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**MITIGATION OF TANK 241-SY-101
BY PUMP MIXING: RESULTS OF
TESTING PHASES A AND B**

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ABSTRACT

A spare mixing pump from the Hanford Grout Program was installed in Hanford double-shell waste Tank 241-SY-101 on July 3, 1993, after being modified to take advantage of waste stratification. It was anticipated that pump mixing would prevent large episodic flammable gas releases that had been occurring about every 100-150 days. A cautious initial test plan, called Phase A, was run to find how the pump and tank would behave in response to very brief and gentle pump operation. No large gas releases were triggered, and the pump performed well except for two incidents of nozzle plugging. On October 21, 1993, the next test series, Phase B, began, and the pump was applied more aggressively to mix the tank contents and mitigate uncontrolled gas releases. Orienting the pump in new directions released large volumes of gas and reduced the waste level to a near-record low. Results of the entire period from pump installation to the end of Phase B on December 17, 1993, are presented in detail in this document. Though long-term effects require further evaluation, we conclude from these data that the jet mixer pump is an effective means of controlling flammable gas release and that it has met the success criteria for mitigation in this tank.

SUMMARY

A mixer pump was found to be effective in controlling and possibly eliminating large episodic flammable gas releases from Hanford Tank 241-SY-101. A gas release event (GRE) is apparently initiated when a major portion of the gas-bearing sludge layer accumulates sufficient gas to become buoyant, pull free from the surrounding material, rise through the surface crust, and release the trapped gas into the dome space. Mixer pump operation is intended to keep enough of the gas-generating material in suspension so that gas is released continuously instead of periodically in large, potentially dangerous GREs.

A spare mixing pump from the Hanford Grout Program was modified and installed in the tank on July 3, 1993, seven days after a typical GRE that met the safety criteria for pump installation. The modifications were made to take advantage of the density stratification in the waste, providing vertical buoyant motion as well as high jet velocity to promote mixing. The initial pump operations in Phase A testing were extremely gentle, beginning with a series of daily pump 'bumps' intended to keep the pump nozzles clear. Because nozzle plugging did occur, bump speed and duration were increased, eventually arriving at the accepted five-minute period at 1000 rpm on July 26. There has been no nozzle plugging since then. Bumping was initially performed twice a day through mid-August and once a day through the start of Phase B testing October 17. By the end of Phase B, thrice-weekly bumping during non-testing periods became the rule.

Phase B testing began October 21, 1993. The jets were aimed into previously undisturbed material, and gas release induced by the pump increased immediately. In November the pump jet was indexed progressively around the entire tank in 30° steps, releasing a relatively large quantity of retained gas at each position and reducing the waste level to 400 inches, the lowest in many years. By December, the jets had apparently excavated most of the gas-bearing sludge within reach, because only modest gas releases and essentially no level changes occurred after pump operation. For the rest of Phase B testing there were no large gas releases that would indicate a large volume of unmixed waste, and the two thermocouple trees indicated a uniform vertical temperature profile. As of the month following the end of Phase B, minimal pump operation had apparently maintained most of the mixing achieved during testing.

The primary measures of success for mixer pump mitigation testing are to maintain the maximum hydrogen concentration in the tank dome space well below 7,500 parts per million (ppm) (which is 25% of the lower flammability limit of 3%) and to keep the waste level below some acceptable value for an extended period. Because hydrogen concentrations remained below 400 ppm and the waste level remained below 402 inches from late November through the time of this writing, the jet mixer pump has met the main criteria for successful mitigation of Tank 241-SY-101.

Based on the objectives of the Phases A and B test plans, the behavior of the waste, and the performance of the mixer pump to date, we conclude that mixing has mitigated Tank 241-SY-101 by essentially eliminating the hazard of large flammable gas releases. Evidence continues to accumulate that the pump will maintain this state while it remains in operation.

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ACRONYMS AND ABBREVIATIONS

DACS	Data Acquisition and Control System
FFT	Fast Fourier transform
FIC	Food Instrument Corporation (indicates a type of waste level indicator)
FTIR	Fourier transform infrared spectrophotometer
GC	Gas chromatograph
GMS	Gas monitoring system
GRE	Gas release event
LFL	Lower flammability limit
MIT	Multifunction instrument tree
MMS	Molecular mass spectrometer
ppm	Parts per million
rpm	Revolutions per minute
SA	Safety Assessment
SHMS	Standard hydrogen monitoring system
TRG	Test Review Group
USQ	Unresolved safety question
VDTT	Velocity-density-temperature tree
VFD	Variable frequency drive

1.0 INTRODUCTION

Tank 241-SY-101 is a double-shell, high-level 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 this tank over the next three years, and by November 1980 it contained about one million gallons of waste, filling it to a depth of 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, creating potentially flammable gas mixtures in the tank dome space and ventilation system.

In 1990, this tank was declared to have an unresolved safety question (USQ) because of this behavior; a safety program was established to characterize the waste and released gases and to develop an effective means to control or prevent accumulation and uncontrolled releases of gas. Pump mixing was selected as a candidate mitigation strategy in 1992.

This report describes the testing performed with the jet mixing pump in Tank 241-SY-101 from July through December 1993. The testing periods have been designated Phase A and Phase B. The purpose of these tests was to evaluate the ability of pump mixing to control gas releases and preclude future episodic gas release events (GREs).

1.1 Background

Core samples from Tank 241-SY-101 in mid-1991 showed the tank waste comprised a "crust" floating on a liquid with a layer of settled solid material on the bottom (Babad et al. 1992). The crust was about four feet thick, the liquid layer 13-14 feet thick, and the settled solid layer was about 16 feet thick. Because the liquid is free to circulate in response to natural convection, it has been called the 'convective' layer; the solid, sludge layer is called the 'nonconvective' layer. The thickness of the sludge layer and the amount of solids suspended in the convective layer varied depending on the size and origin of the last GRE.

According to the prevailing theory, a GRE is initiated when a major portion of the sludge layer accumulates sufficient gas to become buoyant, pulls free from the surrounding material, and rises through the surface crust, releasing the gas to the dome space (Babad et al. 1992). This has happened about every 100-150 days since about 1981 (Antoniak 1993). On the evidence of vertical temperature profiles, the section of the tank involved in the GRE temporarily becomes quite well mixed, with most of the sludge in that section becoming resuspended in the liquid. The waste that does not accumulate enough gas to become buoyant remains undisturbed until the next event.

Each GRE releases most of its trapped gas in a few minutes, but gases continue to issue at a significant rate for many hours. The suspended solids begin to resettle within a few days after the release. This halts natural convection in the lower (nonconvective) layers, and the parabolic temperature

profile characteristic of heat conduction with volumetric heating reappears within a few weeks. Gas newly generated in the sludge cannot escape and accumulates until the next release event.

Mixer pump operation is intended to keep sufficient gas-generating material in suspension so that gas is released continuously instead of periodically in large, potentially dangerous GREs. The pump pulls in liquid from the 260-inch level and injects it as a high-speed jet about two feet from the tank bottom in the sludge layer. To some extent the jet fractures and erodes the sludge, releasing previously trapped gas and suspending the gas-generating solids in a convective slurry.

The pump chosen for mitigation testing in Tank 241-SY-101 was originally purchased for the Hanford Grout Program as a spare pump for mixing the contents of a staging tank that stored waste before it was to be converted to concrete. The Barrett, Haentjens & Co. Model 10" GN, Hazelton Type "SSB" pump was designed to discharge 2800 gpm of clear water through two opposed 2.6-inch-diameter nozzles at 114 feet of head while drawing 103.3 hp. In its original configuration, the pump suction and discharge nozzles were located at about 12 and 18 inches above the tank bottom, respectively. The major modification accomplished for mitigation testing was extending the original discharge nozzles to keep the pump suction in the liquid layer at an elevation of about 20 feet, while allowing the nozzles to discharge into the sludge layer 28 inches above the tank bottom.

The jet mixer pump was installed on July 3, 1993, seven days after Event I, a major GRE that met the safety criteria for pump installation (LANL 1993). 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 selected for Phase B tests and the location of important instruments are shown in the tank plan view in Figure 1.1.

Important items in the tank plan view that need to be identified for future reference are the velocity-density-temperature trees (VDTTs), which are placed in risers 14A and 1B on the 35° azimuth. The sensors on these trees are not activated, but they are equipped with strain gauges that indicate a strain induced by the force of 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.

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 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 of the convective layer distributes heat evenly to give a uniform temperature. Pure heat conduction in the nonconvective crust creates a straight linear temperature profile; thus a change from a parabolic profile to a uniform temperature could indicate that part of the sludge layer had been resuspended in the vicinity of the MIT.

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

Several facts about the physical condition of the waste and the geometry of pump installation are very important in understanding the mixing process. The sludge appears to be very different from clay, sand, or other sediments that one might visualize, particularly in its ability to retain gas, and the action of the jet must be understood in the context of this condition. The main points are that

- The density of solid material is only about 20% greater than the liquid, and it consists of relatively small crystal particles (Herting et al. 1992). The sludge layer probably forms more by agglomeration than settling, evolving from a loose 'slush' to a tighter 'mush.' Once suspended, the relatively light small particles tend to stay suspended, particularly if bubbles are attached.
- The pump nozzles were initially inserted under a deep layer of sludge so that liquid injected near the bottom would lift, fracture, and undermine large sections. Once freed, these could rise to the base of the crust intact without immediately releasing their accumulated gas. The accompanying decrease in pressure would expand the gas to cause the characteristic surface level rise and drop typical of most pump-induced gas releases.

Figure 1.2. Tank 241-SY-101 Mixer Pump Installation

1.2 Overview of Jet Mixer Pump Testing

This section presents an overview of how the mixer pump disturbed the waste; when, where, and how the stored gas was released; and how the waste configuration might have evolved as a result of Phases A and B testing. The following scenarios are consistent with the data; however, other explanations may also be appropriate.

The overall view of how the tank behaved over the entire period from just prior to Event I to January 12, 1994, is given in Figures 1.3 and 1.4. Figure 1.3 shows waste level and the dome hydrogen concentration, while Figure 1.4 is a plot of the waste level and daily gas releases. Figure 1.5 shows several "snapshots" of the vertical temperature profiles at the thermocouple tree at riser 17B (and one for 17C) before and after various events that indicate changes in the waste configuration. Major events such as large gas releases are also noted on Figure 1.3. The following are some important dates and features to note from the figures:

Figure 1.3. Hydrogen Concentration History

Figure 1.4. Daily Gas Release History

Figure 1.5. Temperature Profiles
1.6

- June 26: Five-inch level drop of Event I (estimated 6000 ft³ gas released)
- July 8—August 27: Steady level growth during Phase A tests and pump bumping
- July 26: Gas release (150 ft³) induced by start of 1000-rpm bumping
- August 27: Gas release (2200 ft³) and level drop
- August 28—October 20: Steady level growth prior to Phase B tests
- September 17: Gas release (580 ft³) with level spike
- October 16: Gas release (280 ft³) with level spike
- October 25: Gas release (360 ft³) and level rise with 720-rpm Phase B run at 35°
- October 25—November 2: High-level 'plateau,' bumping only
- November 2: Gas release (380 ft³) and level drop with 720-rpm run at 35°
- November 5—24: Level reduction and high gas releases (510, 480, 305 ft³)
- November 24—December 17: Steady low level during balance of Phase B testing.

The pump was installed at a time when only part of the tank was relatively well mixed. Event I was not one of the largest GREs (6000 ft³ compared with 12,000 ft³ in Event E). The 17B temperature profiles before and after the event (Figure 1.5a) show significant mixing, but the profile at 17C did not change. The gas released during the water lancing operation that preceded pump installation (indicated in Figures 1.3 and 1.4) shows that some fraction of relatively undisturbed sludge must have remained in the pump region after the GRE. It might be expected that pump operation would release more of it.

The initial pump operations (Phase A) were extremely gentle because of concerns that pump operation might trigger a major GRE. Beginning on the day of pump installation, a series of daily pump 'bumps' were begun to keep the pump nozzles clear. Initially, the bumps were very brief (10-second) runs at a very low speed of 380 rpm. Phase A tests were run for a maximum of only a few minutes at 340 rpm (see Appendix A). Because nozzle plugging did occur under these conditions, bump speed and duration were increased, eventually arriving at the accepted five-minute period at 1000 rpm on July 26 (see Appendix C). There has been no nozzle plugging since. Bumping was initially performed twice a day through mid-August and once per day through the start of Phase B testing October 21. By the end of Phase B, thrice-weekly bumping became the rule.

The initial, low-speed bumping did very little to disturb the waste and release gas, as shown by the low hydrogen concentrations in Figure 1.3. Most of the liquid probably flowed up around the pump

column without excavating much more sludge than the water lancing. But the effect of a more powerful jet is clearly evident on July 26 when the 1000-rpm, five-minute pump bumps began. The hydrogen concentration increased markedly, indicating that the 'canyon' around the nozzles was being excavated in the 0—180° orientation. The 17B temperature profile in Figure 1.5b clearly shows that hot material has been injected into the convective layer, though no sludge was moved in that vicinity.

But even the relatively small amount of sludge that was lifted into the convective layer had a marked effect. Figure 1.6 shows the average temperatures of the convective and nonconvective layers as calculated from the 17B thermocouple readings for the period covering the last two large GREs. It is clear that even the early period of minimal pump operation was sufficient to keep the temperature of the convective layer high compared with the strongly decreasing trend after the two prior events, although mixing was not sufficient to prevent heating the nonconvective layer at the location of the thermocouple trees.

The sludge in regions away from the jet was probably not disturbed and continued to accumulate gas, as indicated by the steady rise in waste level. This led to a release of 2200 ft³ on August 27. The material involved in this event was probably "left over" from before Event I and was evidently centered around the 17C thermocouple tree. The change in its profile shown in Figure 1.5d indicates that the sludge layer was resuspended down to almost its full depth, compared with almost no effect on the 17B tree in Figure 1.5c.

The waste level continued to grow as pump bumping continued after the August 27 gas release, though not quite as fast, and two pump-induced gas releases occurred on September 17 and October 16 that produced waste motion visible on the in-tank video camera. Comparing Figures 1.5e and 1.5f establishes that only the October 16 event was close enough to the 17B tree to affect the temperature profile there. Neither affected the temperature profile at 17C (not shown).

Each of these events was accompanied by a sharp level rise followed by a decline lasting several days. The gas release profile was similar. Large sections of sludge may have been lifted and gradually loosened from their surroundings as 1000-rpm bumps continued along the 0—180° azimuth. When these finally detached, the gas trapped inside them expanded and sharply increased the waste level. During the process some sludge disintegrated and released its gas suddenly, while the rest of the gas issued slowly from beneath the crust, gradually reducing the waste level.

Gas release increased immediately when Phase B testing began October 21. The pump nozzles were aimed into the sludge outside the region excavated by almost four months of pump bumping at 0—180°. The increasing temperatures in the nonconvecting layer near MIT 17B (compare Figures 1.5b, c, e, and f) and continued level growth indicated that this material had remained relatively undisturbed. Thus when the pump began to run at 35°, the jet began undermining a new region.

On October 25, one of the more interesting events of the Phase B test series occurred. The pump had been aimed at 35° for twenty minutes at 360 rpm on October 21 and twenty minutes more at 520 rpm the next day with no significant gas release. But after eleven minutes at 720 rpm on October 25,

Figure 1.6. Average Waste Temperature History (17B)

a very large island of buoyant sludge was apparently freed and stayed relatively intact under the crust for more than a week. This was signaled by a gas release (360 ft^3) and sudden level rise of almost two inches. The undisturbed temperature profile at 17B in Figure 1.5g shows that the island probably lifted from the northwestern quadrant of the tank.

On November 2, after a 13-minute run at 720 rpm at 35° , the remains of the large island apparently disintegrated, resulting in a gas release (380 ft^3) and waste level drop. This event also seemed to have produced a broader disturbance that turned over the sludge layer near 17B, as shown in Figure 1.5h.

During Phase B testing in November, the jets were indexed progressively around the entire tank in 30° steps, releasing a relatively large quantity of retained gas. Figure 1.3 shows that the level decreased steadily to the apparently stable post-Phase B value of around 400 inches. A gas release of about 500 ft^3 occurred November 5 and two more on November 10 (4380 ft^3) and November 21 (300 ft^3), but the waste involved was evidently broken up by the jet, and the level dropped in proportion to gas release each time.

There is considerable evidence that the tank was being mitigated after November 24. The jet apparently had excavated most of the gas-bearing sludge within reach. Only modest gas releases and

essentially no change in level occurred for even the most aggressive pump operation for the balance of Phase B, including 35-minute runs at 920 rpm. Figure 1.5i shows that the pump finished mixing the waste to a nearly isothermal state during this last week of Phase B operation, at least in the area of the 17B and 17C trees (the latter not shown). The change in the 17B temperature profile from beginning to end of Phase B, specifically the diminishing sludge layer and reduction in peak temperature, is shown in Figure 1.7a. Figure 1.7b compares 17B temperatures from immediately after Event I to those at the end of Phase B. This indicates that pump operation also mixed the tank more completely than the rollover of Event I. A rollover is a natural occurrence in which a portion of the nonconvective sludge layer overturns, thus releasing a significant amount of trapped gas.

The total hydraulic power delivered to the waste before and during Phase B is shown in Figure 1.8. Figure 1.8a shows that the east-west azimuth has received by far the most energy because of the long period of daily or more frequent 1000-rpm pump bumping in this orientation. During Phase B, the jet penetration tests aimed at the 17B and 17C MITs injected the most power along the 35° and 95° azimuths, while the northeast and southwest quadrants were relatively much less disturbed. Thus more undisturbed sludge might remain in that region and between the trenches that may have been excavated in the directions chosen for the Phase B tests (35°, 65°, 95°, 125°, and 155°). The latter suspicion is reinforced by the prompt gas releases that have accompanied pump bumping aimed at these 'scalloped' areas during post-Phase B operation.

On the other hand, there have been none of the large gas releases that could have been expected to occur had any large volume of waste been undisturbed for nearly six months. Also, though the pump bumps toward the 'scallops' release more gas than those pointed in previously excavated directions, there has been no indication of any great mountain of undisturbed waste there. Estimates of gas volume based on the correlation of waste level to barometric pressure changes (see Section 2.2) point to a definite reduction in retained gas fraction. These observations, along with the steady level and isothermal temperature profiles, tend to confirm successful mitigation.

1.3 Initial Conditions in the Tank

There are three stages in Phases A and B testing that have different starting points, depending partly on prior pump action and partly on the natural evolution of the tank. The initial conditions for pump installation and initial testing are those left over from Event I, slightly modified by water lancing. The tank state at the start of Phase B on October 21 was further modified by three months of high-speed pump bumping and the gas releases of August 27, September 17, and October 16. The October 25 level swell and subsequent gas releases induced by the first Phase B tests created a new tank environment for the balance of testing after about November 10.

Figure 1.9 is a sketch of the possible origin and extent of these major GREs that shaped the waste. The darker shading shows where we think sludge gushed up from the deeper layers, and the lighter shading shows where smaller "gobs" floated free. The location and extent of these regions of influence are inferred from the response (or lack of response) of the temperature profiles at the 17C and 17B

a.

b.

Figure 1.7. Mixing Comparison - 17B Temperature Profiles

Figure 1.8. Map of Pump Hydraulic Power Deposition

Figure 1.9. Map of Possible Gas Release Source Regions

thermocouple trees. The probable prior pump excavation and current jet direction were also considered. The sources of Event I and the August 27 release was mapped from the surface motion observed on the in-tank video tape.

Event I evidently turned over most of the northeast tank quadrant down to within a few feet of the tank bottom. While there is no doubt that the sludge layer thickness was reduced, the gas released during water lancing showed that it was not all resuspended. The gas releases induced by the initial high-speed pump bumping confirm this. Based on the temperature profiles at 17C, the southeast half of the tank was not stirred up, and the southeast quadrant was particularly 'ripe' with accumulated gas.

The waste was generally more mature at the start of Phase B testing on October 21 than when the pump was installed on July 3. The solids suspended in Event I had been settling for almost four months, and a sludge layer reappeared in the northwest quadrant, as indicated by the temperature profile at 17B. Pump bumping excavated material only along the east-west azimuth, and the tank level was about one inch higher. There were three significant GREs during the period, but their total volume was less than half that released in Event I. The undisturbed southeast quadrant rolled over spontaneously on August 27. The smaller release on September 17 probably originated in the southwest quadrant, and the last one, on October 16, near 17B.

The October 25 level swell event induced by the first Phase B tests returned the tank conditions closer to those following a large rollover. When the level dropped on November 2, the resulting agitation converted the sludge into slurry from near 17B to the vicinity of the VDTTs. Almost as much gas was released between October 25 and November 10 as in the August 27 event; however, a substantial amount of sludge of various ages probably remained on the bottom, especially in the southern half. Tank initial conditions for the balance of Phase B testing might have been similar to those existing in early August.

1.4 Test Plans

Phase A testing was carried out from July 14 through July 25. Testing consisted of a series of low-speed (380 rpm) 8-second pump bumps and low-flow operation at 340 rpm. Longer pump runs from 2-10 minutes were performed in an attempt to correct or alleviate nozzle blockage problems. The initial test sequence consisted of short-term/low-speed pump operations intended to minimize the risk associated with the potential release of the gas remaining after a rollover event. The Phase A test sequence is summarized below and the Phase A Test Plan is excerpted in Appendix A.

- Pump orientation set to 0° (i.e., discharge nozzles directed toward risers 5A and 5B).
- Pump-bump operation: ramp to 380 rpm in four seconds, hold at 380 for eight seconds, ramp down at maximum rate to zero rpm. Repeat pump bumping daily (subject to Test Review Group (TRG) approval; pump speed may be increased for bumping if no flow is indicated).
- Low-flow operation: ramp to 340 rpm in one minute, shut down pump (observe response).
- Shutoff operation: maintain pump off until hydrogen concentration returns to less than 0.2% (2000 parts per million [ppm]) at all measured locations (minimum 12-hour hold required).
- Extended low-flow operation: repeat the last two steps for pump operation periods of 2, 5, and 10 minutes.
- Extended shutoff operation: maintain pump off for one week (continue data recording).
- Post-pump-bump operation: perform daily pump bumping.

Phase B testing was carried out from October 21 through December 17. Prior to that, starting on July 26, a daily five-minute pump bump was performed. The Phase B tests are summarized in Table 1.1, and the Phase B Test Plan is excerpted in Appendix B. The tests consisted of a series of extended-duration, phased-velocity, and tank-sweep tests. Pump runs varied from 20 to 60 minutes. Tests B-20 and B-21 were completed for the first and third positions only. The last tests in Phase B were B-21.1 and B-21.3, at 35° and 95°, respectively. After those tests the sequence was halted because of concerns

that the minimum waste level limit would have been violated had the tests continued. Pump bumping on a thrice-weekly schedule resumed December 20 and preceded until the start of full-scale testing on February 4, 1994.

Mitigation is defined as maintaining waste Tank 241-SY-101 in a state such that periodic gas releases that result in hydrogen concentrations exceeding 25% of the lower flammability limit (LFL) are prevented.^(a) This ensures that the maximum concentration of hydrogen gas in the tank dome space will be well below the value that could be ignited, thereby eliminating the concern for tank structural damage and related release of radiation.

The primary measure of success for mixer pump testing is to maintain the maximum hydrogen concentration in the tank dome space well below 25% of the LFL. Since tank waste level can be used as a measure of the gas accumulation, an implicit success criterion is to maintain the waste level below some acceptable value for an extended period. Because hydrogen concentrations remained below 400 ppm and the waste level remained below 402 inches from late November 1993 through the time of this writing, the jet mixer pump has met the criteria for successful mitigation of Tank 241-SY-101.

The balance of this report describes how this was done. Gas releases from the tank are discussed in Section 2.0; waste level and temperatures are covered in Sections 3.0 and 4.0 respectively. Section 5.0 describes strain gauge indications and Section 6.0 presents pump performance parameters. The instrumentation is covered in Section 7.0. Supporting information can be found in the appendixes at the end of the report.

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

Table 1.1. Phase B Test Summary

Test #	Pump Operation	Maximum ^(a) Speed (r/min)	Maximum Test Duration (min)	Minimum Waiting Time (h)
1	35°	360	20	12
2	35°	510	20	12
3	35°	720	20	12
4	35°	920	20	12
5	65°	360, 510, 720 920 r/min (20 min each speed)		22:40
6	95°	360, 510, 720 920 r/min (20 min each speed)		22:40
7	125°	360, 510, 720 920 r/min (20 min each speed)		22:40
8	155°	360, 510, 720 920 r/min (20 min each speed)		22:40
9	185°	360, 510, 720 920 r/min (20 min each speed)		22:40
10	35°	750	60	12
11	65°	750	60	12
12	95°	750	60	12
13	125°	750	60	12
14	155°	750	60	12
15	185°	750	60	12
16	tank sweep ^(b)	750	180	21
17	tank sweep	750	180	21
18	tank sweep	750	180	21
19	tank sweep	750	180	21
20.1	35°	920	35	20:30
20.3	95°	920	35	20:30
21.1	35°	920	35	20:30
21.3	95°	920	35	20:30
(a) Maximum operating Limit.				
(b) Tank sweeps are tentatively defined by the pump azimuthal orientations identified in test numbers 10 through 15, above.				

2.0 GAS RELEASE

2.1 Gas Release Volume

The concentrations of hydrogen (H_2), ammonia (NH_3), and nitrous oxide (N_2O) were monitored throughout Phases A and B testing. Data for hydrogen concentration were available from a number of instruments, but much of the analysis focused on the data from the two gas chromatographs (GC2 and GC3) because of their reliability and resolution in the ranges of observed hydrogen concentration. (The GC3 instrument provided data in the range 0-100 ppm; GC2 provided data above this range.) Data for the nitrous oxide and ammonia concentrations were available from the Fourier transform infrared spectrophotometer (FTIR). Details of the gas monitoring instruments are given in Section 7.0.

Daily release rates provided a simple but effective means of quantifying the results of pump action and waste movement. Daily total gas release volumes were calculated by integrating the product of the hydrogen concentration and the vent header flow rate and dividing by an assumed hydrogen fraction of 0.29 in the released gas.^(b) The resulting daily release volumes are as shown in Figure 1.4.

Because the estimates are calculated for each day, they can also be summed to give a cumulative gas release for the period. The resulting approximate gas release rate can then be compared with the historically observed gas growth rate. Increases or decreases in the retained gas inventory can be estimated from the difference between these rates.^(c)

The cumulative gas release volumes for the period that includes Phases A and B testing are presented in Figure 2.1. Along with the actual release volumes, a baseline release volume and a total generated volume are presented for comparison. The baseline release is taken to be the amount of gas that evolves from the tank in the absence of pump activity and any large-scale waste movement. The baseline release is calculated by integrating the product of the historically observed 19 ppm hydrogen concentration and a 550 ft³/min vent stream flow rate and dividing by an assumed hydrogen fraction of 0.29; this results in approximately 52 ft³/day.

The total generated volume includes both the volume of gas released and that which has historically been retained and caused a rise in waste surface level. The rate at which gas is retained in the waste is estimated from the surface level rise rate. The estimate for surface level rise was taken to be 0.08

(b) The hydrogen gas fraction was originally assumed to be 0.36, based on gas composition analyses that were performed on grab samples during previous GREs. Recent recalibration of concentration calculations from FTIR spectra estimate the hydrogen fraction at 0.29 ± 0.05 .

(c) These estimates were intended to give a qualitative comparison that would complement the information on gas generation and retention that the level data provide. Because of uncertainties in estimating the hydrogen fraction in the release gas, these estimates cannot provide accurate quantitative estimates of gas accumulation over long-time integrations.

Figure 2.1 Cumulative Gas Released Since Pump Operation

inches/day that was observed during April and May of 1993. In addition, the pressure under which the gas is retained must be prescribed to account for changes in volume due to expansion when the gas is released into the dome space. This pressure is taken to be that estimated for the average sludge layer elevation, approximately two atmospheres (atm) (absolute). The product of the rate of surface level rise (0.08 inches/day) and the surface area of the tank (37.5 ft²) multiplied by a pressure correction (2 atm/1 atm) results in approximately 60 ft³/day. Therefore, the total generation rate (the baseline release rate of 52 ft³/day plus the gas retention rate of 60 ft³/day) is approximately 110 ft³/day.

The daily gas release volumes through Phase A testing were approximately 65 ft³/day, only slightly above the baseline release rate (see Figure 1.4). The release rate increased somewhat when the 1000-rpm pump bumps began. The gas released during the August 27 event (approximately 2200 ft³) narrowed the gap between the total volume of gas released since pump activity began and that which would have been generated at the historical rate.

After the August 27 event, the rate at which gas was released was slightly higher on average, but still well below the historical generation rate. The largest daily releases observed thus far (except that of August 27) were those which occurred during Phase B testing. As high-speed, long-duration tests that included new nozzle orientations were performed, large volumes of gas were released. The daily release volumes associated with the Phase B tests were typically in excess of 100 ft³, often (particularly in the first half of Phase B) they exceeded 200 ft³. In the first half of the Phase B testing period the gas release rate actually exceeded the historical generation rate. Thus the inventory of retained gas was decreased by the pump activity. As the tests repeated earlier nozzle orientations, the pump activity released a smaller quantity of gas than had been observed in the earlier tests. However, gas release associated with the Phase B tests still often exceeded 100 ft³/day, well above the baseline release rate.

Since Phase B testing, pump activity has consisted of high-speed pump bumps three times weekly, and the gas release rate has significantly decreased. As with initial pump operations, these bumps have released gas at a rate only slightly above the baseline rate.

2.1.1 Hydrogen

Because many of the safety issues associated with Tank 241-SY-101 are tied strongly to the amount of hydrogen in the retained and released gases, much attention has been focused on obtaining hydrogen concentration measurements. Most tank operations can be performed only when hydrogen concentrations in the dome and vent streams are relatively low (compared with the LFL). Therefore, hydrogen concentration must be carefully monitored to ensure that work is performed within the prescribed safety bounds.

In addition to safety monitoring, the hydrogen concentration measurements provide a critical assessment of the mitigation efforts. 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.

A variety of instruments provide data on hydrogen concentration, including the Whittaker electrochemical cell, two gas chromatographs, the FTIR instrument, and an online mass spectrometer. The Whittaker instruments are diffusion-based devices that provide continuous hydrogen concentration with time. Because their response time is fairly slow, the measurements are not used during rapid transients. The gas chromatography instruments (GC2 and GC3) provide measurements at approximately 10-minute intervals. The FTIR analyzes the gas stream continuously, although it time-averages the measurement over a 15- to 17-minute period. The mass spectrometer provides data at five-minute intervals. All of these measurements are recorded by the data acquisition and control system (DACS). In addition to these, offline analyses have been performed periodically on "grab samples," in-tank samples which are analyzed remotely.

Since the online mass spectrometer was installed in May 1991, concentrations of gas components have been monitored in the vent stream. Particular attention has focused on measurements immediately following gas release events to quantify the content of flammable gases that are released as a result of waste movement. These data indicate that approximately $36 \pm 5\%$ of this gas is hydrogen.^(d) Other major components of the release gas include nitrous oxide, nitrogen, ammonia and water vapor.

In addition to the periodic gas releases associated with waste movement, gas is released continuously from the waste at a relatively slow rate such that the hydrogen content in the vent stream air is typically near 20 ppm. This is referred to as the baseline, or basal, release. At this rate, approximately 16 ft³ of hydrogen gas is released by the waste per day in the absence of pump activity or waste movement, compared with a volume in excess of 3,500 ft³ of hydrogen released in the June 26, 1993, GRE.

Hydrogen concentration data from the GC3 instrument for the period of Phases A and B testing were presented in Figure 1.3 with the level measurements from the FIC instrument. While the GC3 instrument provides quantitative information only at concentrations below 100 ppm, the correct data trends are observed throughout the range presented (although the magnitude of the maxima are under-represented due to instrument saturation).

A baseline release rate of 20-25 ppm is evident as the lower limit of the hydrogen concentration data in Figure 1.3. Significant increases of hydrogen concentration in the vent stream gas occurred as a result of pump activity or waste movement. Gas releases associated with waste movement caused the hydrogen concentration in the vent stream to exceed 200 ppm four times during this period (August 27, September 17, October 16 and 25). Several times (November 2, 12, and 13) pump activity caused gas releases such that the vent stream hydrogen concentration exceeded 500 ppm (as measured with the GC2 instrument). While these concentrations seem large when compared with the baseline value, they are quite small compared with the hydrogen concentration of 3.3%, or 33,000 ppm, observed following the June 26, 1993, event.

(d) Recent measurements based on similar techniques using oxygen as the tie gas (rather than argon, which was previously used) suggested a hydrogen content in the release gas of $29 \pm 5\%$.

Hydrogen concentrations remained near the baseline value during Phase A testing. Slight increases occurred following the tests, but the concentration in the vent stream never exceeded 50 ppm. Increases were also observed following the first short-duration, 1000-rpm pump operations that began on July 26. The maximum concentrations in the vent stream twice exceeded 200 ppm following these operations.

During the period between Phase A and Phase B testing, pump activity consisted of short-duration, 1000-rpm operations at 0° (east-west) orientation. The resulting hydrogen concentration maxima in the vent stream were typically below 50 ppm. Because the daily gas release rate was lower than the generation rate, a steady surface level growth was observed throughout most of this period. As mentioned above, on four occasions GREs caused the hydrogen concentration in the vent stream to exceed 200 ppm. The waste surface level dropped with each of these releases.

The largest hydrogen concentrations associated with pump activity occurred during Phase B testing. During this period the long-duration, high-speed pump operations that included new nozzle orientations caused the vent stream concentrations to exceed 500 ppm on several occasions. These contributed to large daily gas release volumes that actually decrease the inventory of retained gas in the waste. The result was a sustained increase in the release of hydrogen and a decrease in waste surface level.

Following the Phase B tests, pump activity returned to the short-duration, 1000-rpm operations, but with alternating nozzle orientations. The vent hydrogen concentrations remained much lower than those observed during Phase B testing, with the daily maxima typically below 100 ppm. The modest gas releases associated with these lower concentrations were accompanied by a slow rate of waste surface level increase.

Overall, the hydrogen retained and released by the waste responded to pump mixing as desired. The short-duration, low-rpm pump operations provided by Phase A testing allowed testing of the pump without significant impact on the amount of gas released. With the more aggressive use of the pump during Phase B testing, pump operations successfully controlled the amount of hydrogen released. These tests clearly demonstrated that the pump could cause a sustained release of hydrogen from the tank at rates near or above the generation rate. This indicates that pump mixing is an effective means of mitigating the problem of large, episodic gas releases that have occurred in Tank 241-SY-101.

2.1.2 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. Therefore, diffusion and mass transfer must be considered (in addition to bubble release) to understand its behavior.

Estimates of the ammonia content of sludge material were obtained from core samples taken after the December 4, 1991, GRE. These estimates indicated that approximately 0.2 wt% of the sludge

material was ammonia. However, because of the difficulties associated with these measurements, these may be only a lower limit. R. T. Allemann^(e) suggested that an upper bound may be given by assuming a saturation equilibrium condition with the release gas resulting in an estimate of 3 wt%.

The vent stream gas has been analyzed following GREs to determine the ammonia content; online and offline (using grab samples) mass spectrometry have been used. The addition of the FTIR instrument in 1992 has provided consistent online measurements of ammonia concentration. The FTIR measurements following the June 26, 1993, GRE indicate that the maximum vent stream ammonia concentration was approximately 1.4%, or 14,000 ppm. The ammonia concentration exceeded 1000 ppm following the August 27, 1993, release event. The maximum concentrations following the Phase B tests were well below this, typically around 200 ppm or less. Recent recalibration of the FTIR for ammonia yields concentrations about 50% higher than originally reported.

Ammonia represents about 11% of the gas released from the waste during GREs that are associated with large decreases in waste level and releases of hydrogen. The FTIR has shown that nitrous oxide is released at about the same time as hydrogen. Ammonia release occurs more rapidly during the events, but the increase above the baseline rate is much less than that of hydrogen and nitrous oxide. This indicates that a different release mechanism may be involved.

Allemann describes three mechanisms that are important to ammonia release: 1) As a large GRE brings fresh liquid to the surface and overflows the crust, the ammonia dissolved in the liquid evaporates into the dome space and augments the ammonia release for some time after the event. This mechanism is probably responsible for the relatively large increase in ammonia concentration that was seen during water lancing, prior to pump installation. Hydrogen and nitrous oxide are essentially insoluble and are released only in the form of bubbles. 2) Ammonia that is dissolved in the liquid also diffuses through the crust during quiet periods when the surface is not disturbed. This provides about 80% of the basal ammonia release rate, while the rest comes from the continuous bubble release that is assumed to provide the basal hydrogen and nitrous oxide release rates. 3) Ammonia may also be released in the form of bubbles that also contain hydrogen and nitrous oxide.

It is unlikely that pump mixing would release a large amount of ammonia unless pumping induced a large GRE. It is very unlikely that pump action alone could lift fresh waste liquid with sufficient force to disturb the crust and expose it to the dome atmosphere using the current size and velocity of the jet. Control of the tank by mixing should eliminate large GREs and the ammonia release rate will be limited by the diffusion and bubble release mechanisms. On the other hand, any tank operation that disturbs the waste and brings fresh liquid to the surface, such as water lancing, could be expected to cause a significant release of ammonia.

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

2.1.3 Methane

During Phase B testing, questions arose as to whether methane concentrations in the release gas contributed significantly to the flammable gas content. Because of this, some attention was again focused on determining the magnitude of methane concentrations and resolving any associated safety issues.

Analyses were performed on the available data from the FTIR using data from several time intervals, including that immediately following the June 26, 1993, GRE. From these data it was concluded that quantities of methane that are measurable using the FTIR instrument occur only during large gas releases (e.g., natural release events, perhaps some of the releases induced by the early Phase B tests), but that, even in this case, the methane concentration is a maximum of 1.5% the hydrogen concentration. This result is consistent with the analysis performed on grab samples of the vent gas from previous GREs using a mass spectrometer. Because the concentrations of methane are small compared with other flammable gases, the contribution of methane to the flammability of the release gas appear to be unimportant, even considering its higher heat of combination.

2.1.4 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 the gas ratios shows that a gas may not be coming from the same place as the hydrogen. A long-term change in ratios may indicate that the mitigation activities are actually changing the composition of the gas.

The release of gases from the waste to the tank dome space has been characterized during GREs, the baseline period between the February 1993 and June 1993 events, and the period since the mixer pump was installed, including Phases A and B testing. The gas-measuring calibration curves for the FTIR were adjusted from February to December 1993, but this has had little effect on the ratios reported.

The composition of the waste gas (and therefore the ratios between gases) has been estimated for various GREs based on grab samples measured with a mass spectrometer.^(f) The ratios of nitrous oxide to hydrogen and ammonia to hydrogen have been calculated from measurements since early in 1993 based on the online gas chromatograph (GC) and the FTIR. The measurements can be used to compare the release of waste gases during different tank activities.

The period from February to June 1993 (between events H and I) was evaluated to provide baseline gas release behavior to compare with that during mixer pump operations. The average concentrations of hydrogen, nitrous oxide, and ammonia during this period were reported to be 19.1 ppm, 20.7 ppm, and 44.98 ppm, respectively.^(g) (nitrogen (N₂) is also an important portion of the gas released from

(f) Memo, D. A. Reynolds to N. W. Kirch. July 22, 1993. "Gas Composition of 101-SY from the June 1993 Event." IM 7E100-93-090, Westinghouse Hanford Company, Richland, Washington.

(g) Letter, R. T. Allemann (PNL) to J. W. Lentsch (WHC). July 1, 1993. "Updated Report Tank 101-SY Gas Analysis and Waste Level Baseline."

the waste.) During this baseline period, the ratio of concentrations of nitrous oxide-to-hydrogen was slightly greater than 1.^(h) There was only one GRE (May 26) in which hydrogen exceeded 100 ppm, which is an indication that the gas came from deep in the tank.

The ratio of ammonia to hydrogen concentrations during the baseline period varied significantly because of fluctuations in the ammonia concentration about the mean. Early in the baseline period, the ratio of ammonia to hydrogen was about 2.⁽ⁱ⁾ However, as the June 1993 event approached, there were more periods when the ammonia-to-hydrogen ratio was between 3 and 4. During the small gas release on May 26, the ammonia-to-hydrogen ratio dropped to approximately 1.

During the June 1993 GRE, the peak concentrations of hydrogen, nitrous oxide, and ammonia were 3.12%, 3.25%, and 1.3%, respectively (Wilkins 1993). The ratios of nitrous oxide-to-hydrogen and ammonia-to-hydrogen concentrations during the event were 1.04 and 0.4, respectively. Updated FTIR concentrations for nitrous oxide (2.9%) and ammonia (1.4%) decrease the nitrous oxide-to-hydrogen ratio to slightly below 1 for this event.^(j)

The ratios of nitrous oxide to hydrogen and ammonia to hydrogen during the periods since the mixer pump operations were initiated are shown in Figures 2.2 and 2.3. Figures 2.4 and 2.5 show the ratios versus the hydrogen concentrations.

The nitrous oxide-to-hydrogen concentration ratio varies only slightly. It appears that during steady-state release ($H_2 < 50$ ppm), the ratio is slightly above 1. During the release of gas from deep in the waste ($H_2 > 100$ ppm), the ratio drops to slightly below 1.

The ammonia-to-hydrogen ratio is more variable. During steady state ($H_2 < 50$ ppm), ammonia is being released without being coupled to the hydrogen and is fairly constant due to the soluble ammonia being released at the surface by diffusion through the crust. Nearly constant ammonia release would certainly increase the ratio when the hydrogen gets low, as seen in Figure 2.4. When hydrogen is released from deep in the waste ($H_2 > 100$ ppm), the ratio becomes nearly constant at about 1. This suggests that, in this case, the ammonia present in the hydrogen bubbles due to its equilibrium vapor pressure is being released with those bubbles.

(h) Recent recalibration of the FTIR suggests that the ratio of nitrous oxide to hydrogen concentration is about 1.4.

(i) Letter, M. R. Kreiter (PNL) to J. W. Lentsch (WHC). April 23, 1993. "Tank 101-SY Gas Analysis and Waste Level Baseline."

(j) Memo, J. R. Stephens to J. N. Edwards. January 14, 1994. "Summary of NH_3 , N_2O and CH_4 Concentrations."

Tank 241-SY-101 Nitrous Oxide/Hydrogen Ratio

Figure 2.2. Nitrous Oxide and Hydrogen Concentrations and Ratio

Tank 241-SY-101
Ammonia/Hydrogen Ratio

Figure 2.3. Ammonia and Hydrogen Concentrations and Ratio

Tank 241-SY-101
Nitrous Oxide/Hydrogen Ratio

Figure 2.4. Nitrous Oxide-to-Hydrogen Ratio versus Hydrogen Concentration

Tank 241-SY-101
Ammonia/Hydrogen Ratio

Figure 2.5. Ammonia-to-Hydrogen Ratio versus Hydrogen Concentration

2.2 Gas Volume Barometric Correlation

The volume of gas retained in the waste can be calculated by measuring the change in the level of the waste in the tank due to the expansion and contraction of the gas due to atmospheric pressure changes. Using measurements after the April 20, 1992, event, but mostly during May 1992, a retained gas volume of about 18,000 ft³ at one atm was calculated based on the following analysis:

If the gas retained in the waste is assumed to be ideal and isothermal, then

$$PV = \text{Constant}$$

If the atmospheric pressure change is transmitted to the in situ gas volume, the change in volume is related to the pressure change by

$$dV = -\frac{dP}{P^2}$$

Since a change in level is proportional to a change in volume,

$$d\text{Level} = dL = \frac{dV}{A}$$

Combining and solving for volume gives

$$V = -PA \times \frac{dL}{dP} = -2 \times 29.92 \text{ in. Hg} \times \frac{4418 \text{ ft}^2}{12} \frac{dL}{dP} = -22 \times 10^3 \frac{dL \text{ in.}}{dP \text{ in. Hg}}$$

where P = pressure of gas in situ, atmospheric

V = volume of gas in situ, ft³

L = liquid level in tank, inches

A = cross-sectional area of cylindrical tank, ft²

Thus the volume of the gas assumed to be at two atm can be obtained from the last equation if the slope term, dL/dP, can be obtained from the data on level and barometric pressure. The data on level have only recently been recorded continuously for the radar gauge. At this time the gas pressure was assumed to be at two atm, based on the properties of the waste. Subsequent analyses use lower pressures, down to 1.5 atm, based on properties of the waste after the pump had caused some mixing and greatly increasing the amount (level) of the convective layer while reducing the amount of the nonconvective layer.

The calculated slope was -0.42 in./in. Hg $\pm$ 0.07 at a 95% confidence level based on the data taken after the April 20, 1992, using a statistical method. Figure 2.6 plots the data and the calculated slope. This slope yields a volume of 9,200 ft³ at two atm, which would expand to about 18,400 ft³ at

Figure 2.6. Correlation of Level Deviations with Dome Space Pressure Deviation (May 1992)

one atm. Because the slope was based on data taken after the April 20, 1992, GRE, the volume of that gas release (about 5000 ft³ at one atm) could be added to give a total of 23,400 ft³ present when it occurred.

Tank 241-SY-101 data from November 1993 were analyzed to determine if deviations in the tank head space pressure due to barometric pressure shifts induced surface level changes that could be used to calculate trapped gas volume. There were some large pressure changes in November, and it was hoped that these would influence the level enough that the gas remaining in the tank could be calculated, thus showing the effectiveness of the pump mixing mitigation tests. However, due to the very poor signal-to-noise ratio (estimated to be < 1 at most frequencies) in the data, it was not possible to obtain a reliable estimate of trapped gas volume. Estimates ranged from ~ 1100 ft³ of gas to ~ 8600 ft³, depending upon how the analysis was performed. This result does, however, suggest that the amount of gas is less than was predicted during a similar analysis in May 1992.

December 1993 data were also analyzed using extrema of the barometric pressure record. When all of the data from December are used, the estimate for the coefficient between level and pressure is -1.17 ± 0.24 inch/psi at the 95% confidence level, which suggests a trapped gas volume of $\sim 24,900 \pm 5100$ ft³ at one atm, assuming that the gas is held at $\sim$ two atm. If it is assumed that the gas is held at 1.5 atm, the estimate is $14,000 \pm 2900$ ft³.

These estimates are considerably higher than those developed from November 1993 data, which ranged from $\sim 1100 \text{ ft}^3$ to $\sim 8600 \text{ ft}^3$ of gas. There is some evidence that gas volume grew throughout December, as evidenced by the rise in tank level and the increase in the coefficient relating level and pressure. The coefficient between level and pressure was also estimated using two other methods; these estimates were within the 95% statistical confidence limits calculated by using only the extrema of the pressure record, suggesting that the estimate of $-1.17 \pm 0.24 \text{ inch/psi}$ is indeed reliable.

The estimated absolute pressure and radar level gauge measurement are shown in Figures 2.7 and 2.8, respectively. Extrema (local minima and maxima) in the pressure record are indicated in Figure 2.7. The levels at the corresponding times are indicated in Figure 2.8.

The parts of the pressure record in which the change in pressure between extrema was greater than 0.05 psi are shown in Figure 2.9. However, large shifts were experienced in the tank level during the first part of December (shown in Figure 2.8). Thus, part of the record was not used in the final analysis, as shown in Figure 2.10, where the unused part is shown as a dashed line.

The remaining samples (18 in all) are plotted in Figure 2.11, which shows the change in level versus the change in pressure between each pair of extrema. The best fit line through the data indicates that the coefficient between level and pressure is $-1.17 \pm 0.24 \text{ inch/psi}$ at the 95% confidence level, suggesting a trapped gas volume of $\sim 24,900 \pm 5100 \text{ ft}^3$ at one atm assuming that the gas is held at $\sim$ two atm. If it is assumed that the gas is held at 1.5 atm, the estimate is $14,000 \pm 2900 \text{ ft}^3$.

It is also possible to estimate the coefficient between pressure and level changes using all the data and a constant time difference by calculating the change in level divided by the change in pressure over a fixed time interval. In this analysis, however, the coefficient calculated then becomes a function of the time interval considered, as shown in Figure 2.12. Data taken from December 9 through December 31 were used in this calculation. In addition, the apparent spikes in the level data record on December 13 and 15 were smoothed over. Figure 2.12 demonstrates that the calculated coefficient does vary with the time interval considered, from $-0.85 \text{ inch per psi}$ at long time lags to $-1.25 \text{ inch per psi}$ at 7 hours. This variation is not as great as seen in previous analyses (for instance, using data from November 1993, the coefficient varied from -0.1 to $-0.4 \text{ inch per psi}$). Note that coefficient determined from analysis of the local extremes in the pressure record above, $-1.17 \text{ inch per psi}$, lies within the values determined as a function of time interval and is approximately equal to the values determined using a 20-hour lag. It is also significant that all of the coefficients for lags between 1 and 100 hours fall within the range of $-1.17 \pm 0.24 \text{ inch/psi}$ calculated above.

The coefficient between pressure and level can also be estimated by fitting a line through the raw level-versus-pressure data. Trends in either data record due to other factors, such as an overall increase of retained gas over the period, can cause this analysis to give erroneous results. To improve the estimate, the data must be "detrended," i.e., a best fit linear trend is subtracted from both of the data records. The result of this analysis is shown in Figure 2.13, which shows the detrended level versus detrended pressure for December 9 to 31. Using this method, the coefficient estimated between level and pressure is -0.92 inch/psi , which is just at the lower bound (smallest absolute value) of the coefficient

Figure 2.7. Head Space Pressure History for December 1993

Figure 2.8. Radar Gauge Waste Level History for December 1993

Figure 2.9. Segments with Pressure Change in Excess of 0.05 psi Between Extrema

Figure 2.10. Segments Used for Analysis

Figure 2.11. Level Deviations Versus Head Space Pressure Deviations for December 1993

Figure 2.12. Level/Pressure Coefficient Versus Lag Time

Figure 2.13. Detrended Level Versus Head Space Pressure for December 1993

calculated using the extrema. Some offset of the data over the pressure/level swings is apparent in Figure 2.13; these offsets have the effect of decreasing the absolute value of the calculated coefficient. Thus we would expect that the true coefficient would be larger (in an absolute sense) than -0.92 inch/psi. We conclude that the estimate of $14,000 \text{ ft}^3$ is also consistent with this treatment.

2.3 Humidity

Measurements of the relative humidity allow investigation of the diurnal and long-term variations of waste water content. Of particular interest is determining periods of relative crust wetness and relating them, if possible, to concentrations of flammable gases in the dome space and vent streams. This relationship may demonstrate the effect of humidity on the mechanisms of flammable gas release.

The data of interest in this case include not only the relative humidity as measured in the dome space but also the ambient relative humidity and the dome and ambient temperatures. Using the dome and ambient temperatures, the relative humidity data may be converted to an absolute water (moisture) content, and a more accurate picture of relative water content (i.e., without the effect of temperature on relative humidity) may be gained.

Figure 2.14. Vent Stream Moisture Content History

The moisture content of the vent stream gas for the period including Phases A and B testing is presented in Figure 2.14. This indicates a period of relatively moist vent stream gas immediately following Event I (June 26, 1993). A particularly high value is noted following the water lancing that preceded pump installation. A slow decrease in moisture then continued through the end of Phase B testing. Brief increases in moisture often followed periods of waste surface movement and/or gas releases (e.g., August 27, September 17, and October 16).

Recording the above-tank ambient weather conditions that began in mid-September 1993 improved comparisons of in-tank and ambient humidities. The moisture content calculated from the vent stream and above-tank conditions for the period from October 1 to December 31, 1993, are shown in Figure 2.15. Their difference is also shown along with the timing of Phase B tests and pump bumps.

This difference is an indication of changes in waste water content. Positive differences (i.e., when the moisture content of the vent stream is larger than the ambient moisture content) indicate water is being removed from the tank. Conversely, negative differences indicate that water is added to the tank from the incoming ambient air. A difference in moisture content of $0.001 \text{ lb}_m \text{ H}_2\text{O} / \text{lb}_m \text{ dry air}$ over a one day period would transfer approximately 60 lb_m (28 kg) of H_2O to or from the waste. This is an important factor in the observed diurnal variation in gas concentrations discussed in the next section.

Figure 2.15. Tank Moisture Variation (October 1 to December 31, 1993)

2.4 Diurnal variation

On several occasions the concentrations of the three measured gases, hydrogen, nitrous oxide, and ammonia, regularly increased during the afternoon hours independent of pump activity. While these variations do not present a safety problem, understanding them may help improve models of flammable gas release.

Figure 2.16 presents the hydrogen (data from the GC3 instrument), nitrous oxide, and ammonia (data for both from the FTIR instrument) concentrations for approximately one week in October 1993, when only daily pump bumping took place. The timing of the pump bumps is also indicated in the figure. These data demonstrate the clear diurnal variation in gas concentrations mentioned above. Note that, even with changes in the time of pump activity, increases in the gas concentrations occur at approximately the same time of day. Although this variation is evident in all three of the measured gases, the magnitudes (especially the relative magnitudes) of the variations of hydrogen and nitrous oxide are larger than those of ammonia.

Because hydrogen and nitrous oxide are apparently contained in bubbles, the relative magnitude of the diurnal variation of these gases compared with that of ammonia suggests that the variation is related to changes in the rate of bubble rise from deep in the tank. If this were true, one would expect increases in the gas concentrations to be dependent only upon pump activity (or other behavior causing movement

Figure 2.16. Diurnal Variation in Gas Concentrations for a Week in October 1993

in the lower levels). Some additional mechanism is required to either release gas from the lower levels in phase with the observed diurnal variation or hinder the release from the upper levels once the pump activity dislodges bubbles from the sludge below.

Because it is unlikely that any natural release (i.e., that resulting from buoyancy effects) would occur at the same time every day, and because no other source of waste movement (excluding pump activity) is known, environmental changes in the dome space must be considered. Temperature, humidity, vent pressure, flow rate, and, of course, the gas concentrations demonstrated a clear diurnal variation. Of these, pressure and vent flow rate changes can be ruled out, because they are much too small to account for the observed variation in gas concentrations. (The observed diurnal pressure variations in the tank dome space are quite small compared with the absolute pressure.) It is also unlikely that the changes in temperature alone are responsible, because the variation is within a small enough range that phase changes or other dramatic morphological changes probably do not occur.

There is, however, a considerable correlation with humidity. A closer look at Figure 2.15 indicates a clear diurnal variation in the moisture content. These data are presented for the first week in October in Figure 2.17. Early in the week a consistent pattern occurs in the daily variation in the two air streams. During the early morning hours, moisture is removed from the tank. As the temperature

Figure 2.17. Diurnal Variation in Moisture Content (first week in October 1993)

of the ambient air rises, so does its ability to carry moisture. By mid-day, the water content of the air entering the tank exceeds that leaving through the vent stream, and water is being added to the waste. As the ambient air temperature drops in the evening hours, cold, dry air is added to the dome space, and moisture is removed from the waste.

The diurnal variation of moisture may affect the way that the bubble-released gases pass through the upper layers of the waste. Humidity may affect the pore size or membrane thickness in the porous structure or the rate at which the gases diffuse through the uppermost layer.

2.5 Pump-Induced Gas Release Trends

Gas release induced by pump bumping can be a useful indicator of waste behavior. During initial pump bump operations following installation of the pump, we observed that gas releases indicated by the GC3 and FTIR instruments could be correlated with pump operation by means of a delay time measured from the time the pump was started. Examples of typical gas release delay times for hydrogen are shown in Figure 2.18 and for nitrous oxide and ammonia in Figure 2.19.

Figure 2.18. GC3 Hydrogen Response to Pump Bump (8/29/93)

Figure 2.19. Gas Release Composition Resulting From a Pump Operation

The gas release response time for hydrogen, nitrous oxide, and ammonia for all pump bumps from July 4, 1993, through January 14, 1994, are shown in Figures 2.20, 2.21, and 2.22, respectively. The early low-speed (380-rpm), short-duration (8-second) pump bumps seldom created a detectable gas release because of the small volume of waste injected (about 100 gallons). In contrast, the high-speed (1000-rpm for five minutes) pump bumps introduced on July 26 disturbed the waste sufficiently (about 10,000 gallons) to create a clearly defined gas release signature. All three gas constituents showed similar time delay behavior until early August, when ammonia releases occasionally could not be discerned from the background ammonia concentration in the dome space. Hydrogen and nitrous oxide, however, consistently displayed similar time delay signatures in response to all pump bumps. The delay interval was greater for nitrous oxide, but this may be an artifact of the response time of the FTIR compared with the GC3 instruments.

Pump bumping consistently increased the volume of gas released from a few to several hundred cubic feet. But, on November 24, a suppression of hydrogen concentration appeared following the pump bump. The evidence of a suppressed hydrogen release is shown in Figure 2.23.

The beginning of the suppressed hydrogen behavior coincided with the end of Phase B sweep tests whose relatively long durations at moderate jet velocities were apparently quite effective in releasing gas from the waste in the region around the pump column. Subsequent high-velocity jet penetration tests did not exhibit the hydrogen suppression, and only increases in hydrogen concentration followed pump bumps through January. It may be that the background hydrogen release consists of a steady stream of bubbles rising in the vicinity of the pump column. During a pump bump, a large volume of this bubble stream

Figure 2.20. Pump-Induced Gas Release (H_2 response to pump bumps)

Figure 2.21. Pump-Induced Gas Release (N_2O response to pump bumps)

Figure 2.22. Pump-Induced Gas Release (NH_3 response to pump bumps)

Figure 2.23. Tank 241-SY-101 GC3 Hydrogen

is pulled into the pump suction and reinjected near the tank bottom. This interruption in the bubble stream could explain the hydrogen suppression and might also produce the later peak seen in Figure 2.23 when the reinjected bubbles reach the surface.

2.6 TEMPEST Pre-Test Predictions

Because of the sensitivity of a variety of unknown quantities and physical mechanisms, a very conservative approach was taken for estimating the amount of gas that might be released by the mixing pump operation. In the context of these predictions, "conservative" means making assumptions regarding unknown quantities that produce larger gas releases than might actually occur during pump operation. Based on a large number of computations, we believe the TEMPEST code overestimates the amount of gas released when a large release is expected and probably underestimates the amount of gas released in cases where only a small amount is expected.

Computed gas release estimates were found to be very sensitive to assumptions of the initial amount and distribution of gas trapped in the sludge layer.^(k) Sludge material properties such as

(k) Trent, D. S., and T. E. Michener. September 1993. *TEMPEST Calculations for Tank 241-SY-101 Mixing Pump Test - Safety Assessment Cases*. Letter report, Pacific Northwest Laboratory, Richland, Washington.

viscosity and yield strength, along with the mechanism of gas bubble migration, are thought to be equally sensitive aspects of gas release prediction. The predictions are based on results obtained using the following conditions:

Solids fraction:	0.47 (47%)
Liquid fraction:	0.53 (53%)
Liquid density:	91.00 lbm/ft ³
Bulk density:	112.15 lbm/ft ³ (no gas)
Gas fraction required to achieve neutral buoyancy:	0.188 (19%)

TEMPEST predicts a pump-initiated rollover if the sludge gas content is greater than 13 to 14% by volume. If the sludge gas content is less than about 13% by volume, pump-induced circulation will be confined primarily to the sludge layer, and the gas release rate, caused by bubble rise, will be small.

In those cases in which the pump initiates a rollover event, the process cannot be terminated by shutting down the pump. That is, once the event has started, it will carry through to completion using energy stored in the gas compressed by hydrostatic pressure. Energy supplied by the pump discharge initiates the rollover process, but beyond this contribution, provides only a minor contribution to the rollover energy. Sludge viscosity was found to influence the gas release rate rather than the total amount of release.

The potential gas release for the bounding case, with gas fraction of 0.188 (19%), was calculated to be about 14,600 ft³. This case assumes that the sludge contains the maximum possible amount of trapped gas, is therefore neutrally buoyant, and that the entire tank contents will roll over, producing the largest possible gas release. Assuming that the disturbed sludge retains a 6% gas volume fraction after a rollover event gives a release of about 10,000 ft³, which is equal to the largest observed historical gas release. Figure 2.24 compares TEMPEST predictions with "natural" historical releases as well as the later pump-induced gas releases.

Figure 2.24. Comparison of TEMPEST Predictions to Actual Gas Releases

3.0 LEVEL

Because the waste surface level is an important indicator of the inventory of stored gases, much attention has been focused on its measurement. Variations in waste level give insight to the dynamic behavior of the naturally occurring gas release cycle and other related waste phenomena. Waste level data are important for determining the current waste conditions and therefore play a critical role in assessing the safety of any tank operation.

A number of instruments provide data on surface level. These include the radar gauge, the FIC probe, a manual tape, and the two VDTTs. The radar gauge is an ultrasonic device. The data from it are recorded by the DACS system and provide fine resolution measurements. However, data from the instrument have sometimes been unreliable due to surface motion or changes in surface moisture content. The FIC gauge is a conductivity-based instrument. It gives reliable, although somewhat coarse resolution, data under most tank conditions. A known problem with the FIC gauge is the accumulation of waste on the tip of the instrument, which results in larger-than-expected values to be recorded. The instrument is flushed periodically to reduce this bias. The manual tape provides another measurement of surface level based on surface contact. This device also has the waste accumulation problem and is periodically flushed. The in-tank video equipment also allows a visual indication of the waste surface level referenced to the markings on the two VDTTs. The discussion here will rely heavily on the measurements from the FIC gauge because of its reliability and continuity of the data.

Surface level trends for the interval from June 23, 1993, to January 20, 1994, are shown in Figure 3.1. This interval can be divided conveniently according to changes in the surface level behavior. These shorter periods are summarized in Table 3.1, including the approximate dates, level growth rate and total level change observed. An expected level change is also given for reference. This quantity is the product of the historical baseline growth rate (0.08 inches/day) and the number of days in the period.

The first period began just after Event I and was characterized by very little growth compared with the historically observed rate. This is consistent with previous observation that very little surface level growth occurs immediately following a gas release.

The second period preceded the August 27 gas release. Except for the pump activity, the surface level rise would be expected to follow the historical rate during this period. Pump activity during this period consisted of five-minute, 1000-rpm pump bumps which typically occurred twice daily. This increased the daily gas releases and resulted in a lower average level growth rate and a smaller change in level over the period.

The third period followed the August 27 GRE. This period, like the first, was characterized by very little growth in surface level. Pump activity consisted of daily five-minute, 1000-rpm bumps. Again, the slow growth during this period can be attributed partially to typical behavior following a

Figure 3.1. Surface Level Trends

Table 3.1. Surface Level Trends

Period	Start	End	Actual rate of Growth	Expected Change in Level	Actual Change in Level	Pump Activity
1. After Event I	7/8	7/31	0.00	1.8	0.1	Bumps Phase A
2. Before 8/27	8/1	8/26	0.06	2.0	1.5	Bumps
3. After 8/27	8/28	9/17	0.02	1.6	0.4	Bumps
4. Pre-Phase B	9/18	10/20	0.06	2.6	1.9	Bumps
5. Phase B	10/21	12/17	-0.07	4.6	-4.0	Phase B, Bumps
Total				12.6	-0.2	

gas release and partially to enhancement of gas release due to the pump activity. However, it was clear during this period that the pump bumps were having less impact on the daily gas releases than had been initially observed.

The fourth period preceded Phase B testing. The rate of surface level increase during this period was slightly below that observed historically and was very similar to that observed during the second period. As with the third period, pump activity consisted daily five-minute, 1000-rpm bumps. By this point, the enhancement in daily gas release rate had approached a nearly steady amount (see Figure 1.3), and the growth was sustained at a constant rate over the period.

The most dramatic changes in surface level occurred during the fifth period, Phase B testing. Pump activity included the Phase B tests and pump bumps, which occurred two to five times weekly. Because the pump activity included long-duration, high-speed tests and new nozzle orientations, substantial increases in the daily gas releases were observed (see Figure 1.3). For the first time, the daily gas release rate actually exceeded the historical gas-generation rate. This resulted in a decrease in the retained gas inventory and a decrease in waste surface level. The total drop in waste surface level during the period of Phase B testing was approximately four inches, compared with an expected increase (based on the historically observed rate) of 4.6 inches without pump activity. This is a clear indication of pump efficacy during this period.

The net change in surface level for the entire period (from immediately following Event I to the end of Phase B testing) was actually a small decrease. This is quite remarkable, considering that the historically observed level growth rate would have predicted a 12.6-inch increase over this same time, yet the largest daily gas release observed was well under 1000 ft³ (except for the release of 2200 ft³ on August 27). Thus the waste surface level remained well under the imposed safety limits without an excessive episodic release event. This is a strong indication that mixing the waste by pump activity is an effective means of mitigation.

4.0 TEMPERATURE

4.1 Waste Temperature

The temperature of the waste is monitored by thermocouples attached to the two MITs located in risers 17B and 17C. Twenty-two thermocouples are arranged along each MIT, the lowest approximately four inches from the bottom of the tank, the highest thermocouple near the waste surface (402 inches above tank bottom for MIT 17B, 425 inches for MIT 17C). Details of the thermocouple locations are given in Section 7.2. Readings from MIT 17C have not been reliable, so most of the information has been obtained from 17B. A two-dimensional display of the full temperature history at the 17B MIT from June 23, 1993, to mid-January 1994 is shown in Figure 4.1. Also refer to Figure 1.5 for detailed response of the temperature profiles to the various GREs.

The GRE of June 25, 1993, served to nearly homogenize Tank 241-SY-101 waste temperatures in the vicinity of MIT 17B, with only a small nonconvective region present at the July 3, 1993, pump installation (Figure 1.5f). A parabolic temperature profile slowly reestablished itself at MIT 17B but not at 17C. Although 17C was out of calibration, it provided indications of large changes in waste configuration. For example, the major GRE of August 27, 1993, homogenized the waste in the vicinity of 17C with little effect on 17B, as seen in Figure 1.5c and d.

By mid-October the 17B profile resembled the pre-GRE parabolic profile, although it did not exhibit the typical pre-GRE distinct demarcation between convective and nonconvective regions. In the past, the convective region would appear near-isothermal, indicating a fluid waste, while the nonconvective, lower region of heavier waste would exhibit a parabolic temperature profile that suggested lack of mobility and heat loss only via conduction. Apparently, the mid-October 1993 profile, with a flattened, enlarged parabolic profile, resulted from the daily, five-minute pump bumps that were being performed then. The overall MIT 17B average waste temperature then (about 117°F) was equal to the June 25, 1993, average.

A small GRE on October 16, 1993, caused the temperatures at 17B to decrease in the 150—310-inch region and to increase above 310 inches, as shown in Figure 1.5f. The average temperature at 17B fell then by nearly a degree. Thus the temperature profile just prior to Phase B pump operation (initiated on October 21, 1993) was a somewhat modified pre-GRE profile; the chief difference from previous profiles was a hotter convective region.

The first ten days of Phase B testing had only a minor effect on temperatures. The mild GRE preceding the level swell event of October 25 had essentially no effect on the temperature profile; however, the GRE of November 2, 1993, caused substantial (5°F and greater) temperature changes (see Figure 1.5g and h) at 17B. These changes appear to have been mainly a loss of heat from the 75—325-inch layer to the 325—400-inch layer as the gas release/overturn event progressed. The upper thermocouples were the first to show a change, with a temperature increase evident immediately after the GRE. A corresponding temperature drop in the lower thermocouples did not become evident until about

Tank 101SY Temperature History for 1993

Figure 4.1. Full Temperature History at the 17B MIT (June 23-mid-January 1994)

30 minutes later. The average temperature at 17B also dropped by about 1°F. Investigations of the average temperature histories since 1990 do not indicate any noticeable seasonal variation, so changes in average temperature can be attributed to mixing.

Continued Phase B pump operation had only a small immediate effect (temperature profiles before and after pump operation indicated only small perturbations, irrespective of pump nozzle orientation). Little temperature perturbation can be expected from mixing a near-isothermal waste. But pump operation had the desired long-term result of making the waste nearly isothermal by November 19, 1993. With the disappearance of the "bulge" in the temperature profile in the lower region, the waste was essentially isothermal throughout the 50—300-inch level (see Figure 1.7). This near-constant profile provides clear evidence of pump efficacy in mixing the waste.

4.2 Bottom Thermocouple Temperatures

Twenty-four thermocouples are attached to the Tank 241-SY-101 bottom. Their original function was to monitor steel temperatures during tank construction and heat treatment. Twelve of these thermocouples were converted to the DACS during the testing period with temperatures recorded every five minutes to within $\pm 1^\circ\text{F}$. Data for several bottom thermocouples have been plotted for October 1993 in Figure 4.2. Figure 4.3 shows the ambient air temperatures over this time period. Perusal of these data reveals no clear trends. One could infer some response to the October 25 GRE, and there also appears to be a weak dependence of bottom temperatures on ambient air temperature. But, in either case, the data are inconclusive.

Temperature trends and correlations would be easier to discern with the temperature resolution at 0.1°F . Figures 4.4 and 4.5 show temperatures recorded to tenths of a degree by the Wavetek instrument prior to DACS installation. It appears that one or more thermocouples responded after the GREs of September 3, 1992, and February 2, 1993. Had these data been recorded in integer degrees, the effects would probably have been masked. The bottom thermocouples were never intended to record small temperature changes and are not very useful as indicators of waste condition or pump mixing effects. However, it is necessary to record these data to $1/10^\circ\text{F}$ to extract the information they might contain.

Figure 4.2. Bottom Temperature History for October 1993

Figure 4.3. Ambient Air Temperature History (October-December 1993)

Figure 4.4. Wavetek Bottom Temperature History (August-September 1992)

Figure 4.5. Wavetek Bottom Temperature History (January-February 1993)

5.0 STRAIN GAUGES

5.1 Time History Results

Strain gauges are installed on several tank components that can potentially respond to pump operation. The initial motivation for applying strain gauges to tank components was to monitor structural integrity during tank rollovers and to investigate fatigue concerns (i.e., flow-induced vibration of components due to waste flow). To date, observed strain levels have not been sufficient to cause structural concern. While the primary reason for the strain gauges was safety-related, some insights into pump jet penetration distance can perhaps be obtained by studying the magnitude and orientation of these strains during pump operation.

The strains caused by flowing waste are very small (usually 10 to 50 microstrain) compared with those typically found in most strain gauge applications. Signal drift may exceed the true strain value in many cases. The accuracy of this strain gauge measurement system has not been evaluated. For this reason, results should be considered to be both approximate and uncertain. Yet, because of the potential insight that can be obtained, much interest has been focused on these data.

Figure 5.1 shows the tank components to which gauges were applied and the orientations of those gauges. All gauges illustrated are oriented to measure axial strain. Each of the two MITs has two gauges, 90° apart. These gauges (17C01, 17C02, 17B01, and 17B02) are oriented to be in line with the pump center, as shown. The VDTT in riser 1B has three gauges designated 1BA01 through 1BA03. These gauges are equally spaced (120°) around the circumference of the VDTT, with the gauge nearest the pump oriented 18° counter-clockwise from the pump center. The pump column has four strain gauges (12A01 through 12A04) equally spaced around the circumference as shown in Figure 5.1. Underlined numbers in the figure represent the approximate vertical distances between gauge elevations and the component bottoms.⁽¹⁾ Details of strain gauge orientation and location are given in Section 7.3.

For 16 tests during Phase B, the nozzles were pointed directly at one of the MITs or the VDTT. Table 5.1 summarizes the strain gauge results of these tests. Strain levels were estimated from time-history plots, and the direction of the resultant bending moment was assessed. These estimates assume that component loading was predominantly transverse, and that component deflections were caused by changes in strain due to pump action. Indicated strain levels existing prior to the pump startup were assumed to have been caused by instrumentation drift.

To get some physical feel for reported strain values, the equivalent static tip force and tip displacement required to develop this strain were also calculated and reported. Beam models used for these calculations were simplified models of the actual components. The components were assumed

(1) Drawings documenting strain gauge orientations and positions are WHC drawings H-2-81506 Rev.1, H-2-85123 Rev.1, and H-2-89964 Rev.0.

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

Figure 5.1. Strain Gauge Location and Orientation in Tank 241-SY-101
5.2

Table 5.1. Phase B Component Strain Summary

TEST #	PUMP RPM	PUMP ORIENTATION (DEGREES)	COMPONENT	APPROXIMATE PEAK MICROSTRAIN	BENDING MOMENT (IN #)	PSEUDO TIP FORCE (#)	PSEUDO TIP FORCE DIRECTION (TOWARDS)	PSEUDO TIP DISPLACEMENT (IN)
1	360	35	VDTT (1B)	NONE				
			MIT (17C)	NONE				
2	510	35	VDTT (1B)	NONE				
			MIT (17C)	NONE				
3	720	35	VDTT (1B)	100	5090	10	SW	4.9
			MIT (17C)	10	502	1.1	SE	0.41
			MIT (17B)	15	750	1.6	N	0.6
4	920	35	VDTT (1B)	70	3600	7	S	3.4
			MIT (17C)	NONE				
6	360 to 920	95	MIT (17B)	NONE				
10	750	35	VDTT (1B)	30	1548	3	S	1.45
			MIT (17C)	10	502	1.1	SE	0.41
12	750	95	MIT (17B)	NONE				
12B	750	95	MIT (17B)	NONE				
16	750	SWEEP	VDTT (1B)	30	1548	3	S	1.45
			MIT'S	NONE				
17	750	SWEEP	VDTT (1B)	25	1290	2.5	S	1.23
			MIT (17C)	10	502	1.1	SE	0.41
18	750	SWEEP	VDTT (1B)	30	1500	3	S	1.45
			MIT'S	NONE				
19	750	SWEEP	VDTT (1B)	25	1290	2.5	S	1.23
			MIT'S	NONE				
20.1	920	35	VDTT (1B)	35	1806	3.5	S	1.7
			MIT (17C)	NONE				
20.3	920	95	MIT (17B)	NONE				
21.1	920	35	VDTT (1B)	25	1290	2.5	S	1.23
			MIT (17C)	NONE				
21.3	920	95	MIT (17B)	NONE				

to be clamped at the strain gauge elevations and loaded transversely at the lower end. Calculated tip forces and displacements are thus intended only to be representative of actual loads and displacements that might create the strains measured.

As can be seen in Table 5.1, strain levels and corresponding tip deflections and forces are extremely low and must be interpreted in view of potential lack of measurement accuracy. For pump orientation of 35° , the VDTT and MIT 17C are being acted upon by opposed jets. For pump orientation of 95° , the MIT in riser 17B is aligned with a pump nozzle. One curious result is that the 17B strain gauges responded most during test B-3 when the pump was at 35° due to forces apparently pushing northward. Another curiosity is that the pseudo tip force direction corresponding to VDTT loadings indicated that it was being pushed southward. The actual gauge values for the VDTT apparently are opposite in sign to those reported, because a reversal occurring during replacement of an amplification stage was overlooked.^(m) While this is relevant for determining force direction, it is relatively unimportant in fulfilling the original intent of the strain gauge application, which is monitoring VDTT fatigue response and deflection magnitude.

5.2 Spectrum Analysis Results

In an effort to see if the pump jet was reaching the outer regions of the tank, gauge responses of the two MITs were scrutinized. Because time history of these readings did not reveal any definitive effect of pump action during the latter tests of Phase B, Fast Fourier transform (FFT) analyses were performed on strain gauge signals to see whether vortex shedding frequencies might lie hidden in the data. The first two vortex shedding frequencies for the MIT were calculated to be about two and eight Hz. Gauge data from Phase B tests B-21.1 and B-21.3 were used in these investigations.

During test B-21.1, about 20 minutes of strain gauge data were taken for the VDTT in riser 1B. The sampling rate was at 20 Hz, and all three gauges were recorded. The VDTT gauges clearly responded to pump action with a strong signal in this situation. Several different windows were investigated with FFT techniques within the 20-minute span, revealing a small spike at about 6 Hz. The same spike was present on all three gauge spectra, but it is not certain whether this is due to mechanical strain or electrical noise.

One interesting feature is that the signal that produced the peak did not start until about 170 seconds after pump startup but remained active throughout the rest of the data. This time lag may represent the time for the jet to penetrate to the VDTT. Time-history and spectrum plots (for gauge 1BA01 only) are shown in Figures 5.2 and 5.3.

During test B-21.3, the pump nozzle was pointed directly at riser 17B. About 20 minutes of data (50-Hz sampling rate) were taken and analyzed. Regrettably, only one of the two gauges (gauge 1) was

(m) Friley, J. R. February 17, 1994. Personal communication with Jim Bussell, Westinghouse Hanford Company, Richland, Washington.

Figure 5.2. Time History Plot of Strain for VDTT Gauge 1BA01, Test B-21.1

Figure 5.3. Partial Spectrum of VDTT Gauge 1BA01, Test B-21.1

recorded. The signal was very small in the time domain—only about 0.3 microstrain peak to peak. The step-like nature of the analog-to-digital conversion process was clearly visible at this level. Two peaks were found at about 4 Hz and 10 Hz. As was the case with the VDTT indications, the 4-Hz component did not appear until about 170 seconds into the sampling period, but the 10-Hz signal was fairly constant throughout. However, it is very likely that these peaks are electrical, not mechanical, in nature.

5.3 Potential Effect of Bottom Sludge and Tank Crust on MIT Strain Levels

For some time, gauge indications of both MITs have been scrutinized for indications of jet penetration to the outer regions of the tank. From Table 5.1 it appears that strong gauge readings have not been observed for MIT 17B since test 3 and for MIT 17C since test 17. It is possible that, even though the jet might be penetrating to the MITs, the probes might be fixed, due to either sludge at the tank bottom or crust at the top of the waste (or both), limiting strain levels to less than those that can be readily detected by the current instrument system. A layer of sludge four feet deep with a yield strength of 1 psi could support over 100 lb of force on a three-inch-diameter MIT. This section reports estimated strains that the components might see for realistic loads under several conditions of constraint by the waste.

Loading was assumed to correspond to hydrodynamic drag induced by a pump nozzle velocity of 60 fps. A drag load (acting radially outward from the pump location) of approximately 14 pounds on the MIT was calculated for this operating condition.⁽ⁿ⁾ This load was assumed to act in a concentrated fashion approximately six feet from the bottom of the probe. Structural stiffness of the internal components of the MITs was neglected. Fixity caused by either the crust or the sludge was assumed to prevent local transverse motion but not local rotations (i.e., 'knife edge' supports were assumed). Calculated strains for several types of fixity are given in Table 5.2. It seems that unless instrumentation can resolve strains down to 4 microstrain, gauge indications cannot determine jet penetration distance if the MIT is restrained by either the crust or the bottom sludge.

Table 5.2. Estimated MIT Strain Levels for Various Levels of Waste Constraint

Crust Fixity	Sludge Fixity	Microstrain Level
No	No	45
No	Yes	4.0
Yes	Yes	0.2

(n) Approximate drag force loading was provided by Don Trent, Pacific Northwest Laboratory, Richland, Washington, in a personal communication with J. R. Friley.

6.0 PUMP PARAMETERS

6.1 Pump Description and Installation

The pump chosen for mitigation testing in Tank 241-SY-101 was originally purchased as a spare mixer pump for the Grout Program to mix the contents of staging tank that stored waste before it was to be converted to concrete. The Barrett, Haentjens & Co. Model 10" GN, Hazelton Type "SSB" pump was designed to discharge 2800 gpm of clear water through two opposed 2.6-inch- diameter nozzles at 114 feet of head. In its original configuration the pump suction and discharge nozzles were located at about 12 and 18 inches above the tank bottom, respectively.

The major modification accomplished for mitigation testing was to add downcomer piping to place the pump suction in the liquid layer at an elevation of about 20 feet while allowing the nozzles to discharge into the sludge layer 28 inches above the tank bottom (WHC 1992d). This unique configuration not only injects liquid into the waste at high velocity, but, because the injected liquid is less dense than the surrounding sludge, it also imparts a considerable vertical buoyant motion to the jet. Gas bubbles expand as they are lifted by the resulting vertical circulation and are more readily released at the surface.

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 selected for Phase B tests are shown on Figure 1.1. A detailed view of the pump motor and impeller assembly is shown in Figure 6.1. Instrumentation is described in Section 7.5.

Figure 6.1. Mixer Pump Motor and Impeller Assembly

6.2 Pump Performance Analyses

The Phase B test series was summarized in Table 1.1. Tests B-1-4 were short-duration tests run for a maximum period of 20 minutes. Tests B-5-9 were each run at four discrete speeds from 360 to 920 rpm. Most of the tests (tests B-10-19) occurred at 750 rpm; tests B-20.1-21.3 were performed at 920 rpm. Excerpts of the Phase B test plan are in Appendix B. The log of all pump operations from installation through mid-January 1994 is listed in Appendix C.

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, flow (output) power, and efficiency.

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

The average volute pressure and nozzle pressure for each Phase B test are plotted versus pump speed in Figures 6.2 and 6.3, respectively. The curve fits show that each of these pressures increases approximately as the square of the speed. This agrees with the pump affinity law that states that the pump head is proportional to the square of the pump speed.

Figure 6.2. Phase B Test Mixer Pump Volute Pressure Versus Pump Speed
(10/21/93 - 12/20/93)

Figure 6.3. Phase B test Mixer Pump Nozzle pressure Versus Pump Speed
(10/21/93 - 12/20/93)

6.2.1 Pump Power and Efficiency

Figure 6.4 shows the important pump performance parameters determined during Phase B testing. These consists of the averaged pump volute pressure, calculated motor input power, and calculated pump flowrate as a function of pump speed, all displayed as curve fits (data were plotted from the origin to allow for extrapolation). It is clear that the pump performance was highly repeatable.

The average pump motor input power, in horsepower (hp), is plotted against pump speed in Figure 6.5 for all of the completed Phase B tests. This curve fit shows that the pump input power increases approximately as the 2.6 power of pump. This trend reflects electrical losses imposed by use of a variable-speed drive, which is the reason for a deviation from a pump affinity law that states that pump power increases as the cube of the pump speed.

The pump flow power, output power, or hydraulic horsepower, defined as the rate of energy supplied by the pump to the waste, is shown in Figure 6.6 as a function of pump speed. Pump flow power is calculated from the product of pump volute pressure differential (volute pressure minus the static head) and flowrate with conversion to units of horsepower. The flowrate 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 third power of the motor speed.

Figure 6.4. Phase B Test Mixer Pump Performance (10/21/93 - 12/20/93)

Figure 6.5. Phase B Test Mixer Pump Input Power (hp) Versus Pump Speed (10/21/93 - 12/20/93)

Figure 6.6. Phase B Test Mixer Pump Flow Power (hp) Versus Pump Speed (10/21/93 - 12/20/93)

The partitioning of total power between motor heating and jet dissipation is described by the pump efficiency for Phase B test data shown in Figure 6.7. About 45% of the total motor input power is lost through cooling to the waste directly, while the remaining 55% is hydraulic power supplied at the jet nozzles and dissipated via jet mixing. At 750 rpm, for example, a total of 60 to 65 hp is input to the waste during pump operation, of which about 29 hp is motor cooling transferred to the waste as heat and about 35 hp is hydraulic power dissipated in the waste via jet mixing. Only the hydraulic power is able to suspend the sludge and maintain circulation.

Observations indicate that the waste level was essentially constant from November 16 to the end of Phase B testing on December 17. Until December 9 the pump was run at 750 rpm (corresponding to 35 hydraulic horsepower) at each of six positions for one hour on alternate days, and three-hour sweeps separated by an average 60-hour waiting period. After this the pump was operated mainly at 920 rpm (corresponding to 65 hydraulic horsepower) for 35 minutes in various directions every other day.

A total hydraulic energy of 1450 hp-hr was delivered to the waste during this 29-day period, yielding an average of 50 hp-hr hydraulic power each day. This level of intermittent pump operation was apparently sufficient to maintain a constant level over this one-month period. Pump operation after December 17 consisted only of directional bumps (five minutes at 1000 rpm in a different position every other day) delivering only about 2.8 hp-hr per day. This resulted in an apparent level growth, though at a lower rate than historically observed.

Figure 6.7. Phase B Test Mixer Pump Efficiency Versus Pump Speed
(10/21/93 - 12/20/93)

The energy imparted to the waste by the pump during Phase B testing did not raise its temperature significantly. The total pump energy input during the above 29-day period, consisting of both motor cooling and flow energy, averaged 9,640 Btu/hr (91 hp-hr/day), assuming 55% efficiency. This is approximately 20% of the total heat generated by the waste itself, estimated at 46,800 Btu/hr. If all other parameters were held constant, this would raise the average waste temperature about 0.8°F in one month, approximately equal to the measurement uncertainty.

6.2.2 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 would exceed the predetermined 190°F limit if more than one sweep position were tested consecutively.^(o) The temperature limit also caused minor difficulties for the 750-rpm tank sweep series unless prolonged pump-off times were enforced toward the end of the sequence.

The resistive losses in the stator excitation and rotor, bearing friction losses, and windage losses from rotor movement are responsible for heat generation. The harmonics from the variable frequency drive (VFD) require 5% more current than a pure sinusoidal current flow, increasing the resistive losses.

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

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 Phase B test data. Motor oil temperature versus time data from selected pump operations are curve fit in Figure 6.8 for 360, 750, and 920 rpm. A cross plot of the data for the oil temperature cutoff limit of 190°F (Figure 6.9) shows maximum pump operating time for any pump speed up to 1000 rpm; it shows that only 20 minutes of continuous operation are possible at 1000 rpm without exceeding the 190°F cutoff limit, while approximately 40 minutes are available at 920 rpm.

6.3 Pump-Bump Data Trend Analysis

This section describes results of a trend analysis of all 1000 rpm pump bumps through January 24, 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

Figure 6.8. Mixer Pump Predicted Oil Temperature Transient

Figure 6.9. Mixer Pump-On Time to Maximum Oil Temperature

any effect on the waste density. The first four bumps were not included in the trend analysis because water injection influenced the pressure and power during that period. A final period includes pump bumps following the Phase B testing.

The volute pressure is measured as a 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 6.10. A slight downward trend is apparent for the initial two-bump per day sequence with a slight upward trend in pump volute pressure results for the period up to the beginning of Phase B testing on October 21 (also to the beginning of the sweep tests on November 5 but not fitted). 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. 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. This change in density and volute pressure might result from ingestion of gas bubbles from the undisturbed waste into the pump inlet.

The averaged pump outlet nozzle pressures (measured in psid) are shown in Figure 6.11. Though the nozzle pressure is nearly constant, a slight downward trend in pump nozzle pressures can be seen during the two-bump per day period (until August 22). The trend continues at a lower rate until the start of the Phase B sweep tests. For the pump bumps during Phase B, the trend increases slightly. Following the Phase B test period, a small downward trend is again evident.

Figure 6.10. Average Pump Volute Pressure During Pump Bumps
(7/26/93 - 1/24/94)

Figure 6.11. Average Pump Nozzle Pressure During Pump Bumps
(7/26/93 - 1/24/94)

A perturbation analysis of pump affinity laws and pump electrical/hydraulic power results in the following two relations, which provide independent methods of determining the change in waste density due to mixing:

$$\frac{\delta \rho}{\rho} = \frac{\delta I}{I} + \frac{\delta V}{V} - 3 \frac{\delta N}{N}; \text{ from power data} \quad (1)$$

$$\text{and } \frac{\delta \rho}{\rho} = \frac{\delta \Delta P}{\Delta P_v} - 2 \frac{\delta N}{N}; \text{ from volute pressure data}$$

where ρ = waste density
 I = motor current
 V = motor voltage
 N = motor speed
 ΔP_v = pressure head (minus static head) at pump volute

A similar analysis of flow nozzle pressure drop and pump volute pressure relationships results in the following expression for a change in nozzle friction resistance coefficient (K):

$$\frac{\delta K}{K} = \frac{\delta \Delta P}{\Delta P_n} - \frac{\delta \Delta P}{\Delta P_v} \quad (2)$$

where the dimensionless changes in nozzle (n) and volute (v) pressure are measured values extracted from data and data trends.

Table 6.1 shows the results based upon trends in the variables I , V , N , ΔP_n , and ΔP_v determined from curve fits of the data. Interpreting these trends yields the following conclusions:

Prior to Phase B testing (26-day and 69-day periods)

- Waste density increases by 5 to 6% with circulation through the pump (mixing). Increased solids fraction at the pump suction elevation can explain this trend.
- Nozzle (exit jet) friction loss decreases with operating time. This effect may be due to a polishing effect (solids deposits) of the casting surface roughness initially present on the converging elbow shape upstream of the nozzle opening or a reduction in viscosity of the fluid as tank mixing proceeds.

Following Phase B testing

- Waste density decreases with circulation through the pump. This trend would be expected with an increase in bubble fraction at the pump suction elevation.
- Nozzle (exit jet) friction loss increased with time enough to offset the entire decrease prior to the Phase B test period. This observation might indicate that the waste solids fraction/viscosity trend observed prior to Phase B is followed by increased gas fraction effects subsequent to Phase B.

Table 6.1. Waste Density and Pump Nozzle Resistance Coefficient Changes

	$\frac{\delta \rho}{\rho}$ (from power data)	$\frac{\delta \rho}{\rho}$ (from volute pressure data)	$\frac{\delta K}{K}$ (from pressure data)
Initial 26-day period (2 bumps per day)	+5.2% in 100 days (+0.00052)	+2.1% in 100 days (+0.00021)	-2.8% in 100 days (-0.00028)
69-day period (one bump per day)	+5.7% in 100 days (+0.00057)	+3.5% in 100 days (+0.00035)	-2.6% in 100 days (-0.00026)
Following Phase B tests, 25-day period	-7.2% in 100 days (-0.00072)	-4.8% in 100 days (-0.00048)	+4.3% in 100 days (+0.00043)

Electrical power demand measured for each five-minute pump-bump is shown in Figure 6.12. 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. After Phase B testing was completed, a clearly defined trend of reduced power demand was observed as increased background gas release (increased void fraction) resulted in a decrease in waste density and/or waste viscosity at the pump suction.

Ultrasonic flowmeters, operating on the principle of Doppler-shift frequency relative to moving particles in a flow stream, were mounted on each of the downcomer pipes feeding the exit jet nozzles. These meters were installed to provide a qualitative indication of flow or verification of the lack of flow if the nozzles were plugged. Therefore, no attempt was made to develop a calibrated flow rate or quantitative measurement of volumetric flow—an extremely challenging task for meters of this type in slurry flow.

A record of the Doppler flow indication for all pump bumps is shown in Figure 6.13. The flow variable is not meant to convey accuracy or even a direct proportionality between volume flow rate and the Doppler signal. The Doppler signal is, however, a qualitative indication of gas bubble void content in the waste ingested at the pump suction. GREs induced by pump bumps and pump tests that exhibited increased void fraction at the pump suction are clearly indicated by Doppler signals immediately following GREs. Examples are seen on August 27, September 17, and October 25.

The marked increase in bump-induced Doppler signals following the end of the Phase B three-hour sweep tests and high-speed directional tests on December 17 resulted from an increase in gas bubble void. This is correlated by an increased background hydrogen release rate observed at the GC3 instrument. Previous background hydrogen measurements of 20 ppm were common during periods without pump operation but have consistently indicated approximately 30 ppm and higher during periods without pump operation subsequent to the end of Phase B testing on December 17.

Figure 6.12. Average Pump Input Power During Pump Bumps
(7/26/93 - 1/24/94)

Figure 6.13. Average Doppler Meter Indications During Pump Bumps
(7/26/93 - 1/24/94)

7.0 INSTRUMENTATION

The instrumentation in Tank 241-SY-101 has evolved with the need to know more about the characteristics of the waste and the effects of mixing. This section contains a summary of the instrumentation associated with current and future pump testing. These instruments monitor gas flow, composition, temperature, and pressure, plus waste temperature, level, and motion. Other tank farm operational parameters such as weather data and equipment trailer status are also recorded but are not discussed here.

There are currently over 200 individual sensors in and on Tank 241-SY-101 that are capable of sending information to the DACS.^(p) Figures 7.1 and 7.2 show the major instrument trees and sensors in the tank. The list of instruments used in Phase B mixer pump tests is given in Table 7.1.

7.1 Waste Level Measurement

Three separate instruments measure the level (height) of the waste surface in the tank: two conductivity probes and a radar gauge. The FIC probe is an automatic conductivity probe located in riser 1C. The FIC is lowered manually to establish the waste surface level once every eight hours. The FIC can be pre-positioned to transmit an electrical signal to the DACS should the waste rise and contact the probe at the preset level. Over many cycles, deposits form on the tip of the probe that must be flushed periodically to avoid a false high level indication. In clear liquid, the FIC is accurate to 0.1 inch, although due to irregularities in the crust surface and deposit buildup, accuracy is reduced to ± 2 inches.

The manual tape is a conductivity probe in riser 17A that is lowered into the tank daily. When the probe contacts the waste, the level is read and manually recorded to the nearest quarter of an inch. Similar to the FIC level measure, crust irregularities reduce the accuracy to ± 2 inches.

The most sophisticated level measurement device is the radar gauge located in riser 13A, which averages the waste level over an area of the crust. Readings are considered accurate to ± 0.08 inches (Ananthamula 1992). Unfortunately, the radar gauge is unreliable when the waste is in motion or the surface moisture content changes, such as during and following a GRE or aggressive pump activity. The radar gauge is controlled by a personal computer in Building SY-271 that reports readings to the DACS.

7.2 Waste Temperature Measurement

The temperature of the waste is monitored by thermocouples attached to instrument probes within the tank or on the tank itself. The tank contains two MITs located in risers 17B and 17C. Twenty-two thermocouples are arranged along each MIT, as listed in Table 7.2. The lowest thermocouple is approximately four inches from the bottom of the tank, while the highest thermocouple is near the waste surface (402 inches above the tank bottom for MIT 17B, 425 inches for MIT 17C).

(p) Westinghouse Hanford Company. 1992. *Tank 101-SY Hydrogen Mitigation Test Functional Design Criteria*. WHC-SD-WM-FDC-022, WHC, Richland, Washington.

Figure 7.1. Instrument Trees in Tank 241-SY-101

Figure 7.2. Riser Locations in Tank 241-SY-101

Table 7.1. Mixing Test Instrumentation/Automatic Data Recording Requirements

Parameter	Location	DACS Sampling Rate/Frequency	Requirement Status
Waste level	Riser 1C (FIC) Riser 13A (radar)	---- 12 sec	X ^a
Hydrogen concentration	Exhaust duct Pump Riser 16A (bottom) Riser 17B (bottom)	12 sec 12 sec 12 sec 12 sec	X ^b X ^b X ^b X ^b
Gas composition (SHMS grab sampling)	Exhaust duct Pump Riser 16A (bottom) Riser 17B (bottom)	Daily Daily Daily Daily	X X X X
Gas composition (FTIR)	Exhaust duct	10 min	----
Temperature distribution	Riser 17B (MIT) Riser 1B Riser 14A	12 sec 12 sec 12 sec	X ^c ---- ----
Hydrostatic pressure	Riser 1B (7 elevations) Riser 14A (7 elevations)	12 sec 12 sec	---- ----
Probe strain	MIT (Riser 17B) Riser 1B Riser 14A	25 Hz (equiv.) 25 Hz 25 Hz	X X X
Dome pressure	Riser 11B Riser 17B (MIT)	12 sec 12 sec	X ^c X ^d
Dome space / temperature	Vent header	----	X
Ventilation flow rate (high and low range)	Exhaust duct	12 sec	X
Exhaust humidity	Exhaust duct	12 sec	X
Video	Riser 5B	----	X
Ultrasonic density meters	Pump (2 locations)	10 min	----
Ultrasonic sludge interface sensors	Pump (4 locations)	10 min	----

Table 7.1. (contd)

Parameter	Location	DACS Sampling Rate/Frequency	Requirement Status
Flow (2 per discharge line)	Each discharge line	1 sec	----
Pump gas pressure	Pump column	----	X
Pump orientation	----	----	X
Pump operation / elapsed time	----	----	X
Pump moisture / oil	Pump motor	----	X
Pump discharge pressure	Pump volute	1 sec	X
Discharge pressure (2/discharge line)	Each discharge line	1 sec	X ^e
Motor current	Pump motor	1 sec	X
Motor voltage	Pump motor	1 sec	----
Motor power	Pump motor	1 sec	----
n strain	Pump support column	200 Hz	X
Pump discharge temperature	Each discharge line	1 sec	X ^f
Pump motor temperature	Motor oil	10 sec	X ^g
Pump speed (rpm)	Variable speed drive	Note h	X ^h

- (a) FIC is the primary gauge/radar alternate.
- (b) Whittaker cells (0-10%) at exhaust and pump locations and also at riser 16A and riser 17B locations. Gas chromatograph (0-1%) located at exhaust duct (GC2 and GC3 sampling rate every 10-12 minutes).
- (c) Individual thermocouples may be inoperable and still allow reasonable tank profile resolution, provided that no more than two nonadjacent thermocouples are out of service.
- (d) One of the two locations must be operable.
- (e) At least one operable on each discharge line. Does not apply to pump bump.
- (f) Applies to pump bump only.
- (g) Two instrument measurements available; one required. Does not apply to pump bump.
- (h) Two independent measurements of pump speed are required during low-flow operation. DACS sampling frequency tentatively set at one sample per second for pump bumping and one sample per 10 seconds for subsequent low-flow retesting.

Table 7.2. Sensor Location on MIT Instrument Probes

Sensor	MIT-17B Distance from Tank Bottom	MIT-17C Distance from Tank Bottom	Sensor	MIT-17B Distance from Tank Bottom	MIT-17C Distance from Tank Bottom
Strain gauge cluster	465.5"	465.5"	T/C #12	208"	208"
Lower gas inlet	432.1	n/a	T/C #11	196	196
T/C #22	402	425	T/C #10	172	172
T/C #21	392	402	T/C #9	148	148
T/C #20	364	392	T/C #8	124	124
T/C #19	338	364	T/C #7	112	112
T/C #18	316	340	T/C #6	98	98
T/C #17	292	292	T/C #5	76	76
T/C #16	268	268	T/C #4	52	52
T/C #15	244	244	T/C #3	28	28
T/C #14	232	232	T/C #2	16	16
T/C #13	218	218	T/C #1	4.6	4.6

Readings from MIT 17C thermocouples as recorded by the DACS have not been reliable because of a nonuniform (but apparently constant) offset. Manual readings have been taken since January 15, 1993. These readings, $\pm 1^{\circ}\text{F}$, uncalibrated, are useful for determining relative changes in temperature and seem to agree with readings from MIT 17B thermocouples.

There are twenty-four thermocouples welded underneath the primary tank shell, as shown in Figure 7.3. These thermocouples were originally installed to monitor heat treatment during tank construction. Two thermocouples in the annulus space between the primary and secondary tank are currently not functional. Twelve of these thermocouples (1—12) are currently connected to DACS, and readings are recorded every five minutes to within 1°F . Thermocouples 1—4 are on a seven-foot radius, and 5—12 are on a 21-foot radius. Examination of the data showed that thermocouples 6, 9, and 11 are giving erroneous readings, with indicated temperatures showing a spurious diurnal variation and often showing temperatures significantly higher than the 17B tree reading at the lowest thermocouple, which is about four inches above the tank bottom.

Figure 7.3. Thermocouples on Tank Bottom and Sides

Thermocouples were also installed in the VDTTs in riser 1B and 14A, but they are no longer functional and are disconnected from the DACS.

7.3 Waste Movement Measurements

Tank waste movement (caused by a GRE or pump operation) can potentially be determined using strain gauges attached to MIT 17B, MIT 17C, the pump column, and the two VDTTs. Figure 7.4 shows the placement and orientation of these strain gauges. The strain gauges were originally installed to determine if the trees were being bent. Detecting waste movement was a secondary benefit of the strain gauges. Each MIT has two strain gauges mounted at 90° relative to each other on the same horizontal plane, 463.5 inches from the bottom of the MIT.

Strain gauges are also located on the two VDTTs installed in riser 1B and riser 14A. Each VDTT contains a cluster of three strain gauges installed 120° apart on the same horizontal plane. The strain gauges on VDTT-1B are installed 506.6 inches from the bottom of the VDTT. The strain gauges on VDTT 14A are installed 478.6 inches from the bottom of the VDTT. The strain gauges on VDTT 14A have never been energized, because leakage of waste into the pressure sensors has created a potential safety hazard. (The wiring installed in the VDTTs is not Class 1 Division 1 NFPA [hazardous atmospheres]; therefore, the potential for a burn accident exists.) However, the strain gauges on VDTT 1B were energized and produced data during the test period.

The VDTTs were also intended to measure waste movement by a flowmeter (velocity probe) and fluid density transducers. These are currently not operational. The VDTTs are scheduled to be removed from the tank during the next fiscal year.

7.4 Dome Space Instrumentation

The tank dome space pressure monitoring system consists of a pressure transducer mounted on a 0.5-inch-diameter probe inserted in riser 11B. This transducer sends a pneumatic signal to a pressure to current (P/I) converter which feeds a direct current signal to a Hewlett Packard 75000 data logger and the DACS system. The transducer operates in the range of -4 to +6 inches of water gauge.

A pressure transducer also monitors tank pressure at MIT 17B, 507.85 inches from the tank bottom, and is connected to a pressure transmitter located in the Gas Monitoring System-1 (GMS-1) shed. This transducer has a gauge pressure range of -5 to +20 inches of water. From the GMS-1, the signal is sent to the DACS.

The dome space is kept under slightly negative gauge pressure by actively exhausting gas through the vent header located above riser 7A. Included in the vent header are a ventilation flowrate probe connected to a low range (0 to 1275 CFM) transmitter and a high range (-1000 to 7333 CFM) transmitter. A relative humidity probe and a temperature probe are also included in the vent header space. The transducers in the vent header send data to the DACS, and either a HP 75000 data logger or a Chessel strip recorder.

Figure 7.4. Orientation of Active Strain Gauges in Tank 241-SY-101

7.5 Mixing Pump Instrumentation

The mixing pump installed in riser 12A is heavily instrumented to record pump operating characteristics. The sensors also help to describe tank characteristics during times other than pump operation as shown in Figure 7.5.

Four strain gauges are located on the pump column, 90° apart in the same horizontal plane in the dome space above the waste surface. These gauges show pump deflection and can also detect low-frequency vibration caused by pump operation.

The amount of waste moving through the pump is determined by pressure and flow transducers. One pressure transducer is located near the inlet of each nozzle, and one near the outlet nozzle. Likewise, one thermocouple is located near the inlet of each nozzle, and one near the outlet nozzle to monitor waste temperature. A pair of ultrasonic Doppler flow sensors are mounted on each downcomer near the nozzles. These are intended only to indicate lack of flow if a nozzle is plugged and are not calibrated to record actual flow rate.

Other sensors, used only as status indicators, provide information during pump operation. On the submerged mixing pump, one sensor tests for moisture in the pump oil, two thermocouples monitor pump oil temperature, and a transducer senses pressure inside the pump assembly. On the riser above the tank, sensors monitor the pump position, pump rotational motor amperage, current, voltage, frequency, and speed. Additional operating parameters, such as mixing pump motor amperage, voltage, frequency and speed are all recorded by the DACS. These operating readings can be used to calculate the amount of energy the pump transmits to the tank.

7.6 Gas Monitoring Instrumentation

To determine gas composition, gas is drawn off the ventilation duct in the vent header and fed into an inlet manifold that leads to GMS-2. The vent header supplies four gas monitoring devices:

- a Whittaker electrochemical cell calibrated to detect hydrogen
- a gas sample grab bottle for laboratory analysis
- a high-resolution gas chromatograph calibrated for hydrogen at 2—100 ppm
- a wide range gas chromatograph calibrated for hydrogen at 100—50,000 ppm

Three more hydrogen monitors measure the concentration of hydrogen in the tank dome space. Standard hydrogen monitoring systems (SHMS) are located at risers 16A and 12A. Each SHMS is composed of a Whittaker electrochemical cell and a grab sample station. A Whittaker electrochemical cell is also sited in GMS-1, which draws samples from riser 17B. A molecular mass spectrometer (MMS) is also located in GMS-1 and samples gas from riser 17B.

Nitrous oxide and ammonia concentrations are measured by a FTIR. This instrument reflects full infrared spectra for each sample but is currently only being analyzed for N₂O and NH₃. The spectra can be reanalyzed for CH₄ and other gases; however, calibrations are required for these gases. The FTIR is located in the GMS-2 shed and samples from the vent header at riser 7A.

Figure 7.5. Mixing Pump Instrumentation

The gas composition data collected by the gas monitoring systems installed on Tank 241-SY-101 are not directly reported to the DACS. Data loggers located in the GMS record data that are periodically downloaded to the DACS.

7.7 In-Tank Video Camera

The waste surface is viewed with a black and white video camera and lights located in riser 5A and can record sudden surface movements during GREs. The camera enclosure is pressurized with an inert gas, nitrogen, to prevent any potential sparks from causing a safety problem in the tank. The pan and tilt controls and a 0.5-inch VHS video recorder are located in an equipment trailer outside the SY Tank Farm houses and in the DACS trailer. A unit that prints still pictures from the video tape is also located in the equipment trailer. The camera can run at normal speed or at variable speeds for time-lapse photography. Video is also displayed continuously in the "War Room" in the 2750 Building.

7.8 AMES Instruments

The AMES Echo Ranger, known more commonly as the AMES sludge monitor, was developed by researchers at the Ames Laboratory at Iowa State University. The AMES sludge monitor is intended to measure temperature and temperature difference and map the density of the sludge in the non-convective layer of the waste. The instrument uses a more sophisticated version of the ultrasonic transmitters/receivers found in common "fish finders" to characterize the waste. Three transmitter/receiver transducers, a thermistor for temperature measurement, and four ultrasonic range finders are mounted on the pump column in riser 12A. The AMES sludge monitor was not used during recent pump testing, although it may prove useful for future testing.

7.9 Data Acquisition, Control, and Quality

The DACS system consists of nine individual PCs networked together to perform specific tasks. The DACS hardware and software are located in the DACS instrument trailer near Tank 241-SY-101, although some computer terminals are located several miles away in the "War Room" in the 2750 Building. A partial list of the measurements that are automatically recorded and the sampling rates was given in Table 7.2.

In addition to automatically recording transducer signals from the tank, the DACS is also responsible for other cross checks. DACS compares current tank readings with predetermined minimum and maximum limits. When an individual signal falls outside of the boundaries, the DACS activates the appropriate warnings or abort systems. An example of this function is the mixing pump abort if hydrogen concentrations get too high or camera nitrogen purge is lost.

The DACS stores records to three decimal places, well beyond the actual resolution of the instruments. The most difficult factor to quantify is the accuracy of each reading. The accuracy of a single data point is a combination of many small errors introduced as data are transmitted from transducer to being recorded in the DACS. Errors are introduced by basic transducer inaccuracies, A/D conversion, signal conditioning circuits, and other factors. A complete error analysis has not been performed for each instrument.

Table 7.3 shows the best estimates of instrument resolution and accuracy available at the time this report was written. A complete list of calibration dates for instruments in Tank 241-SY-101 was not readily available. Documenting calibration and error estimates is the subject for continued investigation.

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Table 7.3. Estimated DACS Data Resolution and Accuracy

Physical Location	Data tag	Description	Signal	Range	Subrange	Resolution	Accuracy
12A	XIR12A03	TEMPERATURE AT 7.0 FT HEIGHT	RS232	0-100 DEG C			
12A	XIR12A04	TEMPERATURE AT 18.3 FT HEIGHT	RS232	0-100 DEG C			
12A	XIPNO301	DENSITY AT 7.0 FT HEIGHT	RS232	1.3-1.8 G/ML			
12A	XIPNO401	DENSITY AT 13.7 FT HEIGHT	RS232	1.3-1.8 G/ML			
1B	FIR01B01	FLUID VELOCITY AT LEVEL 24"	4-20 mA	0-20 FT/SEC		.005 ft/sec	
14A	FIR14A01	FLUID VELOCITY AT LEVEL 24"	4-20 mA	0-20 FT/SEC		.005 ft/sec	
1B	FIR01B02	FLUID VELOCITY AT LEVEL 48"	4-20 mA	0-20 FT/SEC		.005 ft/sec	
14A	FIR14A02	FLUID VELOCITY AT LEVEL 48"	4-20 mA	0-20 FT/SEC		.005 ft/sec	
12A	PITN0110	PUMP #1 NOZZLE TAP PRESS.	4-20 mA	-10 to 90 PSIG			
12A	PITN0111	PUMP #2 NOZZLE TAP PRESS.	4-20 mA	-10 to 90 PSIG			
12A	ZIMPE142	PUMP COLUMN GAS PRESSURE	4-20 mA	0-25 PSIG			
	WIR12A01	PUMP COLUMN STRAIN #1 45 DEG	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
	WIR12A02	PUMP COLUMN STRAIN #2 135 DEG	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
	WIR12A03	PUMP COLUMN STRAIN #3 225 DEG	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
	WIR12A04	PUMP COLUMN STRAIN #4 315 DEG	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
	XIR12AN2	PUMP COLUMN VIBRATION	+/- 10 Vdc	0-5 G'S			
12A	FIPNO202	PUMP DISCHARGE NOZZLE #1 FLOW 1	4-20 mA	0-1500 GPM		0.367 GPM	
12A	FIPNO201	PUMP DISCHARGE NOZZLE #1 FLOW 2	4-20 mA	0-1500 GPM		0.367 GPM	
12A	PIPNO201	PUMP DISCHARGE NOZZLE #1 PRESS 1	4-20 mA	0-150 PSIG		0.037 PSI	
12A	PIPNO202	PUMP DISCHARGE NOZZLE #1 PRESS 2	4-20 mA	0-150 PSIG		0.037 PSI	
12A	TIPNO202	PUMP DISCHARGE NOZZLE #1 TEMP 1	4-20 mA	32-212 DEG F		0.044 deg F	
12A	TIPNO201	PUMP DISCHARGE NOZZLE #1 TEMP 2	4-20 mA	32-212 DEG F		0.044 deg F	
12A	FIPNO101	PUMP DISCHARGE NOZZLE #2 FLOW 1	4-20 mA	0-1500 GPM		0.367 GPM	
12A	FIPNO102	PUMP DISCHARGE NOZZLE #2 FLOW 2	4-20 mA	0-1500 GPM		0.367 GPM	
12A	PIPNO101	PUMP DISCHARGE NOZZLE #2 PRESS 1	4-20 mA	0-150 PSIG			
12A	PIPNO102	PUMP DISCHARGE NOZZLE #2 PRESS 2	4-20 mA	0-150 PSIG			

Physical Location	Data tag	Description	Signal	Range	Subrange	Resolution	Accuracy
12A	TIPNO101	PUMP DISCHARGE NOZZLE #2 TEMP 1	4-20 mA	32-212 DEG F		0.044 deg F	
12A	TIPNO102	PUMP DISCHARGE NOZZLE #2 TEMP 2	4-20 mA	32-212 DEG F		0.044 deg F	
17B	WHF17B1B	STRAIN GAUGE 17B-1 HIGH FREQ AB	DIG	ON/OFF			
17B	WHF17B1L	STRAIN GAUGE 17B-1 HIGH FREQ AL	DIG	ON/OFF			
17B	WHF17B2B	STRAIN GAUGE 17B-2 HIGH FREQ AB	DIG	ON/OFF			
17B	WHF17B2L	STRAIN GAUGE 17B-2 HIGH FREQ AL	DIG	ON/OFF			
17C	WHF17C1B	STRAIN GAUGE 17C-1 HIGH FREQ AB	DIG	ON/OFF			
17C	WHF17C1L	STRAIN GAUGE 17C-1 HIGH FREQ AL	DIG	ON/OFF			
17C	WHF17C2B	STRAIN GAUGE 17C-2 HIGH FREQ AB	DIG	ON/OFF			
17C	WHF17C2L	STRAIN GAUGE 17C-2 HIGH FREQ AL	DIG	ON/OFF			
1B	WHF1B1B	STRAIN GAUGE 1B-1 HIGH FREQ AB	DIG	ON/OFF			
1B	WHF1B1L	STRAIN GAUGE 1B-1 HIGH FREQ AL	DIG	ON/OFF			
1B	WHF1B2B	STRAIN GAUGE 1B-2 HIGH FREQ AB	DIG	ON/OFF			
1B	WHF1B2L	STRAIN GAUGE 1B-2 HIGH FREQ AL	DIG	ON/OFF			
1B	WHF1B3B	STRAIN GAUGE 1B-3 HIGH FREQ AB	DIG	ON/OFF			
1B	WHF1B3L	STRAIN GAUGE 1B-3 HIGH FREQ AL	DIG	ON/OFF			
17B	WIR17B01	STRAIN GAUGE AT LEVEL 465.5"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
17B	WIR17B02	STRAIN GAUGE AT LEVEL 465.5"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
17C	WIR17C01	STRAIN GAUGE AT LEVEL 465.5"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
17C	WIR17C02	STRAIN GAUGE AT LEVEL 465.5"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
1B	WIR1BA01	STRAIN GAUGE AT LEVEL 530"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
1B	WIR1BA02	STRAIN GAUGE AT LEVEL 530"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
1B	WIR1BA03	STRAIN GAUGE AT LEVEL 530"	+/- 10 Vdc	+/- 684 uIN/IN		.334 uIN/IN	
11B	PIR11B01	TANK DOME PRESSURE	1-5 Vdc	-.4 TO 6 INWG		0.003 INWG	
17B	PIR17B04	TANK DOME PRESSURE (MIT)	1-5 Vdc	-.5 TO 20 INWG		0.006 INWG	
17A	n/a	TANK LEVEL AT MANUAL TAPE	n/a			0.25 in.	+/- 0.5 in.
13A	LIR13A01	TANK LEVEL AT RADAR GAUGE	0-3 Vdc	397-421.58 IN		0.01 IN	+/- 0.06 IN (est)

Physical Location	Data tag	Description	Signal	Range	Subrange	Resolution	Accuracy
17B	TIR17B01	TANK TEMP AT LEVEL 4 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C01	TANK TEMP AT LEVEL 4 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B02	TANK TEMP AT LEVEL 16 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C02	TANK TEMP AT LEVEL 16 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B03	TANK TEMP AT LEVEL 28 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C03	TANK TEMP AT LEVEL 28 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B04	TANK TEMP AT LEVEL 52 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C04	TANK TEMP AT LEVEL 52 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B05	TANK TEMP AT LEVEL 76 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C05	TANK TEMP AT LEVEL 76 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B06	TANK TEMP AT LEVEL 100 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C06	TANK TEMP AT LEVEL 100 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B07	TANK TEMP AT LEVEL 112 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C07	TANK TEMP AT LEVEL 112 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B08	TANK TEMP AT LEVEL 124 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C08	TANK TEMP AT LEVEL 124 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B09	TANK TEMP AT LEVEL 148 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C09	TANK TEMP AT LEVEL 148 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B10	TANK TEMP AT LEVEL 172 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C10	TANK TEMP AT LEVEL 172 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B11	TANK TEMP AT LEVEL 196 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C11	TANK TEMP AT LEVEL 196 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B12	TANK TEMP AT LEVEL 208 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C12	TANK TEMP AT LEVEL 208 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B13	TANK TEMP AT LEVEL 220 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C13	TANK TEMP AT LEVEL 220 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B14	TANK TEMP AT LEVEL 232 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	

Physical Location	Data tag	Description	Signal	Range	Subrange	Resolution	Accuracy
17C	TIR17C14	TANK TEMP AT LEVEL 232 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B15	TANK TEMP AT LEVEL 244 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C15	TANK TEMP AT LEVEL 244 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B16	TANK TEMP AT LEVEL 268 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C16	TANK TEMP AT LEVEL 268 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B17	TANK TEMP AT LEVEL 292 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C17	TANK TEMP AT LEVEL 292 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B18	TANK TEMP AT LEVEL 316 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17B	TIR17B19	TANK TEMP AT LEVEL 340 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C18	TANK TEMP AT LEVEL 340 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B20	TANK TEMP AT LEVEL 364 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C19	TANK TEMP AT LEVEL 364 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B21	TANK TEMP AT LEVEL 392 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C20	TANK TEMP AT LEVEL 392 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17B	TIR17B22	TANK TEMP AT LEVEL 402 IN.	.63 Vdc	12.5-325 DEG F	80-140 DEG F	0.077 deg F	
17C	TIR17C21	TANK TEMP AT LEVEL 402 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
17C	TIR17C22	TANK TEMP AT LEVEL 425 IN.	TYPE K	-148 to 2501	80-140 DEG F	1 deg F	
	TBSTC01	TANK TEMP BOTTOM - SIDE T/C # 1	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC02	TANK TEMP BOTTOM - SIDE T/C # 2	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC03	TANK TEMP BOTTOM - SIDE T/C # 3	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC04	TANK TEMP BOTTOM - SIDE T/C # 4	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC05	TANK TEMP BOTTOM - SIDE T/C # 5	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC06	TANK TEMP BOTTOM - SIDE T/C # 6	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC07	TANK TEMP BOTTOM - SIDE T/C # 7	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC08	TANK TEMP BOTTOM - SIDE T/C # 8	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC09	TANK TEMP BOTTOM - SIDE T/C # 9	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
		TANK TEMP BOTTOM - SIDE T/C #10	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	

Physical Location	Data tag	Description	Signal	Range	Subrange	Resolution	Accuracy
	TBSTC11	TANK TEMP BOTTOM - SIDE T/C #11	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC12	TANK TEMP BOTTOM - SIDE T/C #12	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC13	TANK TEMP BOTTOM - SIDE T/C #13	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC14	TANK TEMP BOTTOM - SIDE T/C #14	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC15	TANK TEMP BOTTOM - SIDE T/C #15	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC16	TANK TEMP BOTTOM - SIDE T/C #16	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC17	TANK TEMP BOTTOM - SIDE T/C #17	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC18	TANK TEMP BOTTOM - SIDE T/C #18	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC19	TANK TEMP BOTTOM - SIDE T/C #19	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC20	TANK TEMP BOTTOM - SIDE T/C #20	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC21	TANK TEMP BOTTOM - SIDE T/C #21	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC22	TANK TEMP BOTTOM - SIDE T/C #22	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC23	TANK TEMP BOTTOM - SIDE T/C #23	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC24	TANK TEMP BOTTOM - SIDE T/C #24	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC25	TANK TEMP BOTTOM - SIDE T/C #25	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
	TBSTC26	TANK TEMP BOTTOM - SIDE T/C #26	TYPE J	-148 to 2192 DEG F	80-140 DEG F	1 deg F	
V.H.	FTE50002	VENT HEADER FLOW HIGH RANGE	0-3.3 Vdc	-1000 to 7333 CFM		2.035 CFM	
V.H.	FTE50001	VENT HEADER FLOW LOW RANGE	1-5 Vdc	0-1275 CFM		0.312 CFM	
V.H.	MT10001	VENT HEADER RELATIVE HUMIDITY	1-5 Vdc	0-100% RH		0.025 % RH	
V.H.	TT10001	VENT HEADER TEMP	1-5 Vdc	30-140 DEG F		0.027 deg F	

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Appendix A

Excerpts from Test Plan for Tank 241-SY-101 Mitigation by Mixing

APPENDIX A

EXCERPTS FROM TEST PLAN FOR TANK 241-SY-101 MITIGATION BY MIXING

Purpose

The purpose of this test is to evaluate the ability of jet mixing to prevent or reduce the accumulation of gases generated in Tank 101-SY. There is evidence that significant quantities of gas remain in the tank even following a major "natural" gas release event (burp). Therefore, the test will also indicate the effectiveness of jet mixing in releasing this residual gas. Finally, the test will be utilized to evaluate the waste and tank hardware response to the mixing pump operation. For example, the extent of waste heating and foaming are of concern as are the hydraulic loads imposed on in-tank hardware (e.g., instrument trees). Information obtained from the test will be utilized to verify or improve computer code models of waste behavior and to determine whether jet mixing is a viable mitigation concept. If pump mixing is chosen from the mitigation options, then data obtained from the test will be utilized in the design of the long term mixing equipment.

Note that concerns about the potential for a large pump induced gas release have been raised. Therefore, testing of the mitigation-by-mixing option will be performed in several phases. The first phase, which is described in detail in this test plan, utilizes a very cautious approach to initial pump operation. Following completion of the initial test phase and a detailed review of the results, detailed plans for subsequent (more prototypic) pump testing will be developed.

Test Philosophy/Success Criteria

The following discussion applies to the overall mitigation test program, not just the initial phase described in detail in this version of the test plan. As described in Section 1.1, the initial test phase is intended primarily to evaluate whether pump operation does result in a significant gas release event as indicated by existing computer models.

The philosophy utilized in the development of the overall test plan is that mitigation only requires prevention of periodic releases that result in hydrogen concentrations that exceed 25% of the Lower Flammability Limit (LFL)^(a) at the tank exhaust. This criterion effectively limits the maximum quantity of hydrogen gas in the tank dome to well below the value that would cause significant tank structural damage and radiological consequences if it were ignited. The quantity of gas retained in the waste is not specifically addressed. Reduction in the retained gas inventory to some defined level may be required to eliminate this issue as an unreviewed safety question, although even this is not clear if the retained gas is in a stable (unreleasable) condition.

The mitigation testing baseline plan, (Appendix A), describes the plan for collecting data used to establish a baseline for Tank 101-SY mitigation employing existing instrumentation and instruments to be installed during the open window. Data will be established for dome space and vent header hydrogen concentration, rate of surface level change, waste density distribution, and rate of temperature change in the non-convective layer.

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

Consistent with the test philosophy, the two primary measures of success for this full-scale test are tank waste level and hydrogen concentration in the tank dome. These two indicators are discussed below.

Tank Level

Complete success would be indicated by a long term stable tank level below some acceptable value (e.g., 410 in.). This would imply that the gas release rate equals the gas generation rate and the periodic tank burps had been eliminated. Partial success would be indicated by a reduction in the rate of level rise between burps (historically about 0.09 in. per day). Although it is theoretically possible that a greater quantity of gas could be retained in the same or even a smaller waste volume, this is considered highly unlikely in the case of agitation of the waste by jet mixing.

Hydrogen Concentration

The overall mitigation objective is to prevent periodic gas releases that result in hydrogen concentrations which exceed 25% of the LFL (i.e., less than 0.75% hydrogen by volume). Measurements of the hydrogen concentration is thus a direct measure of the degree of success. Background hydrogen concentration data will also be useful in determining whether an unexpected increase in gas retention is occurring.

It should be noted that partial success may involve periodic gas releases of smaller magnitude than those which currently occur. For example, this could be the result of the mixing pump affecting less than the full tank radius. The degree of success of the test should be defined following complete evaluation of the test data rather than trying to define it a priori.

Summary of Test Conditions and Sequence

Preparations for this test include modification and installation of a submersible jet mixing pump in riser 12A, incorporation of special instrumentation and installation of a Data Acquisition and Control System (DACS). The DACS will also be utilized by a special test chamber that will be installed in the tank for additional mitigation testing following completion of the mixing pump test. Installation and initial checkout of this special hardware is covered by separate installation procedures. A Test Review Group (TRG) will be formed and will approve the Test Procedure and any changes to it. In addition, several hold points are defined at which the TRG will review the test data and decide whether to continue or terminate the test. Finally, if the test is aborted due to violation of any of the established abort criteria, an appropriate level of approval is required before restarting the test. The Test Director will be required to approve all pump startups, all increases in pump speed, and all operations to change the angular orientation of the mixing pump nozzles.

The test sequence will begin following a tank burp, when all prerequisites have been met. The initial test sequence will consist of short term/low speed pump operations intended to minimize the risk associated with the potential release of the gas remaining after a natural rollover. Detailed planning for the second test phase will be performed following a detailed review of the results of the initial phase.

Initial Low Flow/Short-Term Operation

1. Orient pump at 0° (i.e., discharge nozzles directed toward risers 5A and 5B). Orientation is defined as degrees of rotation clockwise from an east-west line.
2. Verify that the DACS is operational and recording the data specified in Table 1.
3. As soon as possible following insertion of the pump bottom nozzles into non-convective waste, the pump is to be operated in the following manner (pump bump); ramp-up to 380 rpm in four seconds, hold at 380 rpm for eight seconds, ramp-down at maximum rate to zero rpm/shutoff. Pump bumping is to be repeated daily until the formal initiation of low-flow operation is to commence. Temporary recording devices (if necessary prior to DACS hookup) are to monitor temperature sensors TIPNO101/102 and TIPNO201/202 with the recorded period encompassing the pump bump interval and extending from a minimum of one minute prior to initiation of the pump bump and a maximum of five minutes following cessation of the pump bump. If no flow is indicated, the pump speed limit may be increased for the bump operation, subject to approval by the TRG.

Approval is required by the TRG before low flow operation is to commence (step 4).

4. While monitoring downcomer flowmeters, ramp the pump from zero to 340 rpm in one minute, then shut pump off. Observe tank response, in particular hydrogen concentrations, dome pressure, ventilation flow rate and waste level.
5. Maintain the pump off until the hydrogen concentration returns to less than 0.2% (2,000 ppm) at all measured locations. A minimum 12 hour hold is required even if no increase in hydrogen is observed. Continue recording all data as specified for pump operation.
6. Repeat steps 4 and 5 but maintain pump operation at 340 rpm for 1, 2, 5, and 10 minutes.
7. Turn pump off, collect all data generated to date and provide data for evaluation by the TRG for approval to proceed to further testing. Continue data recording for at least one week after pump shut off, or as directed by TRG.
8. Daily pump bumping will be performed (per step 3) unless directed otherwise by the TRG.

Initial Data Package for TRG Review

The data users and the TRG will review data from the mixing pump tests (and initial pump bumps) shortly (within a matter of hours) after performance of these operations. The following is a list of data that should initially be provided for this purpose. It is assumed that the data will be provided in graphical form from the historical data files using the Genesis system in the 2750 Building.

1. Pump operating parameters vs time

- o Speed (rpm)
 - o Flow in each discharge line (gpm)
 - o Discharge pressures in each discharge line and at pump volute (psi)
 - o Waste temperature in each discharge line ($^{\circ}\text{F}$)
2. Hydrogen concentration vs time at all four measured locations (risers 12A, 16A, 17B, and exhaust).
 - o Whittaker %
 - o Mass spectrometer above 10 ppm and Gas Chromatograph 0-10,000 ppm.
 3. Tank level FIC gauge and alternate (radar) vs time.
 4. Waste temperature ($^{\circ}\text{F}$) vs time
 - o MIT (riser 17B)
 - o VDTT in riser 1B
 - o VDTT in riser 14A
 5. Temperature profiles at all three measured locations (risers 17B, 1B and 14A) just prior to and approximately 10 minutes after pump operation.
 6. Tank dome pressure (in. W.G.) vs time.
 7. Tank ventilation flow rate vs time.
 8. In-tank video of response to pump operation.

Precautions and Limitations

Pump Operation Duration Limit

The total duration of pump operation (excluding daily pump bumps) shall not exceed the cumulative time defined in steps 1 - 9 without TRG approval.

Minimum Pump Operation to Prevent Plugging

After pump insertion into the waste, the pump shall be operated for up to eight seconds duration (pump-bump) once per day to flush the pump discharge piping and nozzles with approximately 100 gallons of convective liquid to prevent a possible plugging condition. The following justification is provided for this limitation.

Assuming the pump hardware is lowered into the tank after some period following the tank rollover, the non-convective zone of sludge will be approximately 16 - 18 ft in depth, with 14 - 16 ft convective liquid above. Lowering the pump at a rate which allows trapped gas to be relieved through the vent located in the vicinity of the motor housing, results in convective liquid density (sp. gr. ~ 1.45) containment in all interior passages including downcomer piping extending to the flow nozzles. Since non-convective waste above the nozzle elevation is expected to reflect a higher

equivalent density (sp. gr. ~ 1.7), a pressure difference of approximately 1.5 psi is developed which causes the viscous, non-convective waste to slowly migrate into the nozzle opening over a period of time that the pump is not operating. In addition, solid/particulate settling is taking place within the downcomer piping which contains convective waste and some material which has not completely settled. Gradual development of the resulting high density "plug" within the converging passage of the nozzle presents a condition that requires actuating the pump shortly after insertion. Brief operation of the pump at up to approximately 380 rpm is required to displace that volume of the liquid column within the downcomer piping with convective waste liquid which is relatively free of particulate solids and to dislodge the relatively high-density "plug" in the nozzle geometry. This action is called for on a daily basis to ensure that a plug does not form prior to initiating low flow testing.

If a "plug" of high density waste is allowed to form and is present at the time of low flow startup, a pump head applied to dislodge it must exceed the external pressure resistance of approximately 1.5 psi differential by an amount sufficient to overcome the shear strength of the material held within the converging nozzle passage. Results of initial calculations considering non-convective waste shear strength property, indicate that a 70 psi applied pressure difference would be required to rapidly dislodge the plug. Since low-flow pump operation is limited to less than 400 rpm pump speed, the available pump head will not exceed 6 psi developed pressure differential. This condition provides a maximum of approximately 5 psi differential across the plug, which may be insufficient to dislodge it under the restrictions applied to start-up testing--thus the need for daily, brief operation of the pump to prevent the formation or set-up of a plug.

Maximum Pump Speed

The maximum pump speed during the initial test plan is 400 rpm. However, if no flow is indicated during pump bumping, pump speed limits may be increased to 920 rpm, subject to approval by the TRG.

Orientation

During this initial phase of testing, pump operation is allowed in only a single orientation (0°).

Test Predictions

There is considerable uncertainty in the quantity of gas retained in the waste following a natural tank burp, in the ability of the liquid jet to penetrate the settled solids layer and in the effectiveness of a jet in releasing the trapped gas. Some variation in the background hydrogen concentration in the tank dome space and exhaust has also been observed. Therefore, there is considerable uncertainty in the tank response to operation of the mixing pump. Developing a greater understanding is indeed the primary purpose of the test. However, a range of predictions has been developed based on the best available data, models, and understanding. These predictions are described below. Details of these predictions will be documented separately.

o Effect of Initial Pump Operation

The effect of initial low speed operation of the pump on the residual gas in the tank is somewhat uncertain. On one hand, this test will be started shortly after a natural tank

rollover. A natural rollover introduces considerable mixing energy into the waste, yet appears to result in a large fraction of the gas unreleased. This may suggest that the low energy input by the pump will have little impact on the residual gas. However, the available numerical models (GOTH and TEMPEST) of the periodic gas retention and release phenomena (WHC, 1992b) indicates that even a short period of low speed pump operation could result in a moderately large gas release due to the radial density gradients and natural circulation patterns induced. Test predictions have described gas release behavior as a function of jet velocity, gas bubble distribution/void, and waste properties.

If the pump has little effect on the residual gas, then no significant change in measured tank parameters will be observed. On the other hand, if the behavior is as predicted by the numerical models, then the behavior may be similar to that observed during a typical small natural gas release event. That is, several thousand cubic feet of gas could be released in a relatively short time period, resulting in a few percent hydrogen in the tank dome and a tank level drop of several inches. Again, no mechanism has been identified which would result in a release larger than the previous natural rollover. Large natural rollovers typically release up to 10,000 ft³ of gas, result in up to 6% hydrogen in the tank dome, and cause a level drop of up to 10 in.

References

- WHC, 1992a, "Assessment of Potential Gas Accumulation and Retention - Tank 241-SY-101," WHC-EP-0576, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992b, "Simulation of Gas Release Event in Tank 101-SY Using the GOTH Computer Program," (NAI-9101-1), WHC-SD-WM-ER-150, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992d, "Mitigation Test Management," WHC-SD-WM-MA-014, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992e, "Data Management Plan," WHC-SD-WM-PLN-052, Rev. 0, Westinghouse Hanford Company and Pacific Northwest Laboratory, Richland, Washington.

BASELINE DOCUMENT

1.0 BASELINE DATA REQUIREMENTS

Baseline data are data taken prior to the operation of the mitigation pump. The purpose of baseline data is to establish a reference point of tank waste behavior so that the effect of mixer pump operation can be adequately assessed. As mentioned in Section 1.2, the primary measures of test success will be changes in the rate of surface level rise and the background (or steady state) hydrogen concentration in the tank dome and ventilation exhaust.

Since the purpose of the test is to evaluate the ability of jet mixing to prevent or reduce gas accumulation in the waste, a decrease in the rate of surface level rise and an increase in the background hydrogen concentration will indicate a degree of test success.

1.1 SURFACE LEVEL MONITORING

A statistical analysis of data from the manual tape, Food Instrument Corporation (FIC), and radar gauge surface level devices has taken place. This is based on analysis from three previous growth periods between events (approximately 1 year).

Three devices are currently installed to measure the surface level in the tank, two conductivity probes and a radar gauge. The automatic conductivity probe (manufactured by FIC) is located at riser 1C. The manual conductivity probe (manual tape) is located at riser 17A. The radar gauge, installed during Window C, is located at riser 13A. A fourth method for surface level measurement is visual observation of the velocity-density-measurement trees (VDTT) at risers 1B and 14A.

Both the FIC and the manual tape work on the same principle, described here in a simplified manner. The surface level is determined by the amount of cable used to lower the probe to the level where the electrical contact is made.

Several non-intrusive (non-contact) methods to determine the surface level have been proposed as supplements to or replacements for the FIC and manual tape. An Enraf Nonius^(a) Model 872 Radar Gauge, was installed on the tank during Window C. It averages the level over an area of three feet in diameter directly below the antenna. A reading is provided to the DACS. This instrument is sensitive to variations in surface reflectivity (angle of incidence, and moisture content). Therefore, the variable surface of Tank 101-SY causes the output from this device to be somewhat unreliable.

The newest method to measure surface level is using the VDTT instrument trees. One fourth inch thick marks were placed at two-inch intervals along the length of the instrument tree. Using the in-tank video camera, the surface level can be determined by counting the marks. This method is only accurate to ± 1 inch.

1.2 HYDROGEN CONCENTRATION MONITORING

(a) Enraf Nonius is a trademark of Enraf Nonium Co.

The background hydrogen concentration in the dome space and ventilation exhaust of Tank 101-SY is approximately 20 parts per million (ppm) when the exhaust flow rate is between 500 - 600 cubic feet per minute (cfm). This approximate value is for the time periods outside of a gas release event. This value has significant variability due to the behavior of the tank where hydrogen is not released from the waste at a uniform constant rate but rather it is released at a small (< 0.1 cfm) non-uniform rate. The mean hydrogen concentration with the variable about the mean will be determined to provide a hydrogen baseline. The systems used for the hydrogen monitoring are described as follows.

1.2.1 Gas Chromatograph

The principal gas chromatograph being used for the mitigation tests is manufactured by Trace Analytical and is installed on the vent header. It measures hydrogen gas with a detection range of 1 - 1,000 ppm.

1.2.2 Mass Spectrometer

The Gas Monitoring System-1 (GMS-1) monitors gas from one of three elevations in riser 17B of Tank 101-SY. Each of these sample lines are operated at a flow rate of 1.0 to 1.5 cfm. Only one sample line can be operated at any one time. A Whittaker 800^(b) hydrogen monitor, and an Aero Vac Model 1000^(c) Magnetic Sector mass spectrometer are installed in this system. Periodic grab samples and calibration functions are implemented via manually operated local valves.

The mass spectrometer continuously samples gas from the specified sample line. A spectral analysis is performed once every five minutes producing a table of mass abundance for specified molecular masses. The analysis rate can be adjusted to be as fast as once per minute.

1.2.3 Grab Sampling System

Grab samples are taken as required at three locations (riser 16A, riser 17B, and the vent header). The grab samples are chemically analyzed in the 300 Area laboratory with a gas chromatograph which provides information on the gas composition. A manifold system is currently installed in Tank 101-SY to allow samples to be taken. The samples are analyzed for hydrogen and nitrous oxide.

1.2.4 Whittaker Monitor

Three Whittaker hydrogen monitors are currently installed at risers 16A, 17B, and the vent header of Tank 101-SY. A fourth Whittaker hydrogen monitor will be installed on riser 12A after pump installation. This sensor covers a range of 0 to 10 volume percent (vol%) hydrogen and generates a millivolt signal proportional to the hydrogen in the sample. This is a continuous monitoring system. The tank hydrogen concentration is generally below the detection levels of the Whittaker and therefore, its use is only for releases of larger amounts of hydrogen.

(b) Whittaker is a trademark of ERI Whittaker Co.

(c) Aero Vac is a trademark of VTI Co.

2.1 OTHER DATA PARAMETERS

The release of other waste gases, such as nitrous oxide and ammonia can provide additional confirmation on mitigation test effectiveness. A Fourier Transform Infra-red Spectrometer (FTIR) is installed on Tank 101-SY.

The FTIR utilizes the unique mid-infrared absorption features of specific molecules to determine the concentrations of complex mixtures. The system requires that a beam of infrared radiation pass through the gas being sampled. The attenuation of the beam is recorded as a function of the wavelength. In principle, the diagnostics can be applied to all molecules with the exception of homo-nuclear diatomic molecules such as N_2 and H_2 . The system currently uses a Digilab^(d) FTS-60 spectrometer along with a personal computer.

The FTIR, plus grab sample analysis for nitrous oxide, will be used to provide information on these other waste gases.

2.2 DATA ANALYSIS

The collected tank data will be reviewed and evaluated, using statistical methods, to establish mean rates of level rise and hydrogen concentrations plus the variability of the data. Before the installation of the pump, the TRG will determine if an adequate data baseline exists. If adequate baseline data exists, the TRG will authorize installation of the pump. If an adequate baseline does not exist, additional data collection, evaluation and/or review will be performed prior to pump installation.

(d) Digilab is a trademark of Biorad Digital Lab Division

Appendix B

Excerpts from Phase B Test Plan for Tank 241-SY-101 Mitigation by Mixing Test

APPENDIX B

EXCERPTS FROM PHASE B TEST PLAN FOR TANK 241-SY-101 MITIGATION BY MIXING TEST

Purpose

The purpose of this test is to evaluate the ability of jet mixing to prevent or reduce the accumulation of gases generated in Tank 101-SY. There is evidence that significant quantities of gas remain in the tank even following a major "natural" gas release event (burp). Therefore, the test will also indicate the effectiveness of jet mixing in releasing this residual gas. Finally, the test will be utilized to evaluate the waste and tank hardware response to the mixing pump operation. For example, the extent of waste heating and foaming are of concern as are the hydraulic loads imposed on in-tank hardware (e.g., instrument trees).

Information obtained from the test will be utilized to determine whether jet mixing is a viable mitigation concept, and, if so, data obtained from the test will be utilized in the design of the long term mixing equipment. This series of tests will follow the initial startup and low flow testing of the mixer pump which is described in the Phase A Test Plan in WHC (1992c).

Test Philosophy/Success Criteria

The philosophy utilized in the development of this test plan 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 quantity of gas retained in the waste is not specifically addressed. Reduction in the retained gas inventory to some defined level may be required to eliminate this issue as an Unreviewed Safety Question, although even this is not clear if the retained gas is in a stable (unreleasable) condition.

Baseline data for this phase of the test program will have been collected as part of the preparations for the Phase A low-flow pump start-up testing. Data will have been established for dome space and vent header hydrogen concentration, rate of surface level change, and rate of temperature change in the non-convective layer.

Consistent with the test philosophy, the two primary measures of success for this full-scale test are tank waste level and hydrogen concentration in the tank dome. These two indicators are discussed below.

Tank Level

Complete success would be indicated by a long term stable tank level below some acceptable value (e.g., 410 in.). This would imply that the gas release rate equals the gas generation rate and

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

the periodic tank burps had been eliminated. Partial success would be indicated by a reduction in the rate of level rise between burps (historically about 0.09 in. per day). Although it is theoretically possible that a greater quantity of gas could be retained in the same or even a smaller waste volume, this is considered highly unlikely in the case of agitation of the waste by jet mixing (WHC 1992a).

Hydrogen Concentration

As stated in WHC (1991) the overall mitigation objective is to prevent periodic gas releases that result in hydrogen concentrations which exceed 25% of the LFL. Measurement of the hydrogen concentration data will also be useful in determining whether an unexpected increase in gas retention is occurring.

It should be noted that partial success may involve periodic gas releases of smaller magnitude than those which currently occur. For example, this could be the result of the mixing pump affecting less than the full tank radius. The degree of success of the test should be defined following complete evaluation of the test data rather than trying to define it a priori.

Summary of Test Conditions and Sequence

Prior to this test the submersible jet mixing pump will have been installed in riser 12A, and the special Data Acquisition and Control System (DACS) will have been installed, checked out and in operation as part of the Phase A testing (WHC 1992c). In addition, the Test Review Group (TRG) will have been formed and will approve the Test Procedure and any changes to it. Several hold points are defined at which the TRG will review the test data and decide whether to continue or terminate the test. Finally, if the test is aborted due to violation of any of the established Level 1 and Level 2 abort criteria, approval of the TRG is required before restarting the test. The roles of responsible parties have been defined by the management plan for the mitigation test, WHC (1993). 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.

The purpose of the Phase B test series is to demonstrate the ability of jet mixing to maintain a sufficient fraction of solid particles in suspension that further accumulation of gas within the tank will be prevented. This test sequence will be initiated upon approval by the TRG and as soon as possible after completion of Phase A (to prevent the re-establishment of an unstable gas inventory).

A safety envelope for the Phase B Test Plan is shown in Table 1. Referring to the table, a test is defined as the time period between each pump startup and pump shutdown, followed by a waiting time, except for the sweep tests. Each sweep is defined as a test even though the pump must be shut down before the nozzles are reoriented and locked into a new position within this given test. However, no waiting time is required each time the nozzle orientation is changed in a given sweep. Thus, there are 27 tests defined in Table 1, 12 of which are sweep tests. The total maximum pump operation time is 56 hours for these tests, and they must be performed over a minimum time period of 22 days, 7 hours, and 20 minutes.

Table 1. Phase B Test Plan Summary.

Test #	Pump Operation	Maximum ¹ Speed (r/min)	Maximum Test Duration (min)	Minimum Waiting Time (h)
TRG			0	
1	35°	360	20	12
2	35°	510	20	12
3	35°	720	20	12
4	35°	920	20	12
TRG			1 h 20 min	2 days 1 h 20 min
5	65°	360, 510, 720 920 r/min (20 min each speed) 22:40		
6	95°	360, 510, 720 920 r/min (20 min each speed) 22:40		
7	125°	360, 510, 720 920 r/min (20 min each speed) 22:40		
8	155°	360, 510, 720 920 r/min (20 min each speed) 22:40		
9	185°	360, 510, 720 920 r/min (20 min each speed) 22:40		
TRG			8 h	7 days 1 h 20 min
10	35°	750	60	12
11	65°	750	60	12
12	95°	750	60	12
13	125°	750	60	12
14	155°	750	60	12
15	185°	750	60	12
			14 h	10 days 7 h 20 min
16 ³	tank sweep ²	750	180	21
17 ³	tank sweep	750	180	21
18 ³	tank sweep	750	180	21
19 ³	tank sweep	750	180	21
TRG			26 h	14 days 7 h 20 min
20 ³	tank sweep	920	210	20:30
21 ³	tank sweep	920	210	20:30
22 ³	tank sweep	920	210	20:30
23 ³	tank sweep	920	210	20:30
			40 h	18 days 7 h 2 min
24 ³	tank sweep	920	240	20
25 ³	tank sweep	920	240	20
26 ³	tank sweep	920	240	20
27 ³	tank sweep	920	240	20
TRG			56 h	22 days 7 h 20 min

1. Maximum/Operating.

2. Tank sweeps are defined by the pump orientations identified in Test Numbers 10 - 15, above.

3. Optional Tests. TRG authorization is required to delete individual tests.

Tests 16 through 27 are identified as optional to allow the TRG to determine which tests are to be performed. The basis for the optional provision is to introduce TRG control in limiting the gas release due to pumping and the associated impact upon reduction in tank level considering the Safety Assessment controls on level. Selection of optional tests must consider the allowed 56 hour cumulative operating time.

Table 1 shows that there are five TRG review points scheduled during phase B testing. The times listed at those review points correspond to the total pump operation time and the total time since the beginning of phase B testing. The first TRG review is scheduled before the beginning of phase B testing. At that time, a review of the data from phase A test is required for initiation of the phase B testing.

The second TRG review is planned after 80 minutes of pump operation (at the end of test 4). The first four tests increase the pump speed gradually, keeping the pump orientation and test duration constant. The pump is operated for 20 minutes in each test, and a minimum of 12 hours of waiting time is required before the next test. The waiting-time-to-operating-time ratio is equal to 36 to 1.

The third TRG review is scheduled at the end of test 9, after 8 hour of pump operation. In tests 5 through 9, the pump orientation is changed by 30 degree increments. The pump speed is increased to the maximum speed of 920 r/min stepwise. After each test, a minimum of 22 hours and 40 minutes of waiting time is required. The difference between these tests and tests 1 through 4 is that the pump speed is increased stepwise without requiring a waiting time between speed increases. This accelerates the testing. Large changes in the waste properties in azimuthal 30 degree increments are not anticipated. While nonuniformities are likely, the behavior in these pump directions is not expected to be drastically different than the behavior for the initial orientation (tests 1 through 4). Consequently, a waiting time between various speeds is not required. However TRG review of the previous tests is required, as shown in the table. For tests 5 through 9, the waiting-time-to-operating-time ratio is decreased to 17 to 1.

Tests 10 through 15 allow 60 minutes of pump operation in a given direction, followed by a minimum of 12 hours of waiting time. This procedure is repeated for each direction. The pump speed is set to 750 r/min (20% higher than the average speed in tests 5 through 9). The operating-time-to-waiting-time ratio is decreased to 12 to 1.

Starting with test 16, the daily tank sweep will be tested. Tests 16 through 19 allow for daily test sweeps, with 3 hours of pump operation per day at a maximum speed of 750 r/min. The important features of the sweeps are (1) no more than 3 hours of operation per day, including all orientations; and (2) a minimum of 21 hours of waiting time between sweeps. It is important to note that each time the pump orientation is changed, the pump must be shut down. Pump operation restarts when the pump is rotated to its next orientation and locked in that position. Another TRG review and approval meeting is scheduled at the end of 26 hours of pump operation.

Tests 20 through 27 also consist of tank sweeps. The difference between these tests and tests 16 through 19 is in the pump speed, operation time, and waiting time, as noted in the table. At the end of test 27 (56 hours of pump operation), another TRG meeting is scheduled to review the data and to decide on continuing the test. Testing can continue beyond 56 hours based on TRG approval. However, a maximum of 4 hours of pump operation per day is implemented as a Level I control. Test Predictions

There is considerable uncertainty in the quantity of gas retained in the waste following a natural tank burp, in the ability of the liquid jet to penetrate the settled solid layer and in the effectiveness of a jet in releasing the trapped gas. Some variation in the background hydrogen concentration in the tank dome space and exhaust has also been observed. Therefore, there is considerable uncertainty in the tank response to operation of the mixing pump. Developing a greater understanding is indeed the primary purpose of the test. However, a range of predictions has been developed based on the best available data, models, and understanding. These predictions are described below. Details of these predictions will be documented separately.

- Baseline Tank Level/Gas Content

The tank level has been observed to vary between 415 and 400 in. over the past several years. This variation is characterized by a slow (approximately 0.09 in. per day) rise for approximately 100 days following a gas release event and then a rapid drop during the next gas release event. WHC (1992a) provides an evaluation of the tank gas inventory. .

- Background Hydrogen Concentration

Limited data from the tank has shown a background hydrogen concentration in the dome that varies between approximately 25 and 35 p/m, with occasional transients to approximately 100 p/m. Additional information on the background hydrogen concentration will be obtained during performance of the baseline data gathering activity. Per WHC (1992b) this background hydrogen concentration is due to the continuous release of approximately 77 ft³ per day from the upper portions of the tank waste.

- Effect of Subsequent Pump Operation (Initial Sweep in Phase B)

Behavior during initial Phase B operation is uncertain. One extreme is that little or no effect might be observed. That could occur if Phase A operation effectively released most of the residual gas or if considerable residual gas remains, but the pump is ineffective in releasing it. The other possibility is that as the jet is introduced to previously unaffected regions of the tank (e.g., by increases in pump speed), additional small gas releases could occur.

- Effect of Subsequent Tank Sweeps

No large gas releases should be induced by subsequent operations of the pump. Ideally, the pump operation will maintain the solids in suspension and thus allow the continuous release of the generated gases (note that the particle settling velocity is extremely low and thus only periodic pump operation may be required). This would result in an increase in the dome hydrogen concentration to approximately 65 p/m. Even if the gas is released only during periods of pump operation, the resulting

hydrogen concentration should not exceed 1000 p/m (0.1%). Level changes (or lack thereof) will only be detectable in the long term (several days). If the jet mixing is unsuccessful for mitigation, then the long term hydrogen and level response will be similar to the current behavior.

References

- WHC, 1991, "Technical Basis for Selection of Tank 101-SY Intrusion Window," WHC-SD-WM-TI-458, Rev. 2A, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992a, "Assessment of Potential Gas Accumulation and Retention - Tank 2421-SY-101," WHC-EP-0576, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992b, "Simulation of Gas Release Event in Tank 101-SY Using the GOTH Computer Program," (NAI-9101-1), WHC-SD-WM-ER-150, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1992c, "Test Plan for Tank 101-SY Mitigation by Mixing Test," WHC-SD-WM-TP-140, Rev. 3, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1993, "Mitigation Test Management," WHC-SD-WM-MA-014, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Appendix C

Mixer Pump Operation Log

Table C.1. Mixer Pump Operation Log

Date	Time	Speed	Duration	Comments
7/4	21:03	380	8 sec	
7/5	18:42	380	8 sec	
7/6	18:20	380	8 sec	
7/7	17:46	380	8 sec	
7/8	20:10	380	8 sec	
7/9				Inclement weather and range fire
7/10	16:59	380	8 sec	
7/11	14:40	380	8 sec	
7/12	17:20	380	8 sec	Pressure taps plugged (PIT nozzles)
7/13	18:30	380	8 sec	
7/14	20:37	340	0 min	Phase A (TIP101 nozzle blocked)
7/15	17:38	340	1 min	Phase A (TIP101 nozzle blocked)
7/16	10:58	510	8 sec	No indication/either gas
	22:58	340	2 min	Phase A (tap 110 plugged)
7/17	15:07	510	8 sec	No indication/either gas
7/18	11:16	510	8 sec	No indication/either gas
7/19	11:41	340	5 min	Phase A (TIP202 nozzle blocked)
7/20	06:25	510	8 sec	Bump (nozzle blocked)
7/20	20:02	720	8 sec	
	23:09	340	10 min	Phase A (TIP202 nozzle blocked)
7/21	06:24	720	8 sec	
7/22	06:04	720	8 sec	
7/23	06:07	720	8 sec	Tap 111 (plugged)
7/24	06:09	720	8 sec	Tap 111 (plugged)
7/25	06:00	720	8 sec	Both nozzles blocked (TIP101, TIP202)
7/25	09:46	1000	8 sec	Both nozzles blocked
7/25	19:02	1000	2 min	Both nozzles blocked
7/26	11:29	1000	5 min	Both nozzles blocked

Date	Time	Speed	Duration	Comments
7/26	19:58	1000	5 min	Nozzle flushing at 19:53 blockage removed
7/27	16:35	1000	5 min	Strain/deflection noted at 17B and 1B
7/28	06:14	1000	5 min	Strain/deflection noted at 17B and 1B
7/28	17:05	1000	5 min	
7/28	17:58	380	1 min	Nozzles remained open
7/29	07:00	1000	5 min	Strain/deflection noted at 17B and 1B
7/29	17:36	1000	5 min	Strain/deflection noted at 17B and 1B
7/30	06:06	1000	5 min	Diminished indication of strain deflection
7/30	17:28	1000	5 min	Diminished indication of strain deflection
7/31	06:07	1000	5 min	Diminished indication of strain deflection
7/31	17:15	1000	5 min	Diminished indication of strain deflection
8/1	05:53	1000	5 min	
8/1	16:29	1000	5 min	
8/2	06:03	1000	5 min	
8/2	18:08	1000	5 min	
8/3	06:04	1000	5 min	
8/3	16:44	1000	5 min	
8/4	06:15	1000	5 min	
8/4	20:17	1000	5 min	
8/5	06:04	1000	5 min	
8/5				Farm operations prevented bump
8/6	05:46	1000	5 min	
8/6	18:30	1000	5 min	
8/7	05:35	1000	5 min	
8/7	17:39	1000	5 min	
8/8	05:40	1000	5 min	
8/8	16:52	1000	5 min	
8/9	05:52	1000	5 min	

Date	Time	Speed	Duration	Comments
8/9	16:53	1000	5 min	
8/10	05:51	1000	5 min	
8/10	18:11	1000	5 min	
8/11	06:13	1000	5 min	
8/11	17:12	1000	5 min	
8/12	06:05	1000	5 min	Farm operations, delayed second bump
8/13	00:05	1000	5 min	
8/13	19:06	1000	5 min	
8/14	06:27	1000	5 min	
8/14	17:27	1000	5 min	
8/15	06:08	1000	5 min	
8/15	19:21	1000	5 min	
8/16	06:05	1000	5 min	
8/16	18:05	1000	5 min	
8/17	05:46	1000	5 min	
8/17	17:47	1000	5 min	
8/18	05:28	1000	5 min	
8/18	18:14	1000	5 min	
8/19	05:31	1000	5 min	
8/19	19:11	1000	5 min	
8/20	07:07	1000	5 min	
8/20	18:14	1000	5 min	
8/21	--	--	--	Critical instruments unavailable
8/22	08:42	1000	5 min	
8/22	18:02	1000	5 min	
8/23	21:59	1000	5 min	Single daily bumps instituted
8/24	17:41	1000	5 min	PIP 202 tap plugged
8/25	11:00	1000	5 min	
8/26	19:15	1000	5 min	

Date	Time	Speed	Duration	Comments
8/27	09:09	1000	5 min	Rollover event (09:39 GRE)
8/28	09:54	1000	5 min	
8/29	10:06	1000	5 min	
8/30	10:20	1000	5 min	
8/31	05:26	1000	5 min	Nozzle tap 111 plugged
9/01	04:22	1000	5 min	PIP 202 tap plugged
9/02	04:46	1000	5 min	
9/03	04:39	1000	5 min	
9/04	06:13	1000	5 min	
9/05		1000	5 min	Tank operations
9/06	05:40	1000	5 min	
9/07	04:56	1000	5 min	
9/08	04:23	1000	5 min	
9/09	04:46	1000	5 min	
9/10	05:46	1000	5 min	
9/11	05:41	1000	5 min	
9/12	05:23	1000	5 min	
9/13				Abort/low ventilation flow/low N ₂ pressure
9/14	05:41	1000	5 min	
9/15	05:53	1000	5 min	
9/16	05:14	1000	5 min	
9/17	20:31	1000	5 min	Circuit breaker failure/bump delayed (Significant gas release event 20:54)
9/18 9/19				No bumps - rate of level rise exceeded S.A. control
9/20	18:04	1000	5 min	Minor GRE occurred at 11:50 (Introduced slow rampdown on bumps)
9/21	05:14	1000	5 min	
9/22	04:40	1000	5 min	
9/23	05:07	1000	5 min	

Date	Time	Speed	Duration	Comments
9/24	05:39	1000	5 min	
9/24	04:54	1000	5 min	
9/26	04:54	1000	5 min	
9/27	04:31	1000	5 min	
9/28	04:27	1000	5 min	
9/29	04:23	1000	5 min	Minor GRE (10:00 to 18:00)
9/30	04:18	1000	5 min	
10/1	10:40	1000	5 min	
10/2	09:05	1000	5 min	
10/3	11:38	1000	5 min	
10/4	17:11	1000	5 min	
10/5	06:59	1000	5 min	
10/6	04:47	1000	5 min	
10/7	04:48	1000	5 min	
10/8	04:48	1000	5 min	
10/9	05:32	1000	5 min	
10/10	08:47	1000	5 min	
10/11	05:17	1000	5 min	
10/12	05:19	1000	5 min	
10/13	05:03	1000	5 min	
10/14	17:52	1000	5 min	
10/15	04:49	1000	5 min	
10/16	06:05	1000	5 min	GRE occurred
10/17	05:08	1000	5 min	
10/18	05:05	1000	5 min	
10/19	04:38	1000	5 min	
10/20	04:43	1000	5 min	Minor release occurred at 18:00
10/21	05:17	1000	23 sec	
10/21	07:45	360	20 min	Phase B Test #1/35 ⁰

Date	Time	Speed	Duration	Comments
10/22	11:27	1000	5 min	
10/22	11:50	510	20 min	Phase B Test #2/35 ⁰
10/23	05:05	1000	5 min	
10/24	04:54	1000	5 min	
10/25	05:02	1000	5 min	Bump
10/25	05:23	720	10 min	Phase B Test #3 Abort/GRE at 05:33
10/26				No tests due to exceeding leveling limit
10/27	03:47	1000	5 min	Bump
10/28	04:05	1000	5 min	Bump
10/29	04:20	1000	5 min	Bump
10/30	04:18	1000	5 min	Bump
10/31	09:00	1000	5 min	Bump
11/01	05:02	1000	5 min	Bump and small release
11/02	05:59	1000	5 min	Bump
11/02	06:23	720	13 min	Phase B Test #3, abort at 06:36 GRE 06:35 and 07:05
11/03				No test/FIC, GC-3 failures
11/04	04:07	920	20 min	Phase B Test #4/no bump/35 ⁰
11/05	04:10	360/920	80 min	Phase B Test #5/no bump/65 ⁰
11/06	05:03	1000	5 min	Bump
11/07	05:01	1000	5 min	Bump
11/08				No test FIC failure
11/09				No test FIC failure
11/10	04:11	360	20 min	Phase B Test #6, abort 04:31*
11/11	03:39	360/920	80 min	Phase B Test #6/no bump/95 ⁰
11/12	03:46	360/920	80 min	Phase B Test #7/no bump/125 ⁰
11/13	05:30	360/920	80 min	Phase B Test #8/155 ⁰
11/14				No test

*"Bump" response due to low speed/abort

Date	Time	Speed	Duration	Comments
11/15	04:27	360/920	80 min	Phase B Test #9/185 ⁰
11/16	05:23	750	60 min	Phase B Test #10/35 ⁰
11/17	03:11	750	60 min	Phase B Test #11/65 ⁰
11/17	16:54	750	17 min	Phase B Test #12 aborted - high vent flow
11/19	03:29	750	60 min	Phase B Test #12/95 ⁰
11/21	05:47	750	60 min	Phase B Test #13/125 ⁰
11/22	03:22	750	60 min	Phase B Test #14/155 ⁰
11/24	06:06	1000	5 min	Bump ("suppressed" H ₂ release)
11/26	07:26	1000	5 min	Bump ("suppressed" H ₂ release)
11/27	05:41	750	60 min	Phase B Test #15/185 ⁰
11/29	03:34	750	180 min	Phase B Test #16/sweep
12/01	03:23	750	180 min	Phase B Test #17/sweep - abort 05:28
12/03	05:43	1000	5 min	Bump ("suppressed" H ₂ release)
12/04	05:18	750	180 min	Phase B Test #18/sweep - abort 09:45
12/06	05:09	1000	5 min	Bump ("suppressed" H ₂ release)
12/07	02:35	750	180 min	Phase B Test #19/sweep
12/09	04:52	920	35 min	Phase B Test #20.1/35 ⁰
12/11	05:19	1000	5 min	Bump ("Suppressed" H ₂ release)
12/13	04:52	920	35 min	Phase B Test #20.3/95 ⁰
12/15	04:46	920	35 min	Phase B Test #21.1/35 ⁰
12/17	04:58	920	35 min	Phase B Test #21.3/95 ⁰
12/20	05:35	1000	5 min	Bump/directional/20 ⁰ (positive H ₂ release)
12/22	06:08	1000	5 min	Bump/directional/50 ⁰ (positive H ₂ release)
12/24	05:09	1000	5 min	Bump/directional/80 ⁰ (positive H ₂ release)
12/27	05:31	1000	5 min	Bump/directional/110 ⁰ (positive H ₂ release)
12/30	05:49	1000	5 min	Bump/directional/140 ⁰

Date	Time	Speed	Duration	Comments
12/31	05:52	1000	5 min	Bump/directional/170 ⁰
01/03	05:43	1000	5 min	Bump/directional/20 ⁰
01/06	05:14	1000	5 min	Bump/directional/50 ⁰
01/07	04:35	1000	5 min	Bump/directional/80 ⁰
01/10	08:52	1000	5 min	Bump/directional/110 ⁰
01/12	05:12	1000	5 min	Bump/directional/140 ⁰
01/14	05:09	1000	5 min	Bump/directional/170 ⁰ GRE at 01:38

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