1/29/03 21:48	68 gal waste + 17 gal in-line dilution
		1/30/03 0:00		
			1/30/03 12:00	159.2 gal waste + 39.8 gal in-line dilution

Table A-2. Timeline for Second Phase of Proof-of-Concept Test. (5 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
		1/30/03 12:00	1/31/03 0:00	195.2 gal waste + 48.8 gal in-line dilution
		1/31/03 0:00	1/31/03 12:00	202.4 gal waste + 50.6 gal in-line dilution
		1/31/03 12:00	2/1/03 0:00	222.4 gal waste + 55.6 gal in-line dilution
2/1/03 19:45	Start dissolution water spraying of 1757 gal near wall (large volume) from nozzle SALW-SD-QD-001	2/1/03 0:00	2/1/03 12:00	216 gal waste + 54 gal in-line dilution
		2/1/03 12:00	2/2/03 0:00	204 gal waste + 51 gal in-line dilution
2/2/03 5:30	End near-wall spraying	2/2/03 0:00	2/2/03 7:00	142.4 gal waste + 35.6 gal in-line dilution
2/2/03 14:10	20-gal system flush	2/2/03 12:00		
2/2/03 14:40	20-gal recirc flush			
2/2/03 17:08	5-gal jet pump prime			
			2/2/03 18:20	111.2 gal waste + 27.8 gal in-line dilution
		2/3/03 0:00	2/3/03 12:00	220.8 gal waste + 55.2 gal in-line dilution
		2/3/03 12:00	2/4/03 0:00	123.2 gal waste + 30.8 gal in-line dilution
		2/4/03 0:00	2/4/03 12:00	238.4 gal waste + 59.6 gal in-line dilution
		2/4/03 12:00	2/5/03 0:00	236.4 gal waste + 54.6 gal in-line dilution
2/5/03 7:37	Start dissolution water spraying of 772 gal near wall (large volume) from nozzle SALW-SD-QD-001	2/5/03 0:00		
2/5/03 11:50	43-gal fill of PIC Skid			
2/5/03 12:00	End near-wall spraying		2/5/03 12:00	222.4 gal waste + 55.6 gal in-line dilution
		2/5/03 12:00	2/6/03 0:00	204.8 gal waste + 51.2 gal in-line dilution
		2/6/03 0:00	2/6/03 10:00	226.4 gal waste + 56.6 gal in-line dilution
2/6/03 16:08		2/6/03 12:00	2/6/03 16:20	84 gal waste + 21 gal in-line dilution

Table A-2. Timeline for Second Phase of Proof-of-Concept Test. (5 Sheets)

Time	Activity	Transfer begin	Transfer end	Transfer
2/7/03 9:07	Neutron probe, ILL=103.3 in.			
		2/7/03 12:00		
2/7/03 17:30	21-gal jet pump prime			
			2/7/03 20:00	186.4 gal waste + 46.6 gal in-line dilution
		2/8/03 0:00		
			2/8/03 8:15	186.4 gal waste + 46.6 gal in-line dilution
2/8/03 9:00	32-gal system flush			
2/12/03 9:41	Neutron probe, ILL=102.2 in.			

APPENDIX B

PRE-DEMONSTRATION THEORETICAL DISSOLUTION ESTIMATES

TWS03.011

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

November 11, 2002

Dan Baide, Manager
U-107 Proof-of-Concept Project
MS S7-65
CH2M HILL Hanford Group, Inc.
Richland, WA 99352

Dear Dan:

DISSOLUTION ESTIMATES

This letter summarizes some calculations of the result of the initial 100-kgal proof-of-concept dissolution test and a subsequent continuation with the Nelson and Fury sprinklers.

I begin by repeating the same kind of waste removal calculations that Jim Huckaby presented in his e-mail of October 28, 2002 and extending them to all the sprinkler tests. The main constraints and assumptions are the following:

- The areas covered by each sprinkler are as given in Table 4-1 of the PCP (p. 4-6). The effect of overlapping areas is ignored.
- The dissolution metrics are taken from Table C-3 of the PCP. The insolubles are uniformly distributed throughout the waste. It is assumed that the water can reach the soluble salts without being impeded by any layers of poorly-soluble waste that may already exist or that form during dissolution.
- Percolation of dissolution water into the waste and out to the saltwell is not a problem at the rates at which water will be applied.
- Based on Blaine Barton's suggestion, it was assumed that drainage stops about 42" from the tank bottom with the waste below that not being dissolved or affected in any way.
- Based on the initial (pre-SWP) surface level of 157" and 72 kgal of supernate removed (estimated from SWP behavior), Huckaby calculated that the average waste surface level in the tank is now about 131". The actual waste is higher towards the wall and lower toward the saltwell, as seen in the recent in-tank video.
- The gas fraction is 50 vol% above the present ILL at 92", and after further pumping will be 30 vol% in the waste between 42" and 92". Neutron profiles and pumping records are the bases for this assumption. A neutron profile taken in October 2002 showed no effect of pumping below 105" elevation. At that time 32 in of liquid had been pumped. If 24 in of this was supernatant, as suggested by pumping records, then the remaining 8 in of liquid came from the waste between 130" and 105" elevation, meaning that 31% of that bulk volume was drained. The region between 130" and 92" may have contained roughly 20 vol% gas before pumping, based on

902 Battelle Boulevard • P.O. Box 999 • Richland, WA 99352

Telephone 509-375-2559 ■ Email lenna.mahoney@pnl.gov ■ Fax 509-375-3865

the neutron probe profile. If it did, the current gas volume fraction in the region between 130" and 105" would be about 50 vol% of the bulk waste. It is assumed that the same void fraction will exist between 92" and 105" once that region is drained. A lesser gas fraction of 30 vol% is assumed for the post-drainage waste below 92" because the lower waste contained less gas and is probably less drainable.

Table 1 shows the results of the calculations for the proof-of-concept dissolution test. The waste surface elevation is that calculated for the footprint of each sprinkler.

Table 1. Results of Simple Dissolution Model

	Area (ft^2)	Dissolution Water Added (gal)	Brine Entering DSTs (gal)	Base of Footprint (in)	Waste Surface Elevation (in)	Gassy Waste Removed (kgal)
Near Saltwell – Initial	19	400	990	76	89	0.6
Shadowing – Initial	20	500	1240	67	83	0.8
Near Wall – Initial	2	400	990	42[a]	65	0.6
Near Saltwell – Channeling	150	2000	4970	92	100	3.7
Near Wall – Large Volume	1105	8000	19900	110	114	15
Fury – Large Volume	1105	5000	12400	118	120	9.2
Large Area A	2000	12000	29800	113	117	22
Large Area B (same location as A)	2000	24000 (cumul.)	59600 (cumul.)	96 (cumul.)	103 (cumul.)	44 (cumul.)
TOTAL		40300	100000			73[b]

(a) This test uses more than enough water to dissolve the nominal footprint down to 42" elevation. It is therefore assumed to spread out to affect an area of 11 ft^2, over which dissolution reaches only as far as 42".
(b) This total probably overstates the waste removal, since many of the tests overlap to some extent. The overstatement is on the order of 5 kgal.

When dissolution is extended beyond the proof-of-concept, the dissolution model must be changed. The dissolution metrics from Table C-3 of the PCP, which were used to generate Table 1, were based on the composition of the waste above about 85" elevation. These are the appropriate metrics for most of the dissolution that occurs in the proof-of-concept test. However, this top waste is more soluble (contains more sodium nitrate and less sodium phosphate and sludge) than the average waste in U-107.

The ESP runs that were reported in an earlier letter-report (TWS02.067, September 23, 2002) were based on the average waste composition in U-107 (derived from the post-SWP Best Basis Inventory). These ESP runs provide different dissolution metrics that are less suitable than the PCP values for dissolution

of waste above the 85" level, but more suitable for dissolution that includes the lower waste. Therefore the ESP metrics were used to model dissolution that extended beyond the proof-of-concept.

If the extended dissolution uses the Nelson and Fury sprinklers and the same sprinkler pattern as the proof-of-concept, the addition of 50 kgal of water with the Nelson and 36 kgal with the Fury would extend dissolution in their footprints down to the 42" level. 112 kgal of brine (containing 67 kgal of removed waste) would be sent to the DSTs by the Nelson extension and 80 kgal of brine (containing 52 kgal of removed waste) by the Fury extension. At the point when the 42" level is reached by dissolution, the waste surface level in the affected areas would be 64" (including a 22-in layer of poorly-soluble waste).

Huckaby commented that increasing the Fury's pressure might allow it to cover an area as large as the Nelson. If this could be accomplished, the overall water added with the Fury would be 68 kgal (including what was stated above for extended dissolution, but not including the Fury's use in the proof-of-concept) and 154 kgal of brine (containing 102 kgal of removed waste) would be sent to the DSTs.

The following are some modifying considerations mentioned by Huckaby.

- At higher operating pressures, the Nelson may effectively spray more than 40% of the surface. (+)
- The Fury's water distribution is not as even as the Nelson, and is more apt to result in a bowl-shaped depression. (-)
- The drainage of liquid into the waste surrounding the area being sprayed may cause a larger region to be dissolved. Chuck Stewart has commented that since the Nelson and Fury sprinklers cover only part of the tank area, the buildup of an insolubles layer in the nominal foot print would tend to drive the solvent laterally. This could widen the footprint and maintain dissolution effectiveness. (+)
- Slumping of the waste toward the Nelson may effectively increase the amount that can be dissolved. (+)
- The hydrostatic pressure of liquid may push solvent into the 42" layer. (+)
- The layer below 42" will dissolve to some extent, albeit slowly and from the top. (+)
- The build-up of insolubles (e.g. phosphate) at the surface, their dissolution and subsequent re-precipitation may reduce the drainage and region that can be dissolved. The buildup of poorly soluble layers that could impede drainage is substantial, as shown in Table 1. (-)
- Drainage may indeed be rate-limiting, meaning we have to deal with excessive run-off of unsaturated liquids. (-)

Please call me at 375-2558 with any comments or questions.

Sincerely,

Lenna A Mahoney

Lenna Mahoney
Senior Research Engineer

LAM:ekm

Enclosures

Dan Baide
November 11, 2002
Page 4

cc: File T1.2.5/LB
WB Barton, R2-11
RG Davalle, S7-65
SD Estey, R2-11
DL Herting, T6-07
DA Reynolds, R2-11
SL Swaney, S7-24

APPENDIX C

LESSONS LEARNED: U-107 PROOF-OF-CONCEPT DISSOLUTION DEMONSTRATION

Lessons learned during the U-107 saltcake dissolution demonstration cover key elements dealing with process, people, and hardware. Positive experiences in addition to problems encountered are included for future consideration. Each lesson learned is linked to a functional area of Integrated Safety Management System (ISMS) that address each beneficial practice and item of concern or are identified as "feedback".

- **Improved quality and reliability of in-tank video equipment would enhance the ability to operate retrieval equipment properly.** The standard in-tank camera used at tank U-107 experienced problems with the lighting system and poor video quality. The wide-angle lighting arrangement did not provide enough illumination to observe changes in the waste surface and was not able to clearly view all areas of the tank. Multiple camera and lighting adjustments were necessary to bring the video quality to an acceptable level. (ISMS Principle: Feedback – improved in-tank video imaging systems are needed to support retrieval.)

- **New retrieval equipment, especially first-of-a-kind equipment should be verified as fully functional and operable before installation.** The Topographical Mapping System (TMS) deployed in tank U-107 never functioned properly, and the ability to quantitatively measure waste volume changes was not achieved. The original work plan was to fully assemble the TMS within the tank farm and verify operability prior to installation. This plan was abandoned in favor of extra mockup training at a test facility in the 300 Area. Even with the additional mockup training, problems with correctly assembling the equipment occurred. The original work plan would have identified this problem before final installation. (ISMS Principle: Define Work Scope – full operability tests should not be replaced in favor of other less rigorous methods.)

- **Project records should be strictly controlled when not in use.** The original tank U-107 redlined fabrication drawings were lost. The redlined drawings provide traceability to the final "as-built" drawings. As a general practice, both redlined drawings and receipt inspection are used to validate equipment configuration. In this instance, only one validation method was available, which could have become an issue if fabrication discrepancies had existed. (ISMS Principle: Feedback – handling and storage requirements for quality records must be followed.)

- **Rigorous acceptance testing is capable of identifying equipment problems before field installation.** Testing activities in the 300 Area identified equipment conditions and configuration that required modification prior to field installation in tank U-107. The orientation of in-tank nozzles and other components required rework in order to meet the design requirements. (ISMS Principle: Feedback – rigorous acceptance testing can eliminate problems before field installation.)

- **Establishing priority for needed resources was a continuous struggle because of competition with other activities.** Performing the demonstration at the same time that Interim Stabilization had a production schedule to meet created the need for many resource work-arounds. Implementation of IMES and "schedule accountability" has helped to focus attention on resource needs. (ISMS Principle: Perform Work – resource loaded schedules identify constraints before they become a problem.)

- **Use of the developmental control process is effective for the fabrication of prototypical equipment.** The design and fabrication phases for tank U-107 equipment were performed concurrently using the developmental control process. Concurrent design and fabrication allowed for significant schedule acceleration to occur. (ISMS Principle: Define Work Scope – flexible work processes are valuable when performing first-of-a-kind activities.)

- **Use of streaming in-tank video helps to monitor and provide direction to the field crews performing the work.** The use of real-time streaming video from tank U-107 during fieldwork allowed for immediate communication and feedback with the work crew. (ISMS Principle: Perform Work – new and more advanced methods of communicating information from the field are valuable in performing work right the first time and can minimize rework.)

- **Use of a camera "top-hat" assembly allows an in-tank camera to be deployed and re-secured in a safe and easy manner when not in use.** (ISMS Principle: Perform Work – new tools that support in-tank video camera systems can simplify field work.)

- **Use of a designated field technical representative to solve issues and answer questions on the spot without a work stoppage can keep fieldwork on schedule.** (ISMS Principle: Perform Work – key knowledgeable persons should be in the field with work crews to help resolve questions as they arise.)

- **Labor jurisdictional issues must be fully resolved before work can effectively be planned.** Labor issues regarding the installation of the Topographical Mapping System continued to be raised after steps to resolve the issues were taken. Scheduled Enhanced Work Planning meetings were halted on two occasions because of continued jurisdictional questions. (ISMS Principle: Define Work Scope – management must address and resolve jurisdictional work issues and enforce decisions.)

- **The proper identification of single-point equipment failures result in the correct identification of spare parts.** The reliability of the electronic flow meter used to monitor dissolution water additions was documented during acceptance testing. The information was used to determine spare part inventories and quantities. (ISMS Principle: Feedback – for new pieces of equipment, acceptance testing can be used to identify spare part requirements when prior experience does not exist.)