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**Mitigation of Tank 241-SY-101
by Pump Mixing: Results of
Full-Scale Testing**

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Abstract

The Full-Scale Mixer Pump Test Program was performed in Hanford Tank 241-SY-101 from February 4 to April 13, 1994, to confirm the long-term operational strategy for flammable gas mitigation and to demonstrate that mixing can control the gas release and waste level. Since its installation on July 3, 1993, the current pump, operating only a few hours per week, has proved capable of mixing the waste sufficiently to release gas continuously instead of in large episodic events. The results of Full-Scale Testing demonstrated that the pump can control gas release and waste level for long-term mitigation, and the four test sequences formed the basis for the long-term operating schedule. The last test sequence, jet penetration tests, showed that the current pump jet creates flow near the tank wall and that it can excavate portions of the bottom sludge layer if run at maximum power. Pump mixing has altered the 'normal' configuration of the waste; most of the original nonconvective sludge has been mixed with the supernatant liquid into a mobile convective slurry that has since been maintained by gentle pump operation and does not readily return to sludge.

Summary

The current mixing pump was installed in Hanford Tank 241-SY-101 on July 3, 1993. A cautious initial test series, Phase A, confirmed that no large gas releases would be triggered by very brief and gentle pump operation. High-speed testing in Phase B, which began October 21, 1993, released a large volume of retained gas and lowered the waste level to a historic low of 400 inches. By the end of Phase B testing on December 17, 1993, the waste was well-mixed except for approximately 50 inches of sludge at the bottom. Because hydrogen concentrations have remained below 400 ppm and the waste level below 402 inches from late November 1993 to the present, the jet mixer pump has successfully mitigated the tank and is capable of maintaining mitigation indefinitely.

Between the end of Phase B and the start of Full-Scale Testing, from December 18, 1993, through February 3, 1994, the pump was intentionally operated very little, and the waste level grew steadily, finally reaching about 402 inches. The pump injected very little hydraulic energy into the waste during this interim period, and the previously well-mixed state gave way to slow but distinct settling. A second convective layer, about 50 inches thick, formed above the suspended slurry layer by density stratification. This settling trend actually continued until the full-tank sweep tests at the end of March.

Despite settling, the tank's uniform temperature profile showed that the suspended slurry remained mobile, in marked contrast to the rapid formation of a deep, nonconvective sludge layer following historical rollover, or gas release events. Evidently, once the waste is thoroughly mixed by passing through the pump impellers, it does not regain its sludge-like character easily.

Full-Scale Testing began February 4. The initial 'nominal operation' pump schedule was intended to maintain a constant waste level by running the pump at 750 rpm for one hour thrice per week, each time in a different direction. The waste level remained approximately constant, as desired, during this test, but the solid material continued to settle slowly. This suggests that it may be necessary to run the pump at or near full speed for a longer period occasionally to reverse this trend.

Following this initial phase, mixing was reduced to a minimum to allow gas to begin accumulating. Pump bumps restricted to only the 35° azimuth were run for four weeks to disturb as little of the waste as possible while preventing nozzle plugging. Gas accumulation and the corresponding waste level growth resumed, but the waste level remained approximately constant for the last two weeks after gaining about 3/4 inch. The third sequence of 'knockdown' tests thoroughly mixed the waste and rapidly released the accumulated gas with two daily tank sweeps of 30 minutes in each of six directions at 750 rpm, performed March 28 and 30. This dropped the waste level nearly one inch to the 400-inch limit, which halted testing.

The last series of tests in the Full-Scale Program studied jet penetration by running the pump at the highest practical power level (1020 rpm) with the nozzles at 97°. This direction was chosen to align the jet with a thermocouple tree at the 28-foot radius, so that changes in temperature profile under the influence of the jet could be observed. An infrared camera was also temporarily installed in the tank annulus to view the inner wall in the vicinity of jet impingement, and sensitive data loggers were connected to the bottom thermocouples under the area swept by the jet.

Two 40-minute runs were made at 920 rpm on April 6 and 8, and two runs at 1,000 rpm on April 12 and 13. While none of the tests caused a response on the infrared scanner, bottom thermocouples, or strain gauges on the tree, the transient temperature trends observed on the thermocouple tree confirmed jet flow at that location. The jet also clearly reduced the thickness of the bottom sludge layer and evidently triggered a small gas release event in the first 1,000-rpm test.

The Full-Scale Test Program was thoroughly successful in that test results demonstrated the ability of the pump to control gas releases and waste level, and the four test sequences formed the basis for the operating schedule for long-term mitigation. The Long-Term Operation Plan calls for three types of operations, depending on the waste level, that closely match the first three Full-Scale test sequences. The jet penetration test results also gave rise to a specific sludge excavation procedure that has been incorporated into the Long-Term Operation Plan. Experience gained from Full-Scale Testing has provided excellent operational data and gives confidence that the mixer pump can maintain mitigation indefinitely.

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1.0 Introduction

A spare mixing pump from the Grout Program was modified and installed in Hanford Tank 241-SY-101 on July 3, 1993. Pump mixing was expected to prevent large, episodic flammable gas releases that had been occurring about every 100-150 days (Babad et al. 1992; Antoniak 1993). A cautious initial test series confirmed that very brief and gentle pump operation would not trigger large gas releases and that brief pump operations called 'bumps' were required about every other day to prevent nozzle plugging. Pump bumping continued into October with only a slight effect on the tank behavior.

High-speed mixer pump testing began October 21, 1993. The more aggressive pump operation released a large volume of retained gas over the first few weeks of testing, reducing the waste level to a historic low of 400 inches. By early December, the pump jets had apparently mixed most of the gas-bearing sludge, and there were no large gas releases for the balance of the test period that ended December 17, 1993. The uniform vertical temperature profiles at two in-tank thermocouple trees showed that the waste was mixed well except for approximately 50 inches of sludge at the bottom (Allemann et al. 1994).

The primary measures of success for mixer pump mitigation are maintaining the maximum hydrogen concentration in the tank dome space well below 25% of the lower flammability limit of 3% hydrogen (7,500 parts per million) and keeping the waste level below some acceptably low value for an extended period. Because hydrogen concentration has remained below 400 ppm, and the waste level remained below 402 inches from late November 1993 through the time of this writing (May 1994), the jet mixer pump has met the mitigation criteria for Tank 241-SY-101. It is intended to maintain mitigation until the waste is transferred out of the tank or another means of mitigation is applied (see Section 1.4).

The Full-Scale Test Program was run from February 4 to April 13, 1994, to confirm the long-term operational strategy for mitigation and to show that the mixer pump can control the gas release and waste level. This section describes the results of pump operation and Full-Scale Testing from January through April 1994. Long-term operation plans are also discussed.

1.1 Background

Tank 241-SY-101 is a double-shell, high-level radioactive waste tank located in the 200 West Area on the Hanford Site. This 75-foot-diameter tank was built in 1976 and first received waste in 1977. Additional wastes of different types were put into the tank over the next three years so that, by November 1980, the tank contained about one million gallons of waste that filled it to a depth of just over 400 inches (Babad et al. 1992). The waste expanded because of gas retention and soon began periodically releasing hydrogen, ammonia, nitrous oxide, and other gases into the tank dome space and ventilation system, creating potentially flammable gas mixtures. Mixer pump operation is intended to mitigate this hazard by keeping sufficient gas-generating material in suspension so that gas is released continuously instead of periodically in large, potentially dangerous gas release events.

The submersible mixer pump now operating in Tank 241-SY-101 was originally purchased as a spare mixer pump for the Hanford Grout Program. The original design was modified to place the pump suction at about the 260-inch elevation to ensure it remained in liquid and the nozzles at 28 inches above the tank bottom to enhance vertical mixing. Operating at 1,000 rpm, the pump injects 2,200 gpm of waste slurry at 66 ft/sec through two opposed 2.6-inch-diameter nozzles while drawing about 140 hp (Allemann et al. 1994). Though its operating time is limited by motor oil temperature, the pump has performed flawlessly since installation and has proved capable of mixing the waste and keeping it in suspension operating only a few hours per week.

The orientation of the pump and nozzle axis in the tank is shown by the plan and profile views in Figures 1.1 and 1.2, respectively. The pump is mounted just west of the tank centerline in riser 12A. The nozzle orientation is referenced to true west as 0°. Because the pump has two opposing nozzles, a 0° orientation also directs a jet at 180°. The specific azimuths on Figure 1.1 were selected for the Phase B tests and have become the standard reference for pump orientation.

Figure 1.1 also shows the location of several instrument trees which also provide useful information. The velocity-density-temperature trees (VDTTs) are placed in risers 14A and 1B on the 35° azimuth. Only the strain gauges on these trees are active and can potentially respond to forces

Figure 1.1. Plan View of Tank 241-SY-101

Figure 1.2. Profile View of Tank 241-SY-101 Mixer Pump Installation

induced by the pump jet. The strain gauges on the two multifunction instrument trees (MITs) serve a similar function. One MIT is located to the north in riser 17B at about 95° and another is placed in riser 17C to the southeast near the 35° azimuth. Both MITs are at the 28-ft tank radius about 30-32 ft from the pump nozzles.

The MIT temperature measurements are possibly the most important indicators of waste condition. Thermocouples measure temperatures at 22 locations along the length of the MITs extending to within four inches of the tank bottom. By observing changes in the characteristic temperature profiles in response to pump operation and gas releases, it is possible to infer how these events transformed the waste. Changes in the temperature profiles at the MITs show the state of mixing in the waste and indicate when more pumping is required to maintain it. This helps ensure that waste conditions stay within a safe envelope. Heat conduction with volumetric heat generation in nonconvective sludge produces a characteristic parabolic temperature profile. The free motion in a convective layer distributes heat evenly to give a uniform temperature. Pure heat conduction in the crust creates a linear temperature profile. A typical temperature profile with implied waste conditions is shown in Figure 1.3.

Figure 1.3 Typical Vertical Temperature Profile

1.2 Overview of Full-Scale Testing

This section provides an overall summary of the response of the tank to mixer pump operation during the period from the end of Phase B testing, December 17, 1993, through Full-Scale Testing, which ended April 14, 1994. Five kinds of pump operations were used during this period, as follows:

- December 18, 1993 - February 2, 1994: 'Directional bumping' - five minutes at 1000 rpm three days per week, rotating the nozzles 30° before each run. Directional bumping was intended to allow the waste level to rise enough to give a useful margin above the 400-inch minimum level control while preparing for Full-Scale Testing.
- February 4 - 25, 1994: Full-Scale Testing, Sequence 1 - one hour at 750 rpm three days per week, indexing the nozzles 30° before each run. This procedure was chosen as the most likely strategy for a 'nominal' schedule to maintain a constant waste level during long-term operation.

- February 28 - March 25, 1994: Full-Scale Testing, Sequence 2 - five minutes at 1000 rpm three days per week with the nozzles at 35°. This sequence was intended to investigate how rapidly the waste level could grow under the minimum pump operation that would prevent nozzle plugging. It is also called the 'regrowth' test.
- March 28 and 30, 1994: Full-Scale Testing, Sequence 3 - 30 minutes at 750 rpm in each of six directions (35°, 65°, 95°, 125°, 155°, and 185°) in one day (total of three hours per day). This schedule was intended to show the pump's ability to release gas and quickly reduce the waste level. This has also been called the 'knockdown' test.
- April 6, 8, 12, and 13, 1994: Full-Scale Testing, Sequence 4 - 40 minutes at 920 rpm (April 6 and 8) and 20 minutes at 1,000 rpm (April 12 and 13) with the nozzles at 97° (in line with MIT 17B). This jet penetration test series explored the ability of the pump to cause flow near the tank wall.

Following the last Full-Scale Test on April 13, directional bumping resumed as the first pump schedule for long-term operation. The operation schedule for the entire period above is displayed schematically in Figure 1.4. Excerpts from the Full-Scale Test Plan are given in Appendix A, and the operations log showing each pump operation during the period can be found in Appendix B.

Figure 1.4. Full-Scale Test Schedule

Tank behavior is described by daily gas releases, exhaust hydrogen concentration, surface level and average waste temperature history, and temperature profiles. Figure 1.5 shows the daily gas release with annotations for the type of pump operation or testing occurring each period. Figure 1.6 gives the corresponding hydrogen concentration history. The waste surface level history, as shown by the Food Instrument Corporation (FIC) contact probe, is given in Figure 1.7. The FIC probe is 'flushed' periodically, as shown in the figure, to remove salt deposits that give erroneous readings. Figure 1.8 presents the average waste temperature history starting from the last natural gas release (Event I) on June 23, 1993. The average waste temperature excludes the top three thermocouples in the crust and dome space.

Several temperature profiles that suggest changes in the waste in response to the various periods of pump operation are shown in Figure 1.9. A continuous record of waste temperatures at both 17B and 17C MITs for a similar period is shown in the color-coded history plots in Figures 1.10 and 1.11. The plots are made from bi-hourly averages of data recorded every 12 seconds on the DACS. The vertical blue lines represent missing data. Because of DACS system errors and unusable thermocouples, the parts of the 17C plot in Figure 1.11 before about February 1 and above 350 inches should be disregarded.

Figure 1.5. Daily Gas Release History

Figure 1.6. Hydrogen Concentration History

Figure 1.7. Waste Level History

Figure 1.8. Average Waste Temperature History (17B)

1.2.1 Pre-Test Period Following Phase B

The temperature profiles indicate that the waste was quite well mixed following completion of Phase B testing on December 17, 1993. At that time, the uniform temperature profile in Figure 1.9 shows a convective mixed slurry existed from about 50 inches to almost 350 inches near the two MITs. Only the bottom 50 inches evidently were composed of sludge that was still potentially capable of retaining gas. Evidence of significant mixing is also seen by comparing the average convective layer temperature with the average of all thermocouples (excluding the crust) at the MIT in riser 17B in Figure 1.8. The average temperatures are very close together, indicating temperatures even more uniform than after major rollover Event I on the left side of the figure.

Directional bumping from December 18, 1993 through February 2, 1994, intentionally disturbed the waste very little, and gas releases were generally quite low—about 75 ft³ per day, except for a short period around January 1, as shown in Figure 1.5. As a consequence, the waste level grew steadily at about 0.03 inch/day, reaching the desired level of about 402 inches at the start of Full-Scale Testing, as shown in Figure 1.7.

All Temperatures °F

Figure 1.9. MIT Temperature Profiles

Tank 101SY Temperature History for 1994

17C Tree, 2 Hour DACs Data Averages

Figure 1.10. MIT 17B Temperature History

Tank 101SY Temperature History for 1994

Figure 1.11. MIT 17C Temperature History

The pump injected very little hydraulic energy into the waste during this interim period, and the previously mixed state gave way to slow but distinct settling. This can be seen in the rapid cooling trend of the convective layer temperature through January and February 1994 (Figure 1.8). The temperature profile at the 17B MIT on February 4, shown in Figure 1.9, reveals a second convective layer about 50 inches thick above the suspended slurry layer. This indicates that sufficient solids have settled out of this region to cause a density stratification.

1.2.2 Nominal Operation

The initial test sequence of Full-Scale Testing began February 4. The pump schedule for this test was chosen based on the results of Phase B testing as the best strategy for maintaining a constant waste level. This is the desired result of long-term pump operation, because it requires that gas be released at the same rate as it is generated, and large releases are prevented. Figure 1.5 shows that daily gas releases immediately increased as the pump was run for one hour per day, three times per week. It is also clear from Figure 1.7 that the waste level remained approximately constant, as desired, during this test. The brown shading around the 200-inch level in Figure 1.10 reveals the effect of the pump in lifting warmer material.

However, the solid material continued to settle. This can be seen very clearly by comparing the slurry layer thickness on February 4 with that of February 22, as indicated by the temperature profiles in Figure 1.9, b and c, respectively. Also, the top of the slurry layer coincides with the descending yellow-to-green boundary (114°F) in Figures 1.10 and 1.11. The decrease in slurry layer thickness shown in Figure 1.10 corresponds to a settling rate of approximately one inch per day. At the same time, the static pump volute pressure (during pump-off periods) decreased about 10%, corresponding to an equal decrease in fluid density above the 200-inch level. This settling trend suggests it may be necessary to occasionally run the pump at or near full power for longer periods during long-term operation to reverse the settling trend and prevent the slurry from eventually becoming nonconvective.

1.2.3 Regrowth Test

Following the initial 'nominal operation' phase of Full-Scale Testing, pump operation was reduced to a minimum to allow gas to begin accumulating. Early experience with the pump demonstrated that running five minutes at 1,000 rpm about every other day prevented nozzle plugging. This was deemed the minimum acceptable schedule. However, pump bumps were restricted to the 35° azimuth to disturb as little of the waste as possible and to accomplish the maximum possible level regrowth.

The 35° azimuth directs one of the pump jets at the 17C MIT while keeping 17B almost perpendicular to the jet axis. This means the waste around 17C would feel the full effect of the pump bumps, while 17B would get essentially none. Even though the pump was run only 15 minutes per week, the effects of a month of this nonuniform mixing can be seen clearly in the temperature profiles shown in Figure 1.9. The waste near 17C was mixed sufficiently to maintain a uniform, constant temperature profile and to prevent much additional settling. Around 17B, however, additional settling occurred, the temperature is about 3–4°F higher, and the profile began to show aspects of a nonconvective shape. Also compare the nearly constant color pattern in Figure 1.11 (17C) with the continued settling in Figure 1.10 (17B).

Gas accumulation and the corresponding waste level growth resumed during the first part of the regrowth period. But, after gaining 3/4 inch, the waste level remained approximately constant for the last two weeks. It may be that accelerated settling in the absence of pump action pulled gas bubbles to lower elevations such that hydrostatic compression compensated for gas retention and kept the waste level nearly constant.

1.2.4 Knockdown Test

The third sequence 'knockdown' tests brought about a dramatic change in tank conditions. The daily tank sweeps (30 minutes in each of six directions at 750 rpm) performed March 28 and 30 released much of the gas retained in earlier stages and dropped the waste level nearly one inch, to the 400-inch limit, which halted testing.

Daily gas releases for the two tests were over 400 ft³, as high as those in the initial stages of high-speed testing when the tank was first mixed. These two runs also returned the waste to the thoroughly mixed state it enjoyed earlier. This is shown by the sudden rise in the average convective layer temperature in Figure 1.8 and the uniform temperature profiles of March 31 in Figure 1.9. Note also the sudden warming of the upper region of Figures 1.10 and 1.11. The rapid waste level rise following the last test shown in Figure 1.6 is also indirect evidence of mixing resulting from expansion of gas lifted by pump agitation.

1.2.5 Jet Penetration Tests

The last series of tests in the Full-Scale Program studied jet penetration by running the pump at the highest practical power level with the nozzles at 97°. This direction was chosen to align the jet with the 17B MIT (at the 28-foot radius, about 30 feet from the pump) so that changes in the temperature profile under the influence of the jet could be observed and compared with those of the 17C MIT, which was out of the path of the jet. It was also hoped that the strain gauges on the 17B MIT would register a deflection due to hydraulic forces. An infrared scanner was also temporarily installed in the tank annulus to view the inner wall in the area of jet impingement. It was expected that small changes in temperature would reveal the size of the jet as it hit the wall. Finally, data loggers capable of discriminating $\pm 0.01^\circ\text{F}$ were connected to the bottom thermocouples underlying the jet fan in the hope that they would respond if large amounts of sludge were excavated. The details of these tests are given in Section 5, but the results are summarized here to complete the overview.

Two 40-minute runs were made at 920 rpm on April 6 and 8, and 9- and 20-minute runs were performed at 1,000 rpm on April 12 and 13 (a 20-minute run was planned for April 12 but was aborted after nine minutes, as explained below). The run times were the maximum possible within the 190°F motor oil temperature limit. While none of the tests caused a response on the infrared scanner, bottom thermocouples, or the 17B strain gauges, the transient temperature trends observed on the 17B MIT thermocouples confirmed fluid motion caused by the pump at that location. While the infrared scanner camera did not respond to the jet, it indicated a uniform temperature, which is further evidence that a fluid, rather than a nonconvective solid, is in contact with the tank wall in the scanner's field of view (see Section 5.2.4).

The jet clearly reduced the thickness of the bottom sludge layer, as can be seen by comparing the temperature profiles at 17B before and after the jet penetration tests. The transition to an approximately uniform temperature dropped from about 50 inches to about 28 inches or less (Figure 1.9, e and f, respectively). Sludge layer reduction is also visible at the bottom of Figure 1.10, but not in Figure 1.11. Also, the first 1,000-rpm run on April 12 was terminated after only nine minutes, because it evidently triggered a small gas release event, which caused an abort due to high vent flow. As this happened, the 17B strain gauges showed a small, but immediate, deflection, indicating that the sludge participating in the gas release was near that area, far from the pump. However, the 17B strain gauges did not respond to the second 1,000-rpm run on April 13, so the deflection was likely due to relaxation of sludge rather than jet forces.

Following completion of testing, directional bumping was resumed to begin long-term mitigation. Experience gained from Full-Scale Testing has provided excellent operational data and gives confidence that the mixer pump can maintain mitigation indefinitely.

1.3 Effect of the Pump on Waste Conditions

Continued settling, after Phase B testing through the end of March 1994, reduced the mixed slurry layer to its smallest extent since the beginning of high-speed testing on November 2, 1993. The temperature profile from March 28, in Figure 1.9d, shows the slurry layer extending from about the 76-inch to 232-inch levels for a depth of just under 160 inches. But the slurry has remained convective despite this significant settling. This is unlike historic behavior, where the waste quickly returned to the characteristic nonconvective parabolic temperature profile after being mixed in natural rollovers. Figure 1.12 shows the redevelopment of the nonconvective layer after rollover Event I on June 23, 1993. The profile before the event is marked with the diamond symbol. Note that this occurred despite twice-daily pump bumping.

After being mixed thoroughly by Phase B testing, the nonconvective layer did not redevelop in over four months, even with far less pump bumping than during the prior period. The evolution of the temperature profile at the 17B MIT following high-speed testing is shown in Figure 1.13 with the pre-Event I nonconvective profile indicated by the pyramid symbol. Note that the slurry temperature did start increasing in February and March after considerable settling, but the parabolic temperature profile did not appear immediately, as it did during a similar period shown in Figure 1.12.

Studies of several cores samples from various levels and windows out of Tank 241-SY-101 have shown that waste that has been aggressively disturbed (e.g., repeated rheograms or homogenization) loses its yield strength. More important, this waste apparently does not rapidly regain its original yield strength. Homogenized core samples from Window C were found to be pourable even after several years stored at 100°F in a hot cell.^(a) Sonic vibration at 10g also permanently destroyed

(a) Tingey, J. M., P. R. Bredt, and E. H. Shade. 1994. *The Effects of Heating and Dilution on the Rheological and Physical Properties of Tank 241-SY-101* (Draft). Pacific Northwest Laboratory, Richland, Washington.

Figure 1.12. Temperature Profiles after Rollover Event I

Figure 1.13. Temperature Profiles after High-Speed Testing

core sample yield strength.^(a) Evidently, once the structure responsible for creating the yield strength breaks down, it does not rebuild, at least under the conditions the samples have been stored in.

The pump has circulated about 5 million gallons of waste from installation through the end of Phase B testing. This represents over six times the volume of the tank, allowing enough time for most of the slurry to have been forced through the impellers at least once. The action of the pump impellers may have been sufficient to convert the waste in the tank to a post-yield condition similar to the experience with core samples. A much longer time may be required for the current slurry to return to sludge than tank history would indicate.

The mixer pump has altered the 'normal' configuration of the waste. Before the mixer pump was installed, a nonconvective sludge layer about 200 inches deep lay under approximately 150 inches of supernatant liquid, with roughly 50 inches of crust floating on top, as sketched in Figure 1.14. Following a large gas release event, the sludge layer would temporarily mix with the liquid layer, but settling always returned the solids to sludge within a few weeks after the event.

Current temperature profiles indicate the sludge layer is only about 50 inches deep at the MITs in risers 17B and 17C. It can be safely assumed that the top of this layer slopes down to 20 inches or less under the pump column. Above the bottom sludge layer, the original sludge and liquid have apparently been mixed into a mobile slurry over which about 50 inches of supernatant liquid forms during nominal pump operation. The new configuration is sketched in Figure 1.14. The upper liquid layer tends to grow deeper slowly during periods of gentle mixing but can be erased by a few days of aggressive pump operation.

Figure 1.14. Tank Waste Configuration

(a) Cannon, S., and M. Hall. 1994. *101-SY Waste Sample Speed of Sound/Rheology Testing for Sonic Probe Program*. Letter Report WHC-SD-WM-DTR-034, Westinghouse Hanford Company, Richland, Washington.

Mixing has not changed the gas generation rate in any measurable way (see Section 2.0). But the background gas release rate has increased substantially. This indicates that the waste tends to retain less gas after mixing and reduces the demand on the pump.

1.4 Long-Term Operations

The Full-Scale Test Program was thoroughly successful in that test results demonstrated the ability of the pump to control gas releases and waste level, and the four test sequences formed the basis for the operating schedule for long-term mitigation. The Long-Term Operation Plan, for which excerpts are given in Appendix C, calls for three types of operation, depending on the waste level. If the waste level is near the 400-inch limit, 'minimal' operation, consisting of directional pump bumping (5 minutes at 1,000 rpm) three times per week, is performed until the level rises above 400.5 inches. On the other hand, if the waste level rises above 401.5 inches, aggressive daily sweeps (30 minutes in each of six directions at 750 rpm) are used until the level drops below 401 inches. Between 400.5 and 401.5 inches, 'nominal' operation attempts to maintain a constant level by running one hour at 750 rpm thrice weekly, indexing 30° before each run. These three schedules closely match Full-Scale test sequences 2, 3, and 1, respectively.

Another important result of the jet penetration tests was the evidence that the current pump is able to excavate more of the bottom sludge if run at maximum power. Accordingly, a specific sludge excavation procedure is included in the Long-Term Operation Plan. Excavation will use a 20-minute run at 1,000 rpm each day indexing the nozzles 30° after two or three runs in the same direction. This procedure may uniformly reduce the bottom sludge depth from over four feet to approximately two feet if repeated several cycles. Also, based on the behavior of the waste observed to date, once the bottom sludge is excavated and mixed by the pump, it will tend to remain suspended.

As the regrowth tests began, pump operation was limited to five-minute, 1,000-rpm pump bumps three times weekly only in the 35° direction. Hydrogen concentrations during this period were again relatively low, falling largely within 20 to 40 ppm range. These contributed to daily gas releases which were typically less than 80 ft³/day. Some waste surface level growth was observed during this period.

The knockdown tests consisted of pump operation for 30 minutes at each of six pump orientations (three hours total) per day at 750 rpm. Hydrogen concentrations in the vent stream exceeded 500 ppm following both of these tests. These high concentrations contributed the two largest daily gas release volumes observed during Full-Scale Testing. These were approximately 435 ft³ on March 28 and 465 ft³ on March 30. On only two days during Phase B testing did the daily release volumes exceed these values. These pump-induced releases were accompanied by a noticeable decrease in the waste surface level (see Figure 1.7).

The jet penetration tests consisted of two runs of 40 minutes at 920 rpm and nine- and 20-minute run at 1,000 rpm at the 97° orientation. Hydrogen concentrations were at or above 300 ppm on each of the first three tests, contributing to daily release volumes in the range of 150 to 300 ft³/day. The waste surface level continued to decrease during this period, and temperature profiles showed the sludge thickness was being reduced. In fact, a gas release aborted the third run on high vent flow after only nine minutes into the scheduled 20-minute run.

The release volume depends on both the duration and peak value of hydrogen concentration. Thus the highest concentrations do not always produce the highest daily gas release. For example, the maximum hydrogen concentration following the second jet penetration test (April 6) was only about 250 ppm, but the release volume for that day was over 300 ft³. For the small gas release in the third jet penetration test (April 12), the maximum hydrogen concentration was approximately 500 ppm and the daily release volume was under 250 ft³ (see Figures 1.5 and 1.6).

Another interesting trend is noticeable in the daily release volumes (Figure 1.5). Following each period of intense pump activity there is a gentle rise in the daily release volumes that occurs for about two weeks. After the two-week period, the daily gas release suddenly falls back to a baseline value of approximately 55 to 60 ft³/day. This trend is observed in the data following Phase B testing (from December 18, 1993, to January 3, 1994), following the nominal operation Full-Scale Tests (from February 26, 1994, to March 19, 1994) and following the jet penetration tests (from April 16, 1994, to April 23, 1994).

Overall, the hydrogen retained and released by the waste responded to pump mixing, as desired. During periods of minimal pump operation, more gas was retained by the waste and some waste level increase was observed. During more intense operation, such as the knockdown and jet penetration series, large gas volumes were released and the waste surface level decreased. These tests indicate that pump operation of this type is an effective means of controlling the rate at which hydrogen is retained and released and for maintaining the waste surface level within the prescribed bounds.

2.2 Ammonia

The mixture of gases released from Tank 241-SY-101 contains a significant amount of ammonia which, because of its flammability and toxicity, plays an important role in the safety analyses. Because ammonia is highly soluble in the waste compared with many of the other major components of the release gas (such as hydrogen and nitrous oxide), the liquid and solid phases of the waste may also contain significant quantities of ammonia. Allemann reports that ammonia concentrations in the waste material could be as high as 1%.^(a)

Measurements of the ammonia concentration in the vent stream are available from the on-line Fourier Transform Infrared Spectrometer (FTIR). The measurements from the period of Full-Scale Testing are given in Figure 2.1. A baseline ammonia concentration varies within the range of 30 to 50 ppm; peaks in ammonia concentration coincide with pump activity; small spikes appear during 'nominal' operation in February. Higher peaks are particularly evident during the 'knockdown' tests the week of March 25, and jet penetration tests, approximately two weeks later. The highest concentration marks the small gas release on April 12. In these cases the ammonia concentration exceeded 100 ppm following each test. Although this is more than twice the baseline concentration, this is still small compared with that observed during a large gas release event. The ammonia concentration following the June 26, 1993, gas release event was approximately 1.4%, or 14,000 ppm.

Figure 2.1. Ammonia Concentration History for Full-Scale Testing Period

(a) Allemann, R. T. 1994. *Some Theories of Dissolved Gas Release from Tank 241-SY-101* (Draft). Pacific Northwest Laboratory, Richland, Washington.

2.0 Gas Release

Since the tank was thoroughly mixed in mid-November 1993, the waste level has not risen above 402 inches and no large gas release events have occurred. Pump operation kept the tank gas content to a minimum during this period. But mixing also increased the background release rate substantially, reducing the demand on the pump. Mixing has not changed the gas generation rate by any measurable amount.

The background gas release is measured by the minimum steady hydrogen concentration in the vent strain during quiet periods undisturbed by rollovers or pump operation. This so-called 'basal' hydrogen concentration is a good indicator of gas retention. The higher that basal concentration, the less gas is being retained in the waste. During April and June 1993, before Event I, the 'basal' hydrogen concentration was about 15 ± 3 ppm. After the waste was mixed in Phase B, the 'basal' concentration approximately doubled, to 25 ± 5 ppm (see Figure 1.5). At a vent flow of 550 cfm, assuming the waste gas is 29% hydrogen, the corresponding background release rates before and after mixing would be about 40 and 70 standard cubic feet (SCF)/day, respectively.

The reduced level rise rate during minimal pump operation is another symptom of reduced gas retention. As stated above, the waste level typically rose at 0.08 inch/day between gas release events prior to pump installation. After the pump was installed but before extensive mixing, the waste level history showed rise rates of 0.05—0.06 inch/day (Allemann et al. 1994). After Phase B the level rise was generally 0.025—0.03 inch/day.

The gas generation rate can be estimated by averaging the measured gas releases over a relatively long time period and adding the accumulation rate indicated by the rate of waste level rise. The gas release rate is computed from the vent header hydrogen concentration and flow rate, assuming the gas escaping from the waste is 29% hydrogen, as discussed below.

In April and May 1993, prior to gas release event I, the average gas release rate was 53 SCF/day. At the same time, the level grew at a relatively steady 0.08 inch/day. Assuming that gas accumulates at an average pressure of 1.75 atm (equivalent to a depth of 16 feet), this level growth adds another 53 SCF/day for a total gas generation rate of 106 SCF/day prior to pump installation. The estimate for August and September 1993, after the pump was installed but before mixing, also showed a 106 SCF/day. For the entire period from December 18, 1993, at the end of Phase B testing, to the end of the Full-Scale 'regrowth' test on March 26, 1994, the average generation rate was about 100 SCF/day. With error bounds on the calculation as high as ± 20 SCF/day, the gas generation rate did not change with mixing.

The rest of this section will describe the behavior of the major component gases in detail. Some of the prominent aspects of the gas release response to pump operation as shown in the data will also be discussed.

2.1 Hydrogen

Because many of the safety issues associated with Tank 241-SY-101 are strongly tied to the amount of hydrogen in the retained and released gases, much attention has been focused on obtaining hydrogen concentration measurements. In addition, these measurements are a critical measure of mitigation. One goal of mitigation is to control the release of flammable gases such that their concentration is always low in the dome space and vent flow streams. For this to occur, the long-term average gas release must be roughly the same as the gas generation rate, without the large episodic releases that have been observed historically.

Hydrogen concentration measurements are provided by a variety of instruments in the dome space and vent stream. These are discussed in some detail in the report of Phases A and B Testing (Allemann et al. 1994). This report focuses on the measurements provided by the GC3 gas chromatograph instrument because of its resolution within the 0 to 100 ppm range. Hydrogen concentration measurements above the 100 ppm level are provided by the GC2 gas chromatograph.

Measurements during the large gas release events using the on-line mass spectrometer (with oxygen as a tie gas) have suggested that approximately $29 \pm 5\%$ of the released gas is hydrogen. The recent calibration from the FTIR instrument tends to confirm this. Using this value, a total gas release volume may be calculated by integrating the product of the hydrogen concentration in the vent stream and the vent stream flow rate and dividing by the hydrogen gas fraction. The daily total gas release volumes presented in Figure 1.5 were calculated by this method.

Hydrogen concentration data from the GC3 instrument for the period of Full-Scale Testing were presented in Figure 1.6. A baseline release rate of 25–30 ppm is evident as the lower limit of the hydrogen concentration data. Significant increases of hydrogen concentration in the vent stream gas occurred as a result of pump activity during Full-Scale Testing. Gas releases associated with the more intense pump operations of the 'knockdown' and jet penetration tests caused the hydrogen concentration in the vent stream to exceed 500 ppm three times during this period (as recorded by the GC2 instrument, which is calibrated for values over 100 ppm). These concentrations are nearly as large as the largest observed during Phase B testing. While these concentrations are much larger than the baseline value, they are still small compared with the lower flammability limit of 3% hydrogen (30,000 ppm).

Between Phase B and Full-Scale Testing, pump activity consisted of five-minute, 1,000-rpm pump bumps in alternating orientations. The hydrogen concentrations remained relatively low throughout most of this period, with concentrations falling largely within a 25 to 50 ppm range. On only one occasion (on January 14, 1994) did the hydrogen concentration exceed 100 ppm. The average daily release volume (see Figure 1.6) during this period was about 70 ft³/day.

With the start of Full-Scale Testing, the "nominal" pump tests were one hour at 750 rpm each day, at a different orientation each time. Sharp increases in the hydrogen concentration were observed following each of these tests; hydrogen concentrations often exceeded 200 ppm, contributing to an average daily gas release in excess of 100 ft³/day during this period. These larger gas releases were also accompanied by a corresponding decrease in waste surface level (see Figure 1.7).

2.3 Gas Concentration Ratios

The ratios of the concentrations of various gases to the hydrogen concentration give some information about the mechanism by which gases are released from the waste. A change in gas ratios indicates that a gas may not be generated and/or released by the same processes as the hydrogen. A long-term change in ratios may indicate that mitigation activities are changing the composition of the gas or the rate and/or mechanism of retention and release.

The ratios of nitrous oxide to hydrogen and ammonia to hydrogen during the period from the completion of Phase B testing, December 18, 1993, to the completion of Full-Scale Testing, April 22, 1994, are shown in Figures 2.2 and 2.3, respectively. Figures 2.4 and 2.5 show the ratios versus hydrogen concentration.

The nitrous oxide-to-hydrogen ratios remain relatively constant and are consistent with the behavior observed during the Phase A/B testing. After recalibration of the FTIR on February 23, 1994 (evidenced by the discontinuity on the plot), the nitrous oxide-to-hydrogen ratios were consistently 1.4. During periods associated with longer-duration pump runs, when hydrogen concentrations exceeded 100 ppm, the nitrous oxide to hydrogen ratio dropped to values between 0.5 and 1.0. During periods of pump bumps, when the hydrogen concentration dropped below 10 ppm, the nitrous oxide to hydrogen ratio increased to approximately 2. This behavior is also consistent with that observed during Phase A/B testing and may indicate that some nitrous oxide is stored in the liquid and behaves somewhat like ammonia.

The ammonia-to-hydrogen ratio was more variable during the Full-Scale Tests, because the ammonia concentration remained relatively stable around 50 ppm $\pm$ 10 ppm for the duration of the tests, while hydrogen concentrations fluctuated as a function of pump operations. During the Full-Scale Testing, temperature profiles (see Figure 1.9) indicate a density stratification layer below the crust that may have prevented fresh waste in lower regions from reaching the surface. Therefore, the ammonia was not allowed to diffuse out of the liquid waste. However, hydrogen and nitrous oxide in gas bubbles could rise through the stratified liquid layer easily when released by pump operation, and the concentrations of these gases were therefore relatively independent of ammonia.

2.4 Pump-Induced Gas Release Trends

2.4.1 Doppler Flow Meter Indications

Ultrasonic flow meters operating on the principle of Doppler-shift frequency relative to moving particles or gas bubbles in the flow stream were mounted on each of the downcomer pipes feeding the exit jet nozzles. These devices give a qualitative indication of gas bubble content ingested at the pump suction as described in the Phase A/B Test Report (Allemann et al. 1994).

Figure 2.2. Nitrous Oxide to Hydrogen Ratio History

Figure 2.3. Ammonia-to-Hydrogen Concentration Ratio History

Figure 2.4. Nitrous Oxide Versus Hydrogen Concentration

Figure 2.5. Ammonia Versus Hydrogen Concentration

A chronological record of the Doppler meter signal and volute pressure during pump bumps through the Full-Scale test period including the bump performed on April 25, 1994, is given in Figure 2.6. The decrease in volute pressure that coincides with increasing Doppler signal intensity indicates a decrease in fluid density due to higher gas fraction. Some evidence of gas buildup in the waste following major gas release events was seen following the August 27, September 17, and October 25 events. Initiation of Full-Scale Testing with the 60-minute pump run on February 4, 1994, quickly degassed the waste, and subsequent pump bumps indicate low Doppler readings. Figure 2.7 shows the steady decrease in Doppler intensity during the first 60-minute run.

During this one-hour test, the change in ingested gas fraction decreased pump volute pressure by about 3%. Results of prior research on the effect of noncondensable gas on centrifugal pump performance are summarized in Figure 2.8. The figure indicates that the 3% decrease in volute pressure is consistent with about a 4% decrease in gas fraction if the initial value is in the range 4-6%. Therefore a high Doppler intensity may suggest a void fraction of 4-6%.

Figure 2.6. Doppler Indication at Each Pump Bump

Figure 2.7. Doppler Intensity Transient on 2/4/94

2.4.2 Pump-Bump Hydrogen Suppression

Pump operation most often causes additional gas releases above the background level. But sometimes the hydrogen concentration actually decreases after pump bumps that follow periods of vigorous pump operation. This "suppressed hydrogen" behavior is described in the report on Phases A/B test results (Allemann et al. 1994). Additional experience with hydrogen "suppression" was gained during Full-Scale Testing. Appearance of hydrogen suppression coincided with low Doppler readings. Thus hydrogen suppression occurs when the gas content of the waste is at a minimum.

Pump bumping consistently raised hydrogen concentrations above the background until November 24, 1993, when a "suppression" of hydrogen followed the bump on that day.

This coincides with the end of Phase B "sweep" tests, which were particularly effective in releasing gas from the waste volume surrounding the pump column. This is shown by the low Doppler indication for that period in Figure 2.6. Increased hydrogen concentration resumed after December 20 and continued until the start of Full-Scale Testing. Then nine successive bumps beginning February 11 (and again on April 1 and 4 following the 'knockdown' sweep tests) caused a suppressed hydrogen

response. Hydrogen suppression events following Phase B testing are clearly visible as sharp dips below the baseline on the hydrogen concentration history in Figure 1.6. These all match periods of low Doppler intensity on Figure 2.6.

The long-duration sweep tests essentially degas the region surrounding the pump column. The first few pump bumps following these tests then ingest 10,000 gallons of recently degassed waste at the pump suction and inject it into the lower portion of the tank. This apparently interferes in some way with the "background" bubble transport process that maintains the basal hydrogen concentration at 20–30 ppm and caused the temporary suppression.

Figure 2.8. Centrifugal Pump Head Degradation Versus Gas Fraction

The concentration begins to decrease approximately 60 minutes after the pump bump and reaches a minimum after about four hours. However, there is usually a corresponding increase several hours later, indicating that the transport process was only delayed, not suspended. This means that hydrogen suppression periods are characterized by a long delay time to the peak concentration following pump bumps. Hydrogen release delay times are shown in Figure 2.9 from the end of Phase B to April 25. The delay in nitrous oxide release closely follows that of hydrogen. Ammonia releases were essentially independent of pump operation during the Full-Scale Testing period.

Figure 2.9. Hydrogen Response to Pump Bumps

3.0 Temperatures

The changing temperature of the waste reveals the configuration of the sludge, long-term heat loss trends, and the effectiveness of the mixer pump in maintaining solids in suspension. Temperature measurements are available in the DACS data stream for 22 thermocouples on each of two multifunction instrument trees (MITs) and 24 thermocouples attached to the tank bottom. These are the main indicators of tank thermal conditions along with ambient air, vent header, and pump column temperatures. These and other tank instruments are described more fully in Section 7.0 of the Phases A and B testing report (Allemann et al. 1994).

3.1 MIT Temperature Profiles

Temperature measurements are possibly the most important indicators of waste condition and, of these, the MITs are by far the most useful. By observing changes in the characteristic temperature profiles in response to pump operation and gas releases, it is possible to infer how these events transformed the waste. Heat conduction with volumetric heat generation in settled, nonconvective sludge produces a characteristic parabolic temperature profile. The free motion in a convective layer distributes heat evenly to give a uniform temperature. Pure heat conduction in the nonconvective crust creates a straight linear temperature profile. A change from a parabolic to a uniform temperature profile could suggest that part of the sludge layer had been suspended. Thus changes in the temperature profiles at the MITs show the results of mixing and indicate when more pumping is required to maintain it. This helps ensure that waste conditions stay within a safe envelope.

The relation of the temperature profiles from the 17B and 17C MITs to the various phases of Full-Scale Testing has already been discussed at some length in Section 1.2. The transient response of the 17B MIT during jet penetration testing is given in Sections 5.2.1 and 5.2.2.

3.2 Tank Bottom Temperatures

Although all 24 bottom thermocouples were recorded on the DACS during Full-Scale Testing, those data have not been useful. The report on Phase A and B testing (Allemann et al. 1994) concluded that the DACS bottom thermocouple data, which is recorded only in integer degrees, is of little value in correlating with tank events or pump operation. The thermal inertia of the bottom sludge layer effectively isolates the tank bottom from the effects of changing waste conditions at higher levels. Bottom temperature measurements are not important monitors of tank mitigation.

For the jet penetration phase of Full-Scale Testing, 15 of the bottom thermocouples were temporarily connected to data loggers that recorded temperatures to 0.01°F. Only the thermocouples underlying the approximate region of the jet were connected, as shown in Figure 3.1. The data loggers enabled observation of the potential effects of changes in the sludge layer thickness due to jet excavation. However, with the high level of precision, the fine detail of bottom temperature behavior could be studied for the first time.

Figure 3.1. Bottom Thermocouples Used in Jet Penetration Tests

The measurements confirm computational predictions that the waste temperature is lower in the central and outer regions and higher at middle radii. Figure 3.2 shows the transient bottom temperature response to a decrease in ventilation flow rate on the evening of March 28. The important feature to observe in the figure is that eight of the thermocouples increase in temperature, while seven show a decrease. Those increasing are on the inner and middle rows, and those decreasing are on the outer row. This confirms that air flow proceeding radially from the tank center first cools the waste at the inner and middle radii, then heats the cooler waste near the tank outer wall. Thus when the air flow rate decreases, the outermost waste temperatures will decrease, seemingly contrary to logic, because the lower flow heats this region less effectively.

Figure 3.2. Bottom Thermocouple Transient (March 28)

3.3 Steady State Thermal Analysis Using the TEMPEST Code

The waste in Tank 241-SY-101 has decreased in temperature since vent air flow rates were increased about three years ago. Some concern has been expressed regarding the safety consequences of the cooler waste. This waste is currently being mixed to varying degrees by the pump, which, if operated frequently enough, tends to homogenize the waste vertically, as evidenced by the nearly isothermal temperature profiles measured. A model of the mixed tank was developed to evaluate the long-term effect of current vent air flow rates and the long-term effect of reduced flow rates.

3.3.1 Thermal Model

A sensitivity study of the thermal response of Tank 241-SY-101 to a reduced vent air flow was performed with the TEMPEST code. The two-dimensional model used is derived from our earlier studies on heat transfer from the tank prior to pump installation. The number of assumptions and approximations in this model have been minimized in two ways. First, separate effects heat transfer analyses were used to identify critical parameters and values and to aid in evaluating approximations.

Second, fidelity to actual processes in Tank 241-SY-101 is obtained by modeling both fluid dynamics and heat transfer that are fully coupled. That is, natural and forced convection processes in the waste and in the dome and annulus air flow spaces are treated as such.

Two changes were made to the model to simulate the waste mixing that resulted from Phase B pump testing. First, the nonconvective waste layer, which had previously been modeled with a depth of 228 inches, was reduced to the 50 inches indicated by MIT temperature profiles at the end of Phase B. Second, the viscosity of the convective layer was increased by a factor of 100 (to about 2,500 cp) to simulate mobilized waste slurry rather than supernatant liquid.

Vent air flow rates of 550/275 and 275/100 cfm in the dome and annulus, respectively, were studied. The higher flow rates are typical of current conditions; the lower flow rates are closer to historic values.

The tank contents were modeled as three distinct regions, based on observed temperature profiles and behavior during gas release events. The bottom layer consists of a heavy nonconvective material. A convective layer overlays the heavy material with an essentially uniform (vertically) temperature. This layer supported a 28-inch-thick crust that was in contact with the air circulated in the dome space and was free to radiate to the dome itself. The material properties used are shown in Table 3.1. The crust emittance is assumed to be 0.9, based on handbook data for similar materials in the infrared, and the fact that it has a very rough surface. Bander (1993) used an emittance of 0.96 for the surface of a similar waste.

Air is withdrawn from the 2.5-ft-wide annular space between the two steel shells in the tank and exhausted through riser 10A, which is an 8-inch schedule 40 pipe (Antoniak 1991; Allemann et al. 1992a). Channels in the insulating concrete that support the inner shell allow the air to contact and cool this shell. This is accomplished by taking in ambient air through the four 4-inch schedule 40 pipes that are routed down the annulus, within the insulating concrete, and join in a header that distributes air to the channels indicated in Figure 3.1. Near the center, there are 16 channels about 14 ft long; these divide into 32 channels about 10 ft long, which further subdivide into 64 channels about 13 ft long. Typical heat transfer coefficients appropriate for each of the three channel types are shown in Table 3.2. Soil properties are shown in Table 3.3.

The average annual air temperature at Hanford is 53.0°F (Stone et al. 1983). Using that figure results in waste temperatures that are significantly lower than those measured (for example, a mixed tank peak waste temperature of only 114°F is calculated). The parametric runs described here used an air temperature of 60°F, to account somewhat for effects that are not part of the current model. These effects include the proximity (on two sides) of other tanks, uncertainty regarding the tank thermal time constant, no heat transfer coupling between the soil and the atmosphere, and variation in vent air flow rates (most often lower than the 550/275 cfm base case flow rates used).

3.3.2 Effect of Ventilation Flow Rates

Parametric runs were made simulating steady-state conditions, with the two dome and annulus air flow rates. Two changes were made to the model to simulate the waste mixing that resulted from pump bumps and Phase B pump testing. The nonconvective waste layer, which had previously been

Table 3.1. Material Properties

Material	Density lbm/ft ³	Conductivity, Btu/hr ft °F	Heat Capacity, Btu/lbm °F	Dynamic Viscosity, lbm/s ft	Heat Generation, Btu/h ft ³
Crust	84 (Allemann et al. 1992)	0.80	0.30	-	-
Convective Waste	~91(a,b)	~0.35(a)	0.99	0.016	0.313(c)
Nonconvective	104	0.8	0.57	-	0.313(c)
(a) Variable, = f (temperature)					
(b) Burke et al. 1993.					
(c) Based on about 46,800 Btu/hr total heat load for the tank (Letter, D. M. Strachan and R. T. Allemann to J. L. Deichman, WHC. 1992. Pacific Northwest Laboratory, Richland, Washington).					

Table 3.2. Annulus Channel Heat Transfer Coefficients

Annulus Air Flow Rate, cfm(a,b)	Innermost Channel Heat Transfer Coefficient, Btu/hr ft ² °F	Mid Channel Heat Transfer Coefficient, Btu/hr ft ² °F	Outermost Channel Heat Transfer Coefficient, Btu/hr ft ² °F
275 (current flow rate)	1.07	1.23	1.46
100 (earlier flow rate)	0.48	0.55	0.62
(a) Personal communication with B. M. Hanlon. 1992. Copy of Psychometric Survey Data.			
(b) Personal communication with D. A. Reynolds, WHC. 1992. Copy of Psychometric Survey Data for Annulus.			

Table 3.3. Soil Properties

Material	Density lbm/ft ³	Thermal Conductivity, Btu/hr ft °F	Heat Capacity Btu/lbm °F	Average Surface Temperature, °F	Average Subsurface Temperature, °F 1.5
Hanford Site earth	100	0.45 (Tignac 1979)	0.44 (Tignac 1979; Stone et.al 1983)	60 (Tignac 1979; Stone et.al. 1983)	60 (Tignac 1979; Stone et al. 1983)

modeled with a depth of 228 inches, was reduced to the 50-inch depth that is indicated by the thermocouple trees in the waste. The viscosity of the convective layer was increased by a factor of 100, to simulate mobilized waste rather than supernatant liquid. These changes were incorporated in the second and third runs of the series noted above. The peak waste temperatures calculated by the final steady state runs are summarized in Table 3.4.

Table 3.4. Code Run Parameters and Results

Dome Air Flow Rate, cfm	Annulus Air Flow Rate, cfm	Maximum Nonconvective Waste Temperature, °F	Maximum Convective Waste Temperature, °F	Comment
550	275	111	114	Representative of mixed (Dec. 1993) tank
275	100	122	124	Mixed tank with lowered vent air flow rates
550	275	121	110	Representative of unmixed (June 1993) tank

The color temperature contours representing the mixed tank at 550/275 and 275/100 dome/annulus flow rates are shown in Figure 3.3 a and b, respectively. Figure 3.3 c and d compare temperature contours between unmixed and mixed waste conditions, respectively.

3.3.3 Effect of Bottom Sludge Removal

The long-term thermal response of Tank 241-SY-101 to potential removal of the bottom sludge layer was studied in two parametric runs. Two cases of excavation were considered, in which the non-convective waste region was reduced first to a 30-inch depth and subsequently removed altogether to bare metal. The base-case mixed tank studied earlier had a 48-inch-deep nonconvective region.

The following are common input parameters for all three cases:

1. Dome/annulus air flow rates were 550/275 cfm; note that the most recent annulus flow rates have been significantly lower than 275 cfm.
2. Emittance of the annulus walls was assumed to be 0.9; recent infrared camera scans suggest that a more realistic emittance value is 0.65-0.7.
3. Proximity of other tanks was ignored.

These parameters are noted here because they would tend to make TEMPEST predictions lower than measured temperatures. Note also that the calculated results are for the steady state, a condition that Tank 241-SY-101 does not achieve. Steady state thermal conditions can only be attained by the tank if it were to remain unperturbed (other than by seasonal/weather variations) for a time period of many months. Therefore, direct comparison between the calculated and measured temperatures is not possible. But the differences among calculated results should be reasonably representative of the actual tank thermal response to continued excavation. The results are summarized in Table 3.5.

Reducing the nonconvective layer from 48 to 30 inches lowers maximum waste temperature by almost 4°F; eliminating the nonconvective layer entirely reduces the maximum temperature by only about another 0.5 degree. Waste velocities and mixing are near the bottom, so the major heat loss is by means of conduction through what is essentially a boundary layer, even for the case of no settled sludge. Temperature contours and vertical temperature profiles at approximately the position of MIT 17B are shown in Figure 3.4.

a

b

c

Figure 3.3. Tank Temperature Contours

Table 3.5. Maximum Waste Temperatures for Three Sludge Depths

Sludge Depth, Inches	Maximum Waste Temperature, °F
48	114.2
30	110.4
0	109.9

3.3.4 Conclusions

Reducing dome/annulus vent air flow rates from 550/275 to 275/100 cfm will increase waste temperatures by about 10°F, which is approximately equal to the temperature drop experienced by the unmixed tank from 1990 to 1993. Reducing the nonconvective layer from 48 to 30 inches lowers maximum waste temperature by about 4°F; eliminating the nonconvective layer entirely reduces the maximum temperature by only about another 0.5°. Thus it appears that reduction in annulus ventilation flow can more than compensate for the increased heat loss resulting from loss of nonconvective material.

Figure 1. 101-SY Temperatures for 550/275 cfm Air Flow Rates

Figure 2. 101-SY Temperatures for 550/275 cfm Air Flow Rates

Figure 3. 101-SY Temperatures for 550/275 cfm Air Flow Rates

Figure 3.4. Temperature Contours and Vertical Temperature Profiles

4.0 Pump Performance

Full-Scale Testing was performed during the period from February 4 to April 13, 1994, to determine the operating parameters required to maintain the degree of tank mitigation effectiveness that had been achieved during Phase B testing (WHC 1993). A second objective was to optimize pump operation and develop a long-term test plan. Excerpts from the Full-Scale Test plan are contained in Appendix A of this report. The log of all pump operations from December 7, 1993 through mid-May 1994 is listed in Appendix B.

4.1 Pump Performance Analysis

Various pump parameters were monitored during the tests to observe and analyze pump operation. These included the average pump operating current and voltage and the average pump volute and nozzle pressure at the exit. Additional performance indicators were calculated from these measured quantities, including pump flow rate, motor input power, hydraulic power, and efficiency.

The time-history data from the DACS system were analyzed and reduced to average nominal values during each pump run, then curve-fitted to determine if long-term trends in pump behavior and waste behavior or properties could be discerned. The average pump motor rpm and voltage for each discrete pump speed remained relatively constant during the entire Full-Scale Test sequence.

Figure 4.1 shows the average pump volute pressure (present in the pump impeller housing), calculated motor input power, and calculated pump flow rate as a function of pump speed for each test. It is clear from the experimental data shown on the figures that the pump performance was highly repeatable. The average volute pressure in Figure 4.1 increases approximately as the square of the pump speed. This agrees with the pump affinity law that states that the pump head is proportional to the square of the pump speed. The curve-fit power coefficient was calculated to be 1.91, which compares to a calculated value of 1.98 for the Phase B test data (Allemann et al. 1994).

4.1.1 Pump Power and Efficiency

The plot of average pump motor input electrical power (kva) (Figure 4.1) shows that the pump input power increases approximately as the 2.5 power of pump speed. This power trend reflects electrical losses imposed by use of the variable-speed drive that is responsible for deviation from the pump affinity law, which states that pump power is proportional to the cube of the pump speed. The input power increased as pump speed to a power of 2.58 for the Phase B test series (Allemann et al. 1994).

The hydraulic, or output power, defined as the rate of energy supplied by the pump to the waste, is shown as a function of pump speed in Figure 4.2. Hydraulic power is calculated from the product of pump volute pressure differential (volute pressure minus the static pressure) and flow rate. The flow rate was calculated from the pre-installation water-test data, because corrections for the more viscous waste material have not yet been made. The flow power is proportional to approximately the 2.9 power of the pump motor speed. For the Phase B test data (Allemann et al. 1994), the calculated flow power was proportional to the 2.96 power of the motor speed.

Figure 4.1. Pump Performance Parameters Versus Pump Speed

Figure 4.2. Pump Flow Power Versus Pump Speed

The partitioning of total power between motor heating and jet dissipation is given by the pump efficiency curve for Full-Scale Test data shown in Figure 4.3. About 55% (at 1,000 rpm) of the total motor input power is supplied at the jet nozzles and dissipated via jet mixing (this is the hydraulic power). Approximately 45% is lost directly to the waste through cooling. At 750 rpm, this partitioning is closer to 50%. The 750 rpm tests generated about 67 hp, of which 33.5% was transferred to the waste as heat. The same amount was delivered as hydraulic power to the waste and dissipated via jet mixing. Only the hydraulic power is able to suspend the sludge and maintain circulation. The pump efficiency during Phase B testing was similar and displayed approximately the same efficiency rating (Allemann et al. 1994).

4.1.2 Pump Energy Deposition

A total hydraulic energy of 228 hp-hr was delivered to the waste during the 49-day period prior to the start of Full-Scale Testing, yielding an average of 4.7 hp-hr of energy each day. Pump operation after December 17 (Phase B test end) and prior to February 4 (Full-Scale Test start date) consisted only of directional bumps (five minutes at 1,000 rpm in a different position approximately every other day). This resulted in an apparent level growth, though at a lower rate than historically observed, and some settling of solids, forming a second convective layer below the crust.

Figure 4.3. Pump Efficiency Versus Pump Speed

The energy imparted to the waste by the pump during Full-Scale Testing did not raise its temperature significantly. A total hydraulic energy of 1635 hp-hr was input to the waste over the 117-day pretest and Full-Scale Test period (December 18, 1994 through April 13, 1994). The total pump energy input during the above pretest and Full-Scale Test period averaged only 14 hp-hr/day.

This deposition of energy is shown in Figure 4.4. The relatively high value at 35° (215° opposing) was due to the extensive pump bumping at the 35° orientation during the regrowth phase. Energy input at 97° was the result of the 40-minute and 20-minute jet penetration tests. The 155° orientation was also repeated for one of the 60-minute, 750-rpm tests, thus giving a relatively high value. Results are shown for the primary nozzle direction; the opposing nozzle direction is also included in the plotted value. The pump heat input was approximately 3.4% of the total radiolytic heat input during the Full-Scale Test period.

4.2 Motor Oil Temperature Limitation

Numerical predictions and test data showed that the pump motor oil (stator cavity/oil bath) temperature would limit the duration of pump operation. At 920 rpm, it was found that the oil temperature

Figure 4.4. Pump Energy Deposition Versus Orientation

would exceed the predetermined 190°F limit if more than one 30-minute test was run consecutively.^(a) The temperature limit also caused minor difficulties for the 750-rpm tank sweep series unless prolonged pump-off times were necessary toward the end of the sequence.

The rotor assembly experiences the highest temperatures. A large portion of its heat is conducted through the shaft to the impeller via the lower bearing. The paths for heat flow are conductive heat transfer out the shaft and end bells and conductive and convective heat transfer from the outside surface of the stator cavity shell. The heat sink provided by the waste flowing through the passageways close to the cavity shell is probably the most significant path for heat transfer.

The peak motor oil temperature was predicted as a function of operating time at a given pump speed based upon the Full-Scale Test data. Motor oil temperature versus time data from selected pump operations are shown as a curve fit in Figures 4.5 through 4.7 for 750, 920 and 1,000 rpm. A cross-plot of the data for the oil temperature cutoff limit of 190°F in Figure 4.8 shows that approximately 25 minutes of continuous operation are possible at 1,000 rpm without exceeding the 190°F cutoff limit, while approximately 45 minutes are available at 920 rpm.

Figure 4.5. Mixer Pump Motor Oil Prediction at 750 rpm

(a) Westinghouse Hanford Company. 1993. *Alarm Response Procedures for Tank 101-SY Mitigation-by-Mixing Test*. WHC-SD-WM-PROC-004, WHC, Richland, Washington.

Figure 4.6. Mixer Pump Motor Oil Prediction at 920 rpm

Figure 4.7. Mixer Pump Motor Oil Prediction at 1,000 rpm

Figure 4.8. Mixer Pump-On Time to 190°F Oil Temperature Limit

4.3 Pump Data Trends

This section describes results of a trend analysis of all 1,000-rpm pump bumps through April 25, 1994, to determine the effects of changes in waste density recirculated by the pump and the changes in nozzle flow resistance (if any) over the course of the pump-bump testing to date. This evaluation used a perturbation analysis of pump affinity laws (empirical rules) and an energy balance between electrical power input to the drive motor and the hydraulic power measured at the pump.

The trend evaluation period was separated into an initial phase prior to Phase B tests with two bumps per day (for 26 days) and a longer period with a single bump per day (69 days). This separation is applied to determine if the solids settling time for 12-hour or 24-hour delays between pump bumps had any effect on the waste density. This analysis is presented in the Phases A and B test report (Allemann et al. 1994). Additional periods treated here include the pump bumps during and following the Phase B testing and the Full-Scale Test periods starting on February 4 and continuing until the last pump bump reported (for this report) on April 25, 1994.

Figure 4.9. Average Volute Pressure During Pump Bumps

The volute pressure is measured as the difference between the pump-on pressure and the static pressure (given here as units of psid). The volute pressure averaged over the five-minute pump-bump operations is plotted in Figure 4.9. A slight downward trend is apparent for the initial two-bump per day sequence, while a slight upward trend in pump volute pressure results for the period up to the beginning of Phase B testing on October 21. A slight downward trend can be seen for the bumps during the Phase B testing, and a pronounced downward trend occurred during the post-Phase B pump-bump sequence. Other downward trends are exhibited in the Full-Scale Test period. The scatter in pump volute pressure can be explained by variations in speed prior to the start of Phase B on October 21.

The change in volute pressure after the start of Phase B implies a change in fluid (mixture) density, which might result from ingestion of gas bubbles from the undisturbed waste flowing into the pump inlet. During the pump sweep and jet-penetration portions of the Full-Scale Tests there is a definite downward trend in the pump volute pressure.

Electrical power demand measured for each five-minute pump-bump is shown in Figure 4.10. Consistent with the increasing trend in waste density, the motor power demand increased slightly over the initial three-month period as limited mixing developed in the east-west jet orientation. The transition through Phase B testing was observed for the few pump bumps experienced during this period.

Figure 4.10. Average Pump Input Power During Pump Bumps

After Phase B testing was completed, a clearly defined trend of reduced power demand was observed as increased background gas release (increased void fraction), resulting in a decrease in waste density and/or waste viscosity at the pump suction. This latter phenomenon can also be seen during the Full-Scale regrowth test. Also, note that during the periods of aggressive pumping (the Full-Scale pump sweep operations) the required power increased to a level exhibited in similar operations in the Phase B tests.

5.0 Jet Penetration Tests

The last series of tests in the Full-Scale Program studied jet penetration by running the pump at the highest practical power level with the nozzles at 97°. This direction was chosen to align the jet with the 17B MIT (at the 28-foot radius about 30 feet from the pump) so that changes in temperature profile under the influence of the jet could be observed and compared with those of the 17C MIT, which was out of the path of the jet. It was also hoped that the strain gauges on the 17B MIT would register a deflection due to hydraulic forces. An infrared camera was also temporarily installed in the tank annulus to view the inner wall in the area of jet impingement. It was expected that small changes in temperature would reveal the size of the jet as it hit the wall. Finally, data loggers capable of discriminating $\pm 0.01^\circ\text{F}$ were connected to the bottom thermocouples underlying the jet fan in the hope that they would respond if large amounts of sludge were excavated. This section describes the results of this specific test sequence as well as the predictions used to plan it.

5.1 Jet Penetration Pre-Test Predictions

Jet penetration simulations were performed with the TEMPEST code to determine the pump speed and run time most likely to penetrate to the tank wall while remaining under the maximum motor oil temperature of 190°F. Past experience has shown that operation of the pump is possible at 1000 rpm for 20–25 minutes, at 920 rpm for about 45 minutes, and at 750 rpm for over an hour. The simulations were intended to show whether it was more effective to run for a shorter time at a higher speeds.

The initial conditions in the tank prior to the jet penetrations tests were based on the temperature profiles recorded by the MIT 17B instrument tree. It was apparent that a layer of sludge of approximately 50 inches existed at MIT 17B. A section view of the three-dimensional finite difference model is shown in Figure 5.1. Gas fractions of 6 and 10% were assumed in the homogeneous slurry and sludge regions, respectively. Solids-to-fluid ratios in the two regions were 47/53 and 24/76, respectively. Two simulations were run to provide initial conditions approximating current tank conditions. First, starting from a well-mixed condition (Figure 5.1), pump operation for 10 minutes at approximately 900 rpm was modeled (similar to back-to-back five-minute pump bumps). The resultant tank material distribution was used as the starting condition for a simulation in which the tank contents were allowed to settle out in a four hour simulation without pump operation. The solids/gas/liquid distribution from this simulation was used as the initial condition for the three jet penetration cases.

Velocity vectors for a 1000-rpm pump run after 15 minutes is shown in Figure 5.2. The vector field for the other two pump speeds were similar. An effective comparison between the three simulations is made by plotting radial acceleration versus time at the MIT 17B radial location at a given vertical location. This measures the time when the jet actually reaches a location at significant strength. Figures 5.3 and 5.4 acceleration trends for vertical locations of 10.5 ft and 4.5 ft, respectively.

Figure 5.2. Velocity Vector Field After 15 Minutes at 1000 rpm

The TEMPEST simulation of the 1000-rpm jet penetration case (a 65-ft-per-second initial jet velocity) was also used to determine the flow field and fluid properties required to calculate the force per unit length along the MIT 17B instrument tree. The resultant force distribution is shown in Figure 5.5. The sum of the forces over the length of tree was 31.7 lbf.

5.2 Results of Jet Penetration Tests

Two 40-minute runs were made at 920 rpm on April 6 and 8, and nine- and 20-minute runs at 1000 rpm were performed on April 12 and 13, respectively. While none of the tests caused a response on the infrared video or bottom thermocouples, the transient temperature trends observed on the thermocouple tree confirmed jet flow at that location. The jet also clearly reduced the thickness of the bottom sludge layer and evidently triggered a small gas release event in the first 1000-rpm test, which aborted the scheduled 20-minute run after nine minutes. These results are discussed in detail in this section.

Figure 5.3. Flow Acceleration at 10.5-ft Elevation

Figure 5.4. Flow Acceleration at 4.5-ft Elevation

Figure 5.5. Force per Unit Length Along MIT 17B

5.2.1 Transient Temperature Response at MIT 17B

The temperature indications at MITs 17B and 17C, in response to the second and the last jet penetration tests on April 8 and 13, respectively, are described in this section. Clear evidence of jet penetration to MIT 17B at a 28-foot radius and approximately 30 feet from the pump centerline is provided by the temperature response of various thermocouples.

The test on April 8 ran the pump at 920 rpm for nearly 40 minutes with jets directed toward 97° (in line with MIT 17B orientation) and toward 277° (70° offset from 17C orientation). A tabulation of responses or delay times of the individual thermocouples relative to the pump-on time at 05:12 is described in the following abbreviated summary (sensors are numbered starting from the tank bottom and extending to the waste level).

TC	Elevation (in.)	17B	17C
1	4	No response	No response
2	16	No response	No response
3	28	Immediate response (+) (20 minutes to max. 0.6 F increase)	----
4	52	Immediate response (-)	Inconclusive
5	76	Immediate response (-)	Inconclusive
6	100	Immediate response (-)	2 minute delay
7	112	Immediate response (-)	Inconclusive
8	124	1 minute delay (-)	----
9	148	2 minute delay (-)	5 minute delay
10	172	2 minute delay (-)	5 minute delay
11	196	2 minute delay (-)	15 minute delay
12	208	3 minute delay (-)	----
13	220	3 minute delay (-)	15 minute delay
14	244	3 minute delay (-)	15 minute delay
15	268	3 minute delay (-)	20 minute delay
16	292	4 minute delay (-)	No response
17	316	4 minute delay (-)	No response
18	340	4 minute delay (-) (30 minutes to max. 2.5 F increase)	8 minute delay
19	364	4 minute delay(+)	----
20	392	----	No response

The temperature trends for 17B MIT thermocouples 3 and 4, 10 and 11, 17 and 18 in the April 8 test are shown in Figure 5.6 a, b, and c, respectively. Trends for only the lower thermocouples are shown in Figure 5.7 a, b, and c for the tests on April 6, 12, and 13, respectively.

Mixing is clearly indicated by the response of thermocouple 18 in Figure 5.6c. This shows that the jet plume penetrates the stratification layer above the 300-inch elevation approximately one-half hour after the pump starts injecting relatively warm material into the cooler convective region. The temperature at thermocouple 18 also increased (by about 4°F) in the first test on April 6, but after a much longer delay—about 30 minutes from pump start. On the two subsequent tests, the region had become mixed, and no significant temperature change occurred at this level.

Trends in the lower thermocouples in Figure 5.7 provide direct evidence of sludge excavation by the jet. The immediate response of thermocouple 4 (52 inches) compared with the linear increase of thermocouple 3 (28 inches) on the April 6 test in Figure 5.7a shows that the boundary between mobile and nonconvective sludge is between these elevations. Thermocouple 3 responded in a similar way on the April 8 test in Figure 5.7a. But the immediate response by thermocouple 3 in Figure 5.7b

a. Thermocouples 3 and 4 (28 and 52 inches)

b. Thermocouples 10 and 11 (172 and 196 inches)

c. Thermocouples 17 and 18 (316 and 340 inches)

Figure 5.6. Temperature Trends at 17B During the April 8 Jet Penetration Test

a. April 6 Test

b. April 12 Test

c. April 13 Test

Figure 5.7. Temperature Trends at 17B for Jet Penetration Tests on April 6, 12, and 13

shows that the pump had excavated beyond the 28-inch level on April 12. The final test on April 13 is even more dramatic. In Figure 5.7c the waste at the 16-inch level can actually be seen going convective about 20 minutes after pump start.

5.2.2 Bottom Thermocouples

The bottom thermocouples were connected to a data logger that recorded temperatures to 0.01°F at 30-second intervals. This was accomplished on March 28, 1994, and except for a power outage between April 1 and April 3, temperature data were taken continuously. The data cover the entire jet penetration test series from April 6 through April 13.

None of the data show any effect of pump operation. A representative plot of the bottom thermocouple transient temperatures is given in Figure 5.8. A high-frequency signal is imposed on the temperature traces during pump operation; its amplitude is on the order of 1–2°F. It is assumed that this signal has its source in electrical noise from the pump. Otherwise, examining the before/after pump operation temperature traces discloses no temperature trends attributable to jet penetration. This agrees with the MIT response to the jet penetration tests, as noted in Section 5.2.1, where only during the last test was a temperature excursion observed at thermocouple 2, 16 inches above the tank bottom.

If the jet had excavated enough sludge to expose the tank bottom, the effect might have been observed in the bottom thermocouple temperatures within a few minutes. Because it appears from MIT temperature profiles that the jet did not fully excavate the nonconvective sludge, it is not surprising that the bottom thermocouples did not show a change in the thermal environment.

5.2.3 Gas Releases

The jet penetration test series was performed immediately after two days of full tank sweeps of three hours at 750 rpm each day. These 'knockdown' tests successfully mixed most of the slurry that had settled during the prior regrowth test and released a large amount of stored gas. Consequently, the jet penetration tests did not release such a large volume. However, the third test, on April 12, at 1,000 rpm apparently was of sufficient force to free a large glob of sludge; this caused a brief gas release that aborted the test due to high vent flow after only nine minutes of the scheduled 20-minute run. This minor event released about 250 ft³ of gas, compared with over 400 ft³ on each of the prior sweep tests. The gas release may have occurred near the 17B MIT, because its strain gauges responded immediately with a step change. There were no more such releases in the subsequent 1000-rpm test that ran the full 20 minutes.

5.2.4 Jet Penetration Results/Infrared Scanning at Tank Annulus

An infrared (IR) scanner was installed in the 12-inch-diameter annulus riser 19B opposite the 97° jet orientation to observe any thermal influence of the jet and to corroborate possible jet penetration to the tank primary wall. A vertical section view of the tank annulus and the locations of the IR scanner is shown in Figure 5.9. A pan/tilt apparatus was employed to view the lower portion (approximately 12-ft height) extending to the tank bottom and annulus floor, a central portion of the tank primary wall extending laterally to the edge view (or wall curvature) of the annulus, the upper portion (about 12-ft height) extending to the tank dome knuckle and annulus ceiling formed with the secondary tank dome.

a. Inner and Mid-Radius Bottom Thermocouples

b. Outer Bottom Thermocouples

Figure 5.8. Typical Bottom Thermocouple Trend

Figure 5.9. Tank Vertical Profile Section View with IR Scanner Positions

The IR scanner is very sensitive to both spacial and temporal temperature changes, but the absolute temperature depends on the assumed surface emissivity. The temperature is inferred by a thermal radiation calculation in the IR image computer software based on the input emissivity value. An emissivity of 0.75 was chosen to reflect the original as-built appearance of the carbon steel wall, as observed by the color TV camera used as an aiming device for the images. Chalk marks made by welders during fabrication were clearly visible, and the surface appeared to be free of excessive oxidation or scaling. Increasing the assumed emissivity (to represent a rougher, corroded surface) lowers the inferred surface temperature, while decreasing the emissivity (for a cleaner, shinier surface) would raise the inferred temperature.

The predicted steady state temperature profile over the height of the primary wall taken from the base TEMPEST simulation in Section 3.2 is shown in Figure 5.10. The TEMPEST model, including the effects of convective flow in a mixed tank, shows a nearly uniform temperature of about 104°F. If the jet were to bring fluid of a slightly different temperature in contact with the wall, the scanner could potentially detect the change. The 0.75-inch steel plate on the wall has a heat conduction time constant of approximately five minutes. This is sufficiently short to register changes over the test period of 20–40 minutes.

Figure 5.10. Predicted Wall Temperature Profile

Attempts were made to view vertically upward to locate the temperature discontinuity at the waste surface level. This was not possible because the riser extended down approximately two feet beyond the 'knuckle' of the secondary tank dome and prevented viewing the 400-inch waste surface elevation.

An IR scan prior to pump operation generated a 'baseline' temperature signature over the entire vertical section of the primary vessel wall of interest. During the test period, the IR camera scanned the wall continuously looking for transient localized temperature change that might result from jet impingement.

A typical IR scan of the second jet penetration test of April 8, when the pump was run at 920 rpm for 40 minutes toward the wall where the scanner was positioned at mid-level, is shown in Figure 5.11. The view is down, and the bottom contour of the tank wall is visible. The IR image showed an essentially uniform wall temperature of 96 to 97°F extending over an elevation of 40 to 370 inches. No transient change in surface temperature was observed with respect to any pump operation.

Although clear jet penetration indications appeared at MIT 17B (see Sections 2.5.1 and 5.2.1), there was no response in the IR image. The indicated temperature remained uniform during and after every test. This is consistent with the well-mixed, convective slurry that is indicated by the MIT temperature profiles and computer predictions accounting for flow. Thermal mixing and entrainment of the jet flow resulted in an isothermal condition at the wall radius.

Figure 5.11. Tank Primary Wall Infrared Image at 5:57

5.3 Conclusions/Jet Penetration Tests

Observation of MIT 17B thermocouple and strain gauge response to jet penetration tests (and subsequent pump bumps with orientation toward 17B) indicated that the waste is a mobile slurry above a level of 30-50 inches. The same responses clearly showed that sludge was excavated from around the bottom of the tree between 16 and 50 inches. However, observation of the primary tank wall temperature with the IR scanner showed no change in wall temperature due to possible jet impingement.

Favorable indications of partial removal of the sludge bed at the MIT 17B location is evidence that prolonged operation of a high-velocity jet will mobilize, or sluice, a settled bed of solids. Future efforts to further mobilize the sludge should be considered as a part of excavation testing during the long-term operation.

6.0 Strain Gauge Observations

Strain gauges are installed on several tank components that can potentially respond to pump operation. Locations and orientations of these gauges are shown in Figure 6.1. The initial motivation for the strain gauges was to monitor structural integrity during tank rollovers and to assess the potential effects of fatigue due to flow-induced vibrations. Strain gauge observations made during Phase A and B testing (Allemann et al. 1994) did not indicate any loads of structural importance. Nor were there any indications of flow-induced vibration. Observations made after Phase B testing up to and including the Full-Scale Test sequence continued to indicate the absence of structural or vibration concerns.

Strains caused by normal pump-induced flows are quite small (usually less than 10 microstrain) and are judged to be less than adequate for accurate quantitative assessments of structure or waste behavior. For this reason, flow predictions based on strain gauge observations should be considered only qualitative.

Following Phase B testing, only the gauges on the VDTT in riser 1B showed significant strains when the pump jet was directed toward them. During the Full-Scale 'regrowth' test sequence of five-minute pump bumps at 1,000 rpm and 35°, the jets were directly in line with VDTT 1B, 17 feet from the pump centerline for a full month. The VDTT gauge responses tended to diminish rapidly after a little over a week. There appears to be a correlation between increasing gas fraction, as indicated by a rise in Doppler signal intensity (Section 2.4.1), and the decrease in strain response of the VDTT as shown in Figure 6.2. It is possible that the limited mixing of the regrowth period allowed sludge to settle back around the base of the VDTT to restrict its motion or deflect the jet. Buoyancy resulting from the increasing gas fraction might also reduce the jet intensity, though computational models predict essentially no buoyancy effect even at very high gas fractions.

During the Full-Scale jet penetration test on April 12 a small gas release event occurred, and the long dormant gauges on the 17B MIT responded. The gauge indications corresponded to a two-pound force applied to the east at the bottom of the probe with no crust restraint. These readings persisted after the pump was turned off. During the pump bumps following the jet penetration test series, the 17B gauges seemed to be more responsive. During the pump bump of April 20, the gauges responded with 20-microstrain readings, but the strains returned to their prior values after the bump, indicating that the bottom of the probe might have been dislodged from the sludge. Succeeding pump bumps have produced a similar strain response independent of pump jet orientation. Gauge readings correspond to a radially inward load of approximately five pounds, neglecting any crust restraint.

It is difficult to pose a condition that would produce an inward equivalent load independent of jet orientation, and the reliability of the gauges has been questioned. In the latter part of May, the 17B gauges reported very high (near 200 microstrain), erratic readings in response to several pump bumps in a row, independent of direction. The problem proved to be a bad electrical ground aggravated by

* Underlined numbers represent approximate distances between gauges and component bottoms.

Figure 6.1. Strain Gauge Location and Orientation in Tank 241-SY-101

Figure 6.2. Strains at VDTT 1B and Doppler Intensity

several days of rain. During the search, the 17B strain gauge leads were found to be reversed. This accounts for the indications of a radially inward deflection, but the potential effects of the bad ground cast some doubt on prior strain gauge data.

Strain gauges on the pump column occasionally indicate strains in the range of 5 to 10 microstrain. This is possibly due to slightly different flow rates in the two nozzles. The gauges on the MIT in riser 17C continue to show no significant activity. It is not known if this is due to lack of loading, restriction by sludge or crust, or instrumentation problems.

Spectral analyses were performed on numerous strain gauge data sets. To date, no significant indication of flow-induced vibration has been observed and spectral investigations have been discontinued.

7.0 References

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Appendix A

Full-Scale Test Plan for Tank 241-SY-101 Mitigation-By-Mixing Test

Appendix A

Full-Scale Test Plan For Tank 241-SY-101 Mitigation-By-Mixing Test

A.1 Purpose and Philosophy

The purpose of the Full-Scale Test is to maintain the degree of mixing effectiveness as demonstrated during Phase B testing (WHC 1993b) within an acceptable pump operation envelope. The specific test objectives, as determined by a joint Westinghouse Hanford Company (WHC), Pacific Northwest Laboratory (PNL), and Los Alamos National Laboratory (LANL) meeting, are the following (not in order of priority):

1. Maintain the approximate tank mitigation effectiveness established during Phase B testing by maintaining the tank level below approximately 402 inches.
2. Maintain the tank level above the 400 inch lower level limit specified by the safety envelope.
3. Obtain data on the tank level regrowth with minimum pump operation to obtain data for the determination of any changes to the gas retention/release characteristic due to mixer pump operations.
4. Operate the mixer pump to determine parameters that are acceptable for long-term mitigation.
5. Perform limited jet penetration tests to obtain data to confirm the design of the permanent pump and to obtain an estimate of how much of the tank waste was undisturbed by previous testing.
6. Operate the mixer pump at only intermediate speed conditions (except for the short pump bumps and jet penetration tests) and minimize pump operations to maximize mixer pump lifetime.

The full-scale tests will extend the knowledge base developed from the Phase B Test and Post-Phase B Operations, which showed that the mixer pump mitigated Tank 241-SY-101 and will generate the data base for defining the long-term operating conditions for the permanent pump.

The success criteria utilized in the development of the mitigation tests is that mitigation only requires prevention of periodic releases that result in hydrogen concentrations that exceed 25% of the

Lower Flammability Limit^(a) (LFL) at the tank exhaust. This criterion effectively limits the maximum quantity of hydrogen gas in the tank dome to well below the value that could be ignited, thereby eliminating the concern for tank structural damage and related radiological consequences.

The Phase B tests demonstrated that, with only limited pump operation, the tank level could be reduced to a historically low level of 400 inches and maintained at that level. The success criterion has been achieved by the mixer pump, because none of the gas releases have exceeded 25% of the LFL. The pump has not been in operation for a sufficiently long period of time to fully demonstrate that satisfying the success criterion requires that the level be maintained near 400 inches.

The Full-Scale tests, except for the jet penetration tests, continue the philosophy of limited pump operation at intermediate speeds to maintain the tank level near 400 inches. These tests, plus the behavior of the tank for the time period of these tests, will provide additional information to determine if the mitigation success criteria will be achieved at this tank level. In addition, the test will provide data on the regrowth characteristics of the tank that could result in a future reduction of a 400-inch lower limit in the safety assessment. This could permit pump operation at higher power and for longer durations, if required to achieve the success criterion for the long term. These tests will provide information to demonstrate that the tank level can be controlled by increasing and decreasing the amount of pump operation.

A.2 Summary Of Test Conditions And Sequence

Authorization to start the full-scale test will be given by the Test Review Group (TRG) following completion of the Post-Phase B Operations. Several hold points are defined in Table A.1, where the TRG will review the test data and decide to continue or terminate a test. Finally, if the test is aborted due to violation of any of the abort criteria, the approvals specified in Section 2.4 are required before restarting the test. The roles of responsible parties have been defined by the management plan for the mitigation test, (WHC 1992d). The Test Director will direct all pump startups, all increases in pump speed, and all operations to change the angular orientation of the mixing pump nozzles. Changes to the order of the test sequences may be approved by the TRG.

The Full-Scale Test is summarized in Table A.1. Referring to the table, a test is defined as the time of pump operation plus a waiting time. The duration of the waiting time is specified to permit tests on succeeding days if authorized by the TRG.

Table A.1 shows four major TRG review points during Full-Scale testing. The first TRG review is scheduled before the beginning of Full-Scale testing. At that time, a review of the data from Phase B

(a) LFL defined as 3% volume fraction H₂ in a nitrous oxide atmosphere.

Tests and Post-Phase B Operations will be performed. The other TRG reviews occur after the one-orientation-per-day pump operation (stepped sweep test - first long term operation test), after the level regrowth test, and after the six orientation per day pump operation (daily sweep test—second long-term operation test).

The three major tests are:

- **Long-Term Operation Test** - demonstrate that pump operation at intermediate speeds , three times per week and for relatively short times, can maintain the tank level near the 400-inch lower limit of the safety envelope. Also demonstrate that certain mixer pump operations are acceptable for the permanent pump to mitigate the tank. It is assumed that the permanent pump must provide adequate mixing, level control, temperature uniformity, and uniform gas release so that major gas burps are eliminated. A relatively constant level will be maintained in this test.
- **Level Regrowth Test** - obtain data on tank level regrowth with minimum pump operation. These data will be used to determine if any changes to the tank gas retention/release characteristics have occurred due to pump operation. Secondly, that the level, gas release, and axial temperature profile can be controlled by the mixer pump using simulated permanent pump procedures, as indicated by obtaining reproducible values for repetitive conditions. The waste level will be allowed to grow as high as 402 inches from a stable level. The pump will be operated only to ensure that the nozzles remain unplugged. After the growth period, the level will then be reduced to a minimum stable equilibrium level using the mixer pump in a prototypic, permanent pump, tank sweeping mode.
- **Jet Penetration Test** - obtain data on jet radial penetration at the 97° position using the multi-function instrument tree (MIT) located in riser 17B to support the design of the permanent pump and to obtain an estimate of how much of the tank waste was undisturbed by previous testing.

A.2.1 Long-Term Operation

The first long-term test sequence is identified as the single-runs-per-day test (Test Sequence #1). It consists of three one-hour pump operations at 750 rpm per week for a maximum duration of three weeks. A two-week duration will be required to cover the six orientations that are required to sweep the entire tank. The normal orientations for one sweep of the tank are at 35, 65, 95, 125, 155, and 185 azimuthal degrees. The objective of this test is to demonstrate stable gas releases and temperatures from long-term pump operations and to maintain the tank level near 400 inches.

Note: the pump operations in this test sequence are the same as for tests B-10 through B-15 of the Phase B test (WHC 1993b).

The second long-term test sequence is identified as the six-runs-per-day test (Test Sequence #3). It consists of 180 minutes of pump operation at 750 rpm three times per week for a duration of one week. Each 180-minute pump operation is divided into 30 minutes of operation at each of the six pump orientations. These orientations are at 35, 65, 95, 125, 155, and 185 degree azimuthal positions. The objectives of this test are to reduce the level established at the end of the Level Regrowth Test (up to 402 inches) to a level near 400 inches and then to maintain the level constant near 400 inches. The pump operations in this test sequence are the same as for tests B-16 through B-19 of the Phase B test (WHC 1993b).

A.2.2 Level Regrowth Test

This test will help determine the effect of prior testing on gas generation/retention and will to demonstrate that pump operation can control the level, gas release, and temperatures within the tank. It will help satisfy Safety Assessment concerns that the tank waste has not departed from historic behavior in a dangerous way. A third objective will be to define the length of time available as a "window" for permanent pump replacement.

This test sequence will be initiated upon approval by the TRG and as soon as possible after completion of the Long-Term Operations test. This test identified as Test Sequence #2 in Table 1 will obtain data of tank level regrowth with minimum pump operation. The maximum pump operation of three pump bumps per week at 1,000 rpm for five minutes each at an orientation of 35° is required to ensure no nozzle plugging. This test is limited to a maximum tank level of 402 inches.

This test consists of monitoring the tank level, gas releases, and in-tank thermocouples with minimal pump bumping or other tank disturbance. Successful completion of the test will result when the level rise rate returns approximately to historic value (0.08"/day) and other indications are consistent with settling sludge. The waste temperature profile may also return to historic behavior. After the level, gas releases, and possibly the temperature profile return to approximately historic values, the pump will be restarted (Test Sequence #3) to demonstrate positive control of these parameters.

A.2.3 Jet Penetration Test

This test, identified as Test Sequence #4 in Table A.1, will obtain data on the radial penetration of the jet at high pump speed. The jet will be oriented at a 97-degree azimuthal angle directed at the MIT located in riser 17B. Data obtained from the thermocouples (T/Cs) and strain gauges on the MIT, the infrared camera (see Section 2.1.5), and the other tank instrumentation will be evaluated to determine the radial jet penetration performance. The test will be performed for up to five days in a row. If the MIT at penetration 17B is unavailable, then the jet is to be directed at the MIT at penetration 17C with an orientation of 30°. A major objective of this test is to provide data to confirm the design of the permanent mixer pump and to obtain an estimate of how much of the tank waste was undisturbed by previous testing.

A.2.4 Infrared Imager Evaluation

These tests consist of obtaining data with an Infrared imager that will be installed in the tank annulus space at riser 19B. The measurements will be taken before, during, and after pump operations specified in Table A.1 for Test Sequence 4. The temperature profile of the outer surface of the primary tank will be observed and recorded in the area that can be surveyed from riser 19B. The objective of these tests is to determine if the infrared camera can discern temperature changes in the tank wall due to the jetting action of the mixer pump and waste motion at the primary tank wall.

Table A.1. Full-Scale Test Plan Summary^(a)

Test Sequence Number One	Pump Operation	Maximum Speed (r/min)	Maximum Test Duration (as noted)	Minimum Waiting Time (h)
TRG (Review Results of Post Phase B Operations and Authorize Start of Full-Scale Test)				
1 ^(b)	Tank Stepped Sweep ^{(a),(d)}	750	Single Orientation Per Day Sweep Test, 60 minute pump operation (1 every other day, 3 per week), 3 week span	12 per pump operation
TRG (Review Results and Authorize Start of Level Regrowth Test)				
2 ^(b)	Pump Bump at 35°	1000	Level Regrowth Test 5 minute pump operation, (1 every other day, 3 per week), 4 week span	12 per pump operation
TRG (Review Results and Authorize Start of Daily Sweep Test)				
3 ^(b)	Tank Daily Sweep ^{(c),(e)}	750	Six Orientations Per Day Sweep Test, 180 minute pump operation, (3 to 5 per week), 1 week span	21 per pump operation
TRG (Review Results and Authorize Start of Jet Penetration Test)				
4 ^(b)	Pump Operation at 97°	(f)	Jet Penetration Test 5 per week (4 hr max. per day), 1 week span	12 per pump operation
(a) TRG authorization is required to change the chronological order of the test sequences.				
(b) TRG authorization is required to delete individual pump operations.				
(c) Sweep orientation 35, 65, 95, 125, 155 and 185 azimuthal degrees.				
(d) Same as Phase B tests B-10 through B-15 (WHC 1993b).				
(e) Same As Phase B tests B-16 through B-19 (WHC 1993b).				
(f) Maximum pump speed and duration to be determined by the TRG and limited by the Safety Assessment (LANL 1994).				

A.2.5 Minimum Pump Operation to Prevent Plugging

To prevent plugging of the pump discharge piping and nozzles, it is recommended that a maximum of three pump operations, with no more than three days between operations, are required per week. Pump operations consist of either Test Sequences 1, 3, or 4 in Table 1. Pump bumps consist of Test Sequence 2 in Table 1. Based on the above requirements, a nominal test sequence consists of pump operation or bumps on Mondays, Wednesdays, and Fridays, with no operations on the other days of each week. TRG authorization is required to reduce pump bump frequency during the Level Regrowth Test.

Based on experience obtained from the Phase A and B testing, the pump bump condition is defined as a five-minute (including startup and shutdown ramps) pump operation at 1,000 rpm. Pump bumps must be performed at the orientation defined by the TRG. With TRG approval the flushing procedure (WHC 1993d) may be used in the event that the nozzle cannot be cleared by the pump bump alone.

A.2.6 Pump Oil Temperature

As a precaution, the pump shall be shut down by a normal ramped shutdown when the oil temperature reaches 190°F.

A.3 References

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- WHC. 1993a. "Mitigation Test Management." WHC-SD-WM-MA-014, Westinghouse Hanford Company, Richland, Washington.
- WHC. 1993b. "Phase B Test Plan for Tank 101-SY Mitigation by Mixing Test." WHC-SD-WM-TP-153, Westinghouse Hanford Company, Richland, Washington.
- WHC. 1993c. "Unplugging 101-SY Mixer Pump Nozzles." WHC-SD-WM-TPI-008, Westinghouse Hanford Company, Richland, Washington.
- WHC. 1993d. "Pump Bump For Tank 101-SY Mitigation by Mixing Test." WHC-SD-WM-TPI-007, Westinghouse Hanford Company, Richland, Washington.

Appendix B

Test Log

Appendix B

Test Log

Table B.1. Test Log

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
12/08					No action
12/09	04:52	35 minutes	920	35	Test B-20.1
12/10					No action
12/11	05:18	Pump bump 4:39 min.	1000	0	
12/12					No action
12/13	04:52	35 minutes	920	95	Test B-20.3
12/14					No action
12/15	04:46	35 minutes	920	35	Test B-20.1
12/16					No action
12/17	04:58	35 minutes	920	95	Test B-21.3
12/18					No Action
12/19					No action
12/20	05:36	5 minutes	1000	20	Pump bump
12/20	05:36	Pump bump	1000	20	
12/21					No action
12/22	06:07	Pump bump	1000		
12/23					No action
12/24	05:09	Pump bump	1000	110	
12/25					No action
12/26					No action

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
12/27	05:31	Pump bump	1000	110	
12/28					No action
12/29					No action, GC3 down
12/30	05:49	Pump bump	1000	140	
12/31	05:52	Pump bump	1000	170	
01/01					No action
01/02					No action
01/03	05:43	Pump bump	1000	20	
01/04					No action
01/05					No action
01/06	05:14	Pump bump	1000	50	
01/07	04:35	Pump bump	1000	80	
01/08					No action
01/09					
01/10	08:52	Pump bump	1000	110	
01/11					No action
01/12	05:12	Pump bump	1000	140	
01/13					No action
01/14	05:09	Pump bump	1000	170	
01/15					No action
01/16					No action
01/17	05:03	Pump bump	1000	20	
01/18					No action
01/19	04:52	Pump bump	1000	50	
01/20					No action
01/21	04:43	Pump bump	1000	80	

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
01/22					No action
01/23					No action
01/24	04:54	Pump bump	1000	110	
01/25					No action
01/26	04:41	Pump bump	1000	140	
01/27					No action
01/28	04:40	Pump bump	1000	170	
01/29					No action
01/30					No action
01/31					No action
02/01	06:01	Pump bump	1000	170	
02/02	05:16	Pump bump	1000	20	
02/03					No action
02/04	04:43	Full Scale Test #1	750	35	
02/05					No action
02/06					No action
02/07	04:53	Full Scale Test #2	750	65	
02/08					No Action
02/09	04:26	Full Scale Test #3	750	95	
02/10					No Action
02/11	05:05	Pump Bump	1000	95	
02/12					No Action
02/13					No Action
02/14	04:39	Full Scale Test #4	750	125	
02/15					No Action
02/16	04:42	Full-Scale Test #5	750	155	
02/17					No Action

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
02/18	04:11	Full-Scale Test #6	750	185	
02/19					No Action
02/20					No Action
02/21	04:30	Full-Scale Test #7	750	35	
02/22					No Action
02/23	04:32	Full-Scale Test #8	750	95	
02/24					No Action
02/25	04:24	Full-Scale Test #9	750	155	
02/26					No Action
02/27					No Action
02/28	05:31	Full-Scale Test #10	1000	35	5 minute run
03/1					No Action
03/2	05:10	Full-Scale Test #11	1000	35	5-minute run
03/3					No Action
03/4	04:47	Full-Scale Test #12	1000	35	5-minute run
03/5					No Action
03/6					No Action
03/7	05:23	Full-Scale Test #13	1000	35	5-minute run
03/8					No Action
03/9	05:08	Full-Scale Test #14	1000	35	5-minute run
03/10					No Action
03/11	05:06	Full-Scale Test #15	1000	35	5-minute run
03/12					No Action
03/13					No Action
03/14	04:53	Full-Scale Test #16	1000	35	5-minute run
03/15					No Action
03/16	04:45	Full-Scale Test #17	1000	35	5-minute run

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
03/17					No Action
03/18	04:56	Full-Scale Test #18	1000	35	5-minute run
03/19					No Action
03/20					No Action
03/21	05:18	Full-Scale Test #19	1000	35	5-minute run
03/22					No Action
03/23	05:14	Full-Scale Test #20	1000	35	5-minute run
03/24					No Action
03/25	05:30	Full-Scale Test #21	1000	35	5-minute run
03/26					No Action
03/27					No Action
03/28	05:18	Full-Scale Test #22	750		Tank Sweep 180 minutes
03/29					No Action
03/30	02:31	Full-Scale Test #23	750		Tank Sweep 180 minutes
03/31					No Action
04/01	04:04	Pump Bump	1000	185	5-minute run
04/02					No Action
04/03					No Action
04/04	05:31	Pump Bump	1000	172	5-minute run
04/05					No Action
04/06	05:34	Full-Scale Test #24	920	97	40 minutes
04/07					No Action
04/08	05:12	Full-Scale Test #25	920	97	39.5 minutes
04/09					No Action
04/10					No Action
04/11	04:53	Pump Bump	1000	97	5-minute run

Date	Time	Pump Action, Ramp, Duration	rpm	Orientation 0° = E-W (degrees)	Notes
12/07	02:35	30 minutes " "	750	35 65 95 125 155 185	Test B-19
04/12	05:03	Full-Scale Test #26	1000	97	Abort
04/13	05:07	Full-Scale Test #27	1000	97	20-minutes
04/14					No Action
04/15	05:06	Pump Bump	1000	35	5-minute run
04/16					No Action
04/17					No Action
04/18	05:24	Pump Bump	1000	65	5-minute run

Appendix C

Long-Term Mixer Pump Operations Plan

Appendix C

Long-Term Mixer Pump Operations Plan for Tank 241-SY-101 Mitigation

C.1 Purpose

The purpose of this plan is to identify, describe, and define those basic mixer pump operations that are to be used to maintain Tank 241-SY-101 in a mitigated state. The desired mitigated state is that which resulted from Full-Scale (WHC 1994) as well as Phase A and Phase B (Allemann et al. 1994) testing of the mixer pump; i.e., hydrogen gas release was controlled and its concentration in the tank dome space was prevented from exceeding safety limits.

C.1.1 Operation Philosophy

The long-term mixer pump operation philosophy is to utilize in a simple and straightforward manner the successful jet mixing techniques developed during the testing phases (Tests A, B, Full Scale) to continue to mitigate Tank 241-SY-101 by preventing the periodic gas releases that result in hydrogen concentrations that exceed 25% of the Lower Flammability Limit^(a) (LFL) at the tank exhaust. By controlling the hydrogen releases and maintaining its concentrations below the LFL in the tank dome to well below the value that could be ignited, mitigation is achieved and the concern for tank structural damage and related radiological consequences is eliminated.

The intent of the plan is to maximize the pump lifetime by minimizing 1) the number of pump starts, 2) the run time, and 3) pump motor oil excessive temperature. Another objective of this plan is to keep the tank level as low as possible (within the limits of the safety assessment) so that, in the event of pump failure, we would maximize the time available to develop mitigation alternatives. The final objective of this plan is to allow additional investigations in the areas of sludge mobilization and alternate instrumentation for additional waste characterizations.

This plan describes three basic types of pump operations that are to be used over the long term starting after completion of full-scale testing and terminating when 1) this plan is replaced by a new plan or 2) tank mitigation by pump mixing is no longer needed because potentially unsafe conditions are prevented by other means. The three modes are defined as maximum, minimal, and nominal pump operation. The requirements for using each mode are determined by the level (elevation) of the top surface of the waste.

(a) LFL defined as 3% volume fraction H_2 in a nitrous oxide atmosphere.

C.2 Descriptions of Pump Operations

The pump operations for all three modes are based on and replicate selected operations used during the testing phases. The three basic types of pump operations are

- **Minimal Pump Operation** - keep nozzles open/minimal waste agitation and minimum gas release. Operate the pump a maximum of three times per week (no minimum) and for relatively short times, five minutes, at 1000 rpm to prevent the waste level from decreasing below 400 inches, the (Level II) lower limit of the SA. If necessary, the pump nozzles need not be rotated during this mode of operation. The waste level is expected to grow at about 0.03 inches/day during this mode of operation.
- **Nominal Pump Operation** - mildly agitate the waste to release gases at about the same rate that they are generated. Operate the pump for a maximum of three times per week and a minimum of once per week for 60 minutes at 750 rpm, with the nozzles advanced 30 degrees between each operation. The orientation of nozzles for the initial operation in the series need not change from the previous operation.
- **Maximum Pump Operation** - aggressively agitate the waste to maximize the gas release and lower the level. Operate the pump a minimum of three times per week and a maximum of six times per day for 30 minutes at 750 rpm, with the nozzles in the directions 30 degrees advanced from the last orientation when the pump was operated under maximum-type conditions.

The orientation of the pump nozzles will follow the sequence 35, 65, 95, 125, 155, and 185 degrees unless otherwise specified. The long-term pump operations are summarized in Table C.1. A pump bump operation is allowed at any waste level to keep the pump nozzles unplugged.

An additional pump operation will be used for the sludge excavation operation. This mode of operation will assist in keeping the waste level as low as possible and is described as follows.

- **Sludge Excavation Operation** - aggressively agitate the waste to maximize the gas release and lower the level. Operate the pump a minimum of three times per week and a maximum of six times per day, for 25 minutes (maximum) at 1000 rpm, with the nozzles in the directions 30 degrees (nominal) advanced from the last orientation when the pump was operated under maximum-type conditions.

The orientation of the pump nozzles, for the above operation, will follow the sequence 28, 65, 97, 125, 155, and 185 degrees, unless otherwise specified. The recommended initial excavation operation is to be initiated in the direction of MIT 17C, 28 degree orientation. The sludge excavation operation is to be repeated until significant sludge mobilization is observed by monitoring the temperature profile at the bottom four tank thermocouples locations (50-inch elevation), and the progression of gas release quantities following each pump operation. Using this observed progression as a guide, apply similar repetitive excavation operations at the other indexed locations. The sludge excavation pump operations are summarized in Table C.2.

Table C.1. Long-Term Mixer Pump Operations Plan Summary

Waste Level (Inches)	Operation Sequence ^(a,b)	Pump Operation	Speed (r/min)	Duration (as noted)
TRG (Review Results of Full-Scale Test Operations and Authorize Start of Long Term Operations)				
400.5 <	Minimum	Pump Bump at Stepped Sweep ^(c,d)	1000 ^(e)	Five-minute pump operation, (One every other day, three per week)
400.5 - 401.5	Nominal	Tank Stepped Sweep ^(d,f)	750 ^(e)	Single Orientation Per Day, 60-minute pump operation (one every other day, three per week)
> 401.5	Maximum	Tank Stepped Sweep ^(c,g)	750 ^(e)	Six Orientations per day, 30 minutes per Orientation (one every other day, three per week)
<p>(a) TRG to regularly review, at least once per month, and report the results of pump and tank waste behavior at least once per quarter.</p> <p>(b) Level above 401.5 inches - use maximum type pump operations at least three times per week until the level drops below 401.0 inches.</p> <p>(c) Sweep orientation 35, 65, 95, 125, 155, and 185 azimuthal degrees.</p> <p>(d) Pump Bump Operation is allowed at any waste level to keep the pump nozzles unplugged.</p> <p>(e) Maximum pump speed and duration to be determined by the TRG and limited by the Safety Assessment (LANL 1994).</p> <p>(f) Similar to Phase B tests B-10 through B-15 (WHC 1993).</p> <p>(g) Similar to Phase B tests B-16 through B-19 (WHC 1993).</p>				

C.2.1 Selection Criteria

Waste level is the main indicator to determine the mode of pump operation. The FIC instrument and manual tape shall normally be used to measure waste level. However, the Test Review group (TRG) may specify other measures (i.e. radar gauge). The objective of the Long Term Pump operations is to maintain the tank waste level below 400.5 inches but within the Safety Assessment limits. The maximum and minimum levels are defined as follows:

Table C.2. Sludge Excavation Operation Plan Summary.

Waste Level (Inches)	Operation Sequence ^(a)	Pump Operation	Speed (r/min)	Duration (as noted)
TRG (Review Results of Long Term Operations and Authorize Start of Sludge Excavation Operation)				
400.5 - 401.5	Sludge Excavation	Tank Stepped Sweep ^(b,d)	1000 ^(c)	One Orientation per day, 25 minutes per Orientation (one every day, five per week)
<p>(a) TRG to regularly review, at least once per month, and report the results of pump and tank waste behavior at least once per quarter.</p> <p>(b) Sweep orientation 28 to 30, 65, 97, 125, 155 and 185 azimuthal degrees (see Figure 1).</p> <p>(c) Maximum pump speed and duration to be determined by the TRG and limited by the Safety Assessment (LANL 1994).</p> <p>(d) Pump Bump Operation is allowed at any waste level to keep the pump nozzles unplugged.</p>				

Level (maximum) - the top surface of the waste must be maintained below the maximum limit in the SA (currently 406 inches). However, it is desirable to maintain a lower maximum level to keep the gas inventory as low as possible within the SA controls. Therefore, when ever the waste level exceeds 401.5 inches the pump shall be operated at least three times a week using the maximum type conditions until the level drops below 401.0 inches.

Level (minimum) - the top surface of the waste must be maintained above the minimum limit in the SA (currently a Level II control set at 400 inches). Therefore whenever the waste level falls below 400.5 the pump shall be operated no more than three times a week and operated using the minimum type conditions.

At all other times/conditions/waste levels the pump shall be operated at least one to three times each week using nominal type conditions.

The waste level shall be determined by either of the FIC gauge or the manual tape. The reported level shall be determined by the lower of the two gauges for the minimum level or the maximum of the two gauges for the maximum level determination. Flushing of the FIC and manual tape should be considered after evidence of deposit buildup is observed monthly with the intank TV camera.

The TRG will periodically review the data associated with the tank such as waste axial temperatures and temperature profiles, peak temperatures, hydrogen concentration and associated vent header flow rate, daily total gas releases, ratios of hydrogen, nitrous oxide and ammonia, change in

level with atmospheric pressure, pump motor current, voltage, volute pressure, flows to determine if there are any undesirable conditions starting to develop that would require changes in this pump operations plan. As defined in Table C.1, the TRG will review pump and tank operations at least once per month during the first year of long term operations.

C.2.2 Precautions and Limitations

The intent of this plan is to permit only pump operations that meet all the limits given in the current SA (LANL 1994). The plan does not impose any additional limits other than those given in the current SA except that only the three types of pump operations specified in this plan may be used. The plan suggests that the pump be operated on Mondays, Wednesdays and Fridays; however, TRG approval is not necessary to operate the pump as seldom as once every five days or as often as three times a day every day if necessary provided that the limits in the SA are met.

Based on prior test results, it is expected that nominal mode pump operations will continue for periods of several weeks or months interspersed occasionally by brief periods in the minimal or maximum modes to adjust level. The pump behavior is expected to be identical for similar operations during the testing phases.

C.4. References

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AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
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Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
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