PNNL-13319

Review of Waste Retrieval Sluicing System Operations and Data for Tanks 241-C-106 and 241-AY-102

J. M. Cuta

Contributors:

K. G. Carothers[a]
D. W. Damschen
W. L. Kuhn
J. A. Lechelt[a]
K. Sathyanarayana[b]
L. A. Stauffer[a]

September 2000

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Richland, Washington 99352

(a) CH2M Hill Hanford Group, Inc.
(b) Fluor Daniel Hanford, Inc.

DISCLAIMER

Summary

Sluicing operations were performed to retrieve high-heat sludge from single-shell tank (SST) 241-C-106 (C-106) and transfer it to double-shell tank 241-AY-102 (AY-102) using the Waste Retrieval Sluicing System. This has eliminated the high-heat safety issue for C-106 and demonstrates a technology for retrieval of SST waste. The behaviors of AY-102 and C-106 were monitored during the waste transfer operations, providing a clear picture of general trends in each tank. Specific issues addressed were evaluation of the data for evidence of flammable gas accumulation in AY-102 and thermal performance of AY-102 under the increasing heat load. Reports summarizing the data were produced on a regular basis from September 1998 through October 1999 and posted to a web page on the internal Hanford intranet. This greatly facilitated communication between the contractors, Pacific Northwest National Laboratory and the Office of River Protection, during the operations.

Sluicing operations were carried out in a series of three campaigns, each of which removed approximately one-third of the C-106 sludge. The first campaign was initiated on November 10, 1998, with the first transfer of sludge from C-106 to AY-102, and was concluded on March 28, 1999. Unexpected delays were encountered due to unacceptably large releases of volatile organic compounds (VOCs) through the C-006 ventilation stack when operations first disturbed the deep layers of sludge in C-106. (Release rates were measured in excess of 450 ppm when the permitted limit was 50 ppm.) Changes in procedures and equipment mitigated this problem, and in the following campaigns, the VOC release rate never exceeded the permitted limit.

The initial estimate based on sluicing data indicated that 75,405 gallons of sludge (approximately 40% of the 192,000 gal originally in C-106) were transferred to AY-102 in Campaign #1. Campaign #2 was initiated on April 23, 1999 after meeting the requirements of hydrogen release rate and level change to determine that gas was not being retained in the waste that had been transferred to AY-102. The amount transferred in Campaign #2, which was terminated on June 3, 1999, was initially estimated as 51,482 gal of sludge. This represents about 27% of the initial sludge volume in C-106, resulting in an estimated 66% transferred to AY-102 in the first two campaigns. Campaign #3 was initiated on July 21, 1999 and continued in 12 separate batches until October 6, 1999. The amount transferred in this campaign was initially estimated as 59,000 gal of sludge, or about 31% of the original amount in C-106. A total transfer amount of approximately 186,000 gal, or 97%, was estimated from measurements during sluicing.

Estimates obtained from thermal analyses of C-106 and AY-102 and other independent calculation methods post-sluicing indicate that at least 182,000 gallons, or 95% and up to 188,000 gallons, or 98%, of the original C-106 sludge was transferred to AY-102. The video inspection performed in C-106 in July 2000 clearly shows that about 45,000 gal of waste remains in C-106, which is mostly liquid with approximately 4,500 gal. of coarse rubble in several piles around the tank wall. The remaining solids cannot be removed with further sluicing. The high-heat problem has been thoroughly mitigated, and flammable gas generation is no longer an issue in this tank.

Post-sluicing monitoring of AY-102 through July 2000 shows that this tank is not retaining flammable gas. The waste in this tank now generates approximately 30 scfd of hydrogen, which

requires at least 2 scfm of ventilation to remain below 10,000 ppm of hydrogen in the headspace. However, active ventilation of the headspace and the annulus is also required to maintain the waste temperature within acceptable limits.

Contents

Figures

Tables

1.0 Introduction

Sluicing operations have been performed using the Waste Retrieval Sluicing System (Carothers et al. 1998) to retrieve high-heat sludge from single-shell Tank (SST) 241-C-106 (C-106) and transfer it to double-shell Tank (DST) 241-AY-102 (AY-102). The purposes of the transfer were to eliminate the high heat safety issue for C-106 and to demonstrate a technology for retrieval of SST waste. C-106 was designated as the High-Heat Watch-List tank because it required constant intervention to maintain the waste temperature within acceptable limits.

The behaviors of AY-102 and C-106 were monitored during the waste transfer operations, to evaluate safety issues related to flammable gas accumulation and to assess the effectiveness of the operation in removing heat-generating material from C-106 and transferring it to AY-102. Reports summarizing data obtained from the WRSS data acquisition system (DAS) (Bailey 1998a), the standard hydrogen monitoring systems (SHMS) on C-106 and AY-102, and the Hanford site TMACS and SACS systems were produced on a regular basis from September 1998 through October 1999. These reports were produced on the Internet, initially weekly, then at approximately monthly intervals. Besides providing a clear picture of general tank behavior trends, these data reports were focused on the following issues:

- Evidence of flammable gas accumulation in AY-102 with the potential to become excessive in the future
- Performance of the AY-102 heat removal from AY-102 in view of the increasing heat load being transferred from C-106
- Evidence of conditions that could lead to exceeding the waste temperature limits in either tank
- Mass of solids transferred between the tanks.

This report summarizes the periodic data reports into a single presentation of all the data and observations covering the entire sluicing period. Section 2 describes the configuration of the tanks before initiation of sluicing operations. Section 3 presents an overall summary of tank behavior during the waste transfer operations, from the beginning of Campaign #1 on November 10, 1998 to the completion of sluicing at the end of Campaign #3 on October 6, 1999. Section 4 discusses the behavior in AY-102 from the end of sluicing operations through June 2000.

2.0 Tank Configurations Before Initiation of Sluicing

This section briefly summarizes the waste configuration, the thermal state, and flammable gas retention and release behavior in each tank before sluicing operations began. A detailed discussion of the presluicing waste chemistry is provided by Reynolds (1997). Appendix A describes the instrumentation in both tanks for monitoring the tank behavior. An energy balance describing the initial heat load in each tank is presented in Appendix B. More details of the thermal behavior of the tanks before, during, and after sluicing are given by Bailey (1998b) and Ogden and Bratzel (2000). The baseline hydrogen release rates for each tank are described in Appendix C. Section 2.1 summarizes the initial state in Tank AY-102; Section 2.2 presents this information for Tank C-106.

2.1 Initial Conditions in AY-102

AY-102 was initially a relatively cool DST with a heat load of approximately 41,200 Btu/hr generated in a sludge layer estimated to be about 9 inches thick.(a) The sludge layer was covered by supernatant liquid to a depth of approximately 240 inches. This depth was increased to 309 inches at the end of June 1998 (between June 29 and July 2, 1998) by the addition of 21,650 gallons of NaOH solution to obtain the desired fluid properties for mixing with the C-106 sludge and supernatant liquid. The waste level was then pumped down to 167 inches at the end of July 1998 to make room for the material to be transferred from C-106 into AY-102.

The temperature of the sludge in AY-102 ranged from about 75–85°F. The temperature of the supernatant liquid was approximately 80°F, varying about 5°F between summer and winter temperatures. Similarly, the tank headspace temperature varied over a range of only about 4°F, with a maximum value of approximately 78°F.

The baseline hydrogen release rate for the waste initially in AY-102 was obtained by monitoring the gas concentration and the ventilation flow rate in the tank headspace over an approximately two-month period from August 8 to November 1, 1998. The method used to derive the baseline values is described in detail in Appendix C. The mean hydrogen release rate was 24 scfd, with an upper bound of 28 scfd and lower bound of 19 scfd (95% confidence). With only about 12 inches of nonconvective waste, the retained gas volume in AY-102 before sluicing was undetectable.

2.2 Initial Conditions in C-106

C-106 is an SST classified as the High-Heat Watch List tank. Its heat load is estimated to be approximately 118,000 Btu/hr (as of 1998) generated in a sludge layer about six feet thick (Carothers et al. 1998) and containing 192,000 gallons of sludge. The supernatant liquid layer above the sludge varied between about six and eight inches due to evaporation and the addition of cooling water every 20 to 30 days. These additions were typically on the order of 2000 to

---

(a) Refer to Appendix B for a discussion of the calculation of the pre-sluicing energy balance in AY-102 and C-106 and subsequent calculations after material was transferred between the two tanks.

3000 gallons each and raised the tank liquid level by approximately one inch. Evaporation would subsequently lower the liquid level at a steady rate until the next addition.

C-106 waste contained a small volume of retained gas. The waste conservatively contained up to 1770 scf at an average void fraction of 0.05. The best estimates of the volume and void were half of these values (Stewart and Chen 1998). As described in Appendix C, the baseline hydrogen release rate for C-106 before sluicing was determined to be 12.5 scfd with an upper bound (95% confidence of 16.9 scfd and a lower bound of 9.4 scfd).

Temperature measurements for the waste in C-106 are limited to two thermocouple trees, one in riser 8 and one in riser 14 (see Appendix A for a map of all instrumentation locations in both tanks.) The thermocouples on riser 8 indicated a waste temperature of 145–150°F near the bottom of the tank. Those on riser 14 showed lower temperatures, ranging from 120–135°F, even though riser 8 is near the periphery of the tank and riser 14 is approximately midway between the center and the edge. Moreover, the temperatures indicated by the thermocouples on riser 14 oscillated markedly with each water addition, indicating that even the very bottom thermocouples felt the effect of the newly introduced water.

This strongly suggests that some sort of convective channel existed around riser 14, producing a local region of enhanced heat transfer. As a result, the temperatures indicated by the riser 14 thermocouples probably were not representative of the actual waste temperature in that region. This inference is further supported by the riser 14 temperatures being consistently lower than the riser 8 temperatures when conditions in the tank would seem to require the riser 14 thermocouples to be in contact with hotter waste. Whatever the actual waste temperature distribution throughout the tank, however, all available instrumentation indicated that the heat load was higher than desirable in an SST, and mitigation of the problem by sluicing material from C-106 to a more effectively cooled and instrumented DST (i.e., AY-102) was necessary.

3.0 Tank Behavior in Response to Sluicing

What happened during the sluicing operations is described in this section. A summary of the sluicing operations is provided in Section 3.1; Section 3.2 describes the response of the instrumentation in AY-102 to sluicing; Section 3.3 presents the much more limited information for C-106; Section 3.4 summarizes the important external environmental conditions affecting the tanks.

3.1 Summary of Sluicing Operations

Sluicing operations were planned as a series of three campaigns. In each campaign approximately one third of the C-106 sludge (i.e., two feet of the total 6-ft depth of the waste) would be transferred to AY-102. Procedures were developed for monitoring and evaluating the behavior of both tanks during sluicing operations and between campaigns to ensure that temperature limits and procedural limitations on flammable gas retention were satisfied.

The amount of material transferred during each sluicing operation and the estimated heat generating capacity moved with the solid material in each transfer are summarized in Table 3.1. The volume of material transferred was determined from mass flow rate and solids loading measurements obtained in the transfer line and refined using AY-102 sediment level and grab sample analysis data. The corresponding heat load transferred with the material was estimated from analysis of grab samples taken at various times between sluicing operations and during each campaign (Adams 1999).[a]

The first campaign began on November 18, 1998 with the first transfer of sludge from C-106 to AY-102. This operation was preceded by a number of level adjustments in which supernatant liquid only was transferred between the two tanks. These occurred on November 10, 12, and 16. Sluicing halted on November 18 when releases of volatile organic compounds (VOC) through the C-006 ventilation stack were measured in excess of 450 ppm. (The permitted limit was 50 ppm.)

Process testing was subsequently conducted to help determine the source and extent of the VOC release and to develop strategies to mitigate it. The process testing was conducted in phases and incidentally included the solids transfers constituting the balance of Campaign #1 to move the first two feet of sludge from C106 to AY102.

(a) The estimates in Table 3.1 are known to be low by about a factor of 2 from the analyses performed by Ogden and Bratzel (2000, RPP-6463, Rev. 2, Section 2.4).

Table 3.1. Summary of Transfer Operations Between C-106 and AY-102

Date	Type of Transfer	Heat Load in Batch (Btu/hr)	Sludge in Batch (gal)	Cum. Heat Load (Btu/hr)	Cum Sludge Trans. (gal)
11/18/98	Batch 1.1.1 waste transfer	680	7810	680	7810
12/16/98	Process Test, Phase 1	491	2310	1171	10,120
3/7/99	Process Test, Phase 2	2746	23,320	3918	33,440
3/28/99	Process Test, Phase 3	7548	41,965	11,465	75,405
	Totals for Campaign #1:	**11,465**	**75,405**		
4/23/99	Batch 2.1.1	331	1843	11,797	77,248
4/28,30/99	Batch 2.1.2	3166	14,603	14,963	91,851
5/24/99	Batch 2.2.1	1830	6683	16,793	98,534
6/3/99	Batch 2.2.2	9017	28,353	25,809	126,887
	Totals for Campaign #2:	**14,344**	**51,482**		
7/21,22/99	Batch 3.1.1	5208	13,365	31,017	140,252
8/4/99	Batch 3.1.2	450	1155	31,467	141,407
8/20/99	Batch 3.1.3	1826	5335	33,293	146,742
9/10/99	Batch 3.2.1	3337	8910	36,630	155,652
9/14/99	Batch 3.2.2	1823	4868	38,453	160,520
9/16/99	Batch 3.2.3	3828	11,770	42,281	172,290
9/21/99	Batch 3.2.4	1628	5005	43,908	177,295
9/24/99	Batch 3.2.5	1159	3658	45,068	180,952
9/26/99	Batch 3.2.6	793	2503	45,861	183,455
9/28/99	Batch 3.2.7	349	1100	46,210	184,555
9/30/99	Batch 3.2.8	410	1293	46,619	185,847
10/06/99	Batch 3.2.9	122	385	46,741	186,232
	Totals for Campaign #3:	**20,932**	**59,345**		
Totals for entire sluicing operation:				**46,741**	**186,232**

Phase 1 of the VOC process test was conducted on December 16 with only a small amount of sludge transferred (2,310 gal). During the test, SUMMA samples were extracted from the headspace in both tanks to characterize the VOCs released due to the disturbance of the waste. The test halted after only about an hour because of a leak detector alarm in the C-106-06C sluice pit. Several types of vapor samples were obtained during the test, but VOC release rates were measured at only about 34 ppm. Repairs to a leaking jumper and revisions of procedures to mitigate the VOC release problems resulted in the next sluicing operation being delayed for nearly three months.

Phase 2 of the VOC process test was conducted on March 7, 1999 (transferring 23,320 gal of sludge). Phase 3 was conducted on March 28, 1999 (transferring 41,965 gal of sludge). In both of these tests, additional gas samples were obtained and analyzed for VOC and other gas constituents. Measured levels of VOC gases remained very low and never again approached the high value observed in November 1998. The VOC were determined to have originated from the phosphate esters and normal parafinic hydrocarbons used for strontium-90 removal process in B-Plant in the early 1970s (Stauffer and Stock 1999).

Campaign #1 was terminated with the sluicing operation on March 28, 1999, initiating a mandated waiting period of 14 days followed by a monitoring period to evaluate the potential of flammable gas retention in AY-102 as a result of waste transferred from C-106. The evaluation consisted of monitoring the rate of change of the waste level and the gas release rate in AY-102. There was no indication of significant hydrogen gas retention in the tank during the monitoring period,(a) and Campaign #2 was initiated on April 23, 1999.

Campaign #2 consisted of four batches that proceeded without significant problems and was terminated on June 3, 1999 with batch 2.2.2. A second waiting and monitoring period was initiated in which the tank again showed no significant tendency toward flammable gas retention.(b)

Campaign #3 began 48 days later, on July 21, 1999, preceded by addition of about 5,000 gal. of caustic to C-106. Campaign #3 consisted of 12 batches in which smaller and smaller quantities of solids were sluiced as there was less waste in C-106 to be mobilized. The campaign was ended with batch 3.2.9 on October 6, 1999. Sluicing operations were considered complete, and sluicing line mass flow measurements (Table 3.1) indicated that about 186,000 gal, or 97% of the sludge in C-106, had been transferred to AY-102.

The history of the three sluicing campaigns is illustrated in Figures 3.1 through 3.6, which show the changes in liquid waste surface level and sludge level in AY-102 over the approximately 12-months of the operation. The net volume change in AY-102 over the entire sluicing program can be calculated simply from the net 57.5-in. surface level change as 158,000 gal. This number includes additions due to activities such as line and instrument flushes. From information recorded in the SACS Comments sheets from the data logs, these

---

(a) Cuta JM, BE Wells, and CW Stewart. April 1999. *Assessment of Flammable Gas Retention.* Letter report C106S99.02, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

(b) Cuta JM, DL Lessor, SA Bryan, CM King, LR Pederson, and CW Stewart. July 1999. *Assessment of Flammable Gas Retention Potential for WRSS Campaign #3.* Letter report C106S99.03 Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

additions totaled 7,488 gal. This indicates that the portion of the net volume change that is due to sluicing from C-106 was 151,000 gal.

During Campaign #1, the liquid level increased by 4.2 in., as shown in Figure 3.1. This includes level changes due to additions for sluicing line and instrumentation flushes, which totaled 3,170 gal during the five-month campaign. This volume of water is equivalent to 1.15 in., so the increase due to sluicing was approximately 3 in. Based on densitometer measurements and the validation probe temperature profiles, Figure 3.2 indicates that the sludge level increased by approximately 17 inches during Campaign #1.

The sluicing batches and level changes during Campaign #2 are illustrated in Figure 3.3. The overall waste level rise was approximately 29.3 in. during this campaign. This was due almost entirely to sluicing operations because liquid additions due to line and instrument flushes during the three-month interval of this campaign totaled only 2,580 gal. This is equivalent to a level of rise of only 0.94 in. Figure 3.4 shows that the sludge level increased by approximately 21 in. during Campaign #2.

The sluicing batches and level changes during Campaign #3 are shown in Figure 3.5. This was by far the most intense campaign, consisting of two increments comprising a total of 12 separate batches. In addition, a level adjustment was made on July 9 in which approximately 25,000 gal of supernatant liquid was pumped out of AY-102 back into C-106 for a caustic addition, lowering the surface level in AY-102 by about 9 in. The net increase in the liquid waste surface level in AY-102 during this campaign was 24.2 in. Figure 3.6 shows that the measured increase in the sludge depth was approximately 21 in.

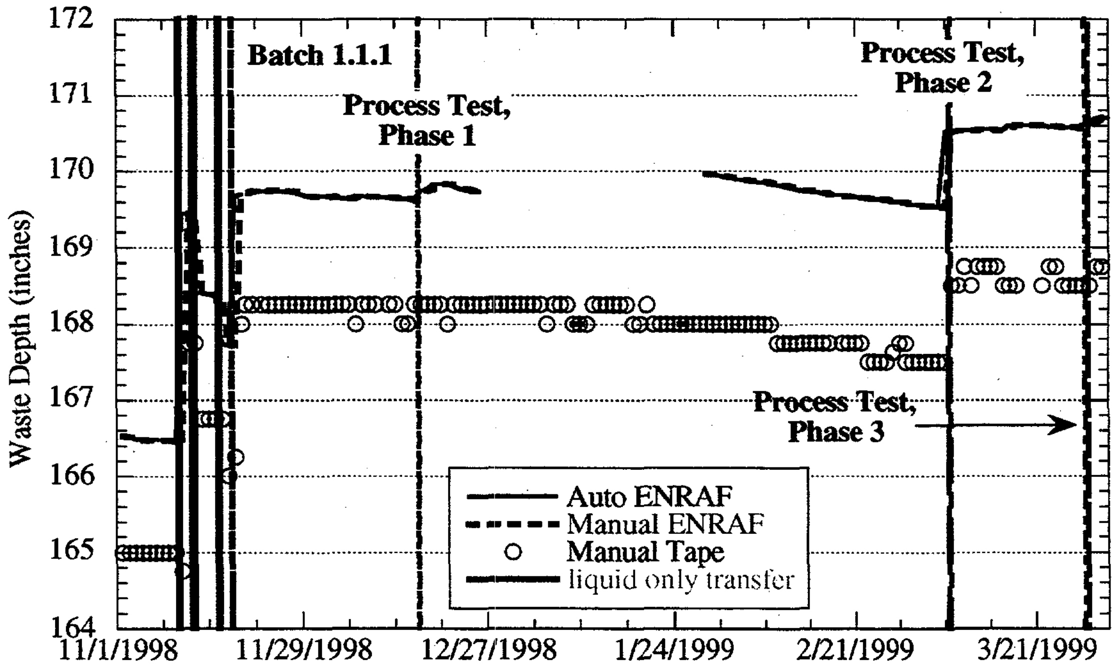

Figure 3.1. A-102 Waste Level During Campaign #1

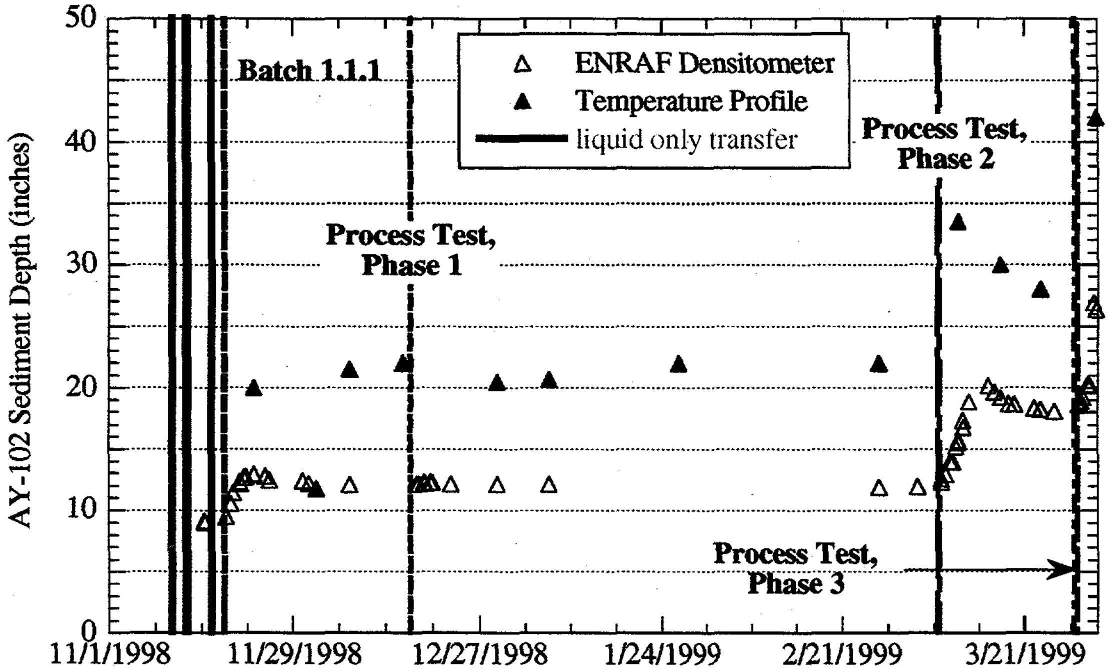

Figure 3.2. AY-102 Sediment Level During Campaign #1

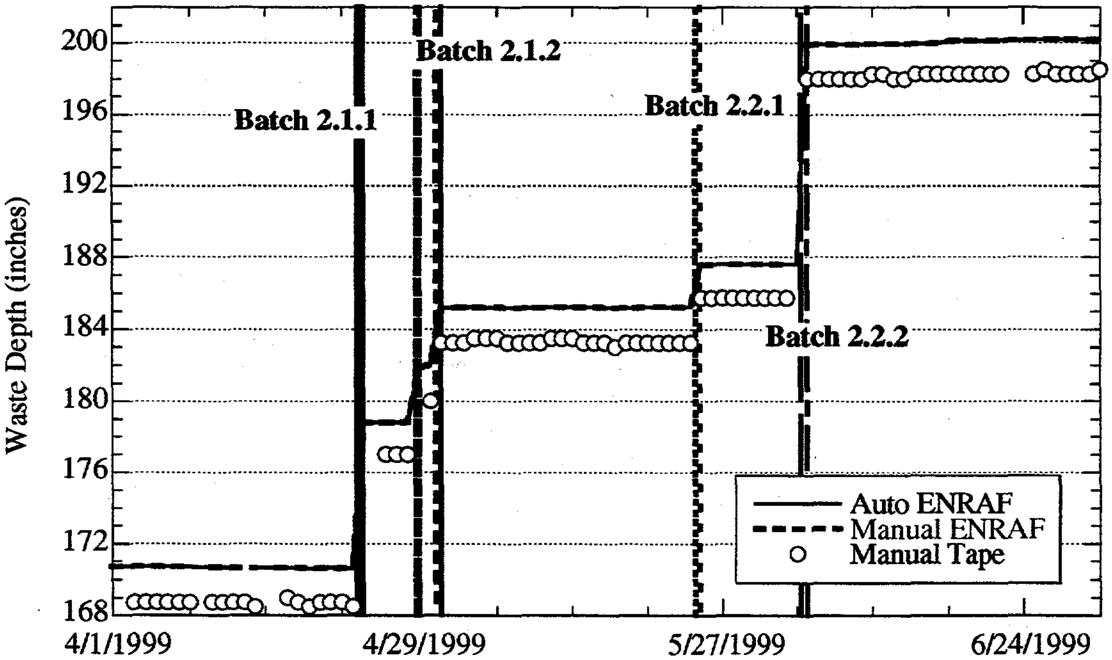

Figure 3.3. AY-102 Waste Level During Campaign #2

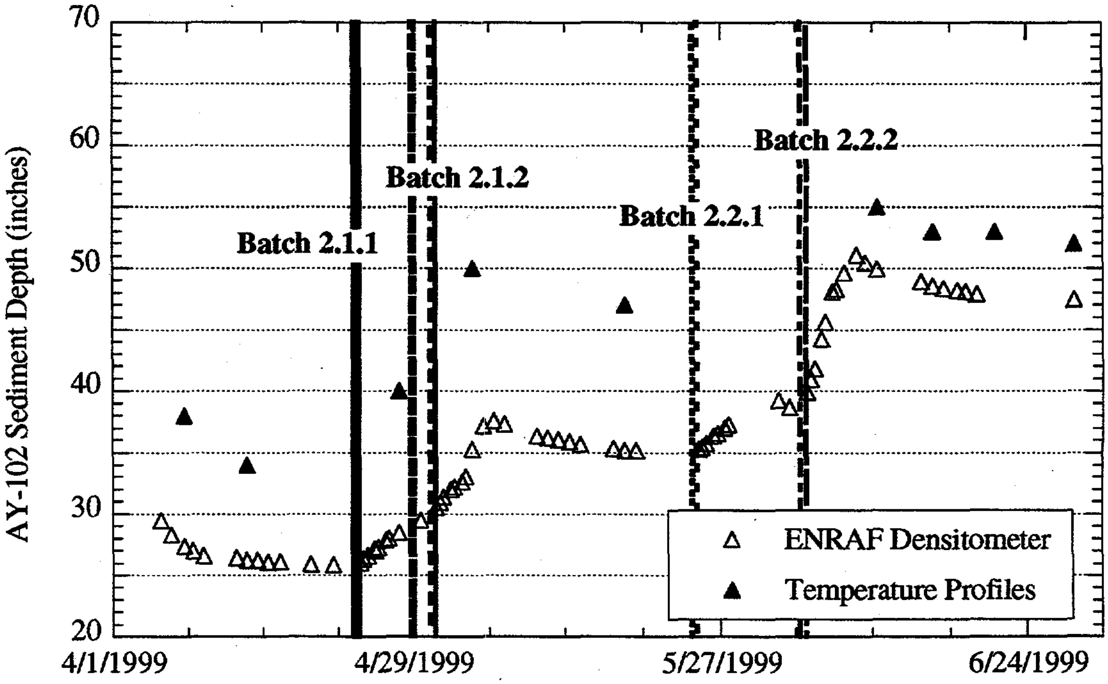

Figure 3.4. AY102 Sediment Level During Campaign #2

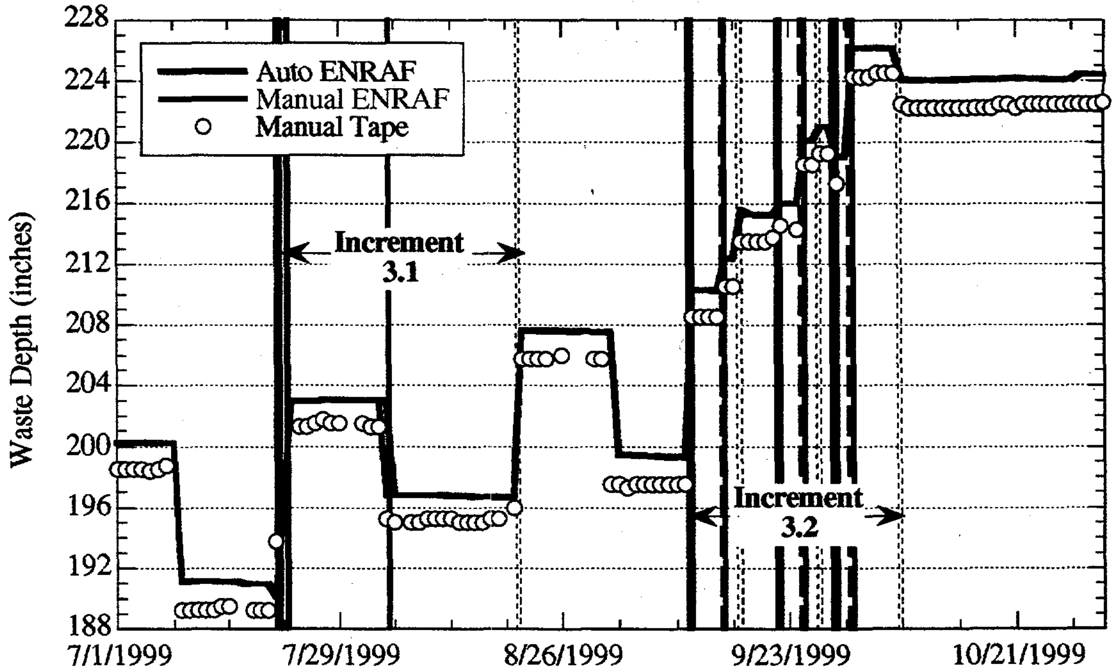

Figure 3.5. AY-102 Waste Level During Campaign #3

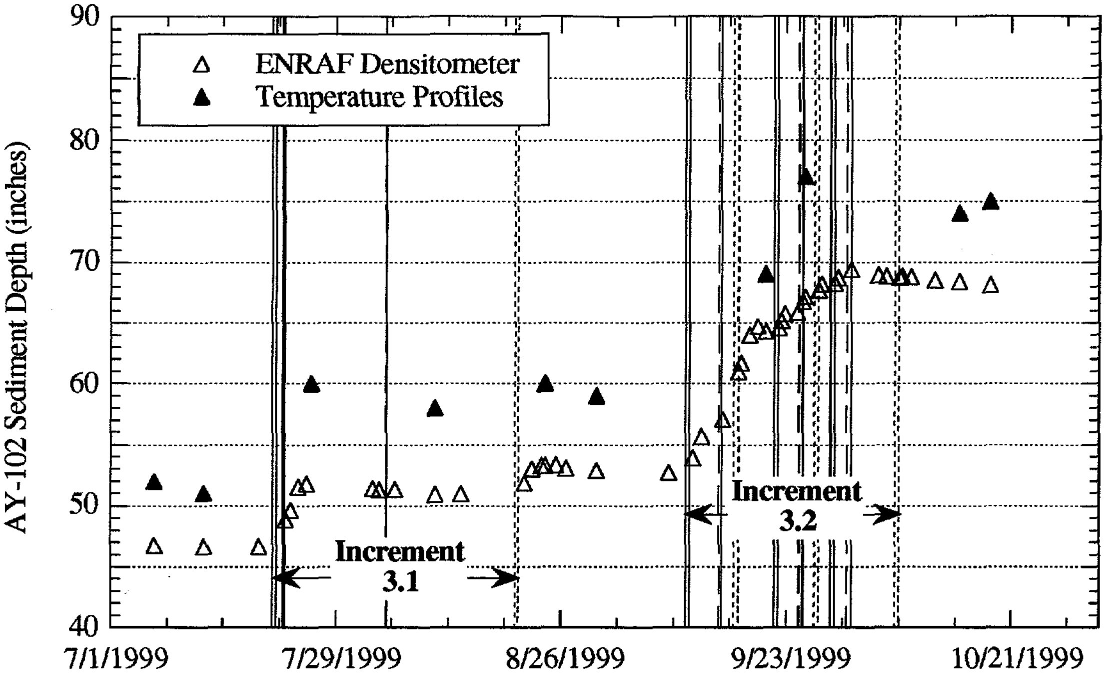

Figure 3.6. AY-102 Sediment Level During Campaign #3

The total thickness of the new sludge layer in AY-102 was 69–70 inches at the end of Campaign #3. Further settling of solids over the next four weeks decreased the sludge depth to about 68 in. via the densitometer. The last densitometer measurement was taken July 27, 2000 at about 66 in. The temperature profile on February 16, 2000 indicated a sediment level of approximately 69 in. A level of 64 in. can be inferred from the temperature profile on June 7, 2000.

3.2 Summary of WRSS Data for AY-102

The following subsections show the measured data from Tank AY-102 during the 12 months of sluicing operations, presenting a broad overall picture of behavior in the tank and the response to waste transfer activities. Tank instrumentation consists primarily of thermocouples in the waste, tank headspace, and on the tank bottom in the insulating concrete beneath AY-102. Waste level, headspace and annulus vent airflow rates, and headspace hydrogen concentration are also measured.

3.2.1 Sludge Temperatures in AY-102

Figure 3.7 shows the temperatures for the sludge four inches from the bottom of Tank AY-102 from November 1, 1998 to November 1, 1999 as measured by thermocouples on risers 13A-D, 16A, and 16C. Figure 3.8 shows temperatures three in. from the bottom of the tank measured with the thermocouples on the airlift circulators (riser 3). All of these instruments show a decrease of about 5–8°F from November 1998 to early March 1999 due both to seasonal

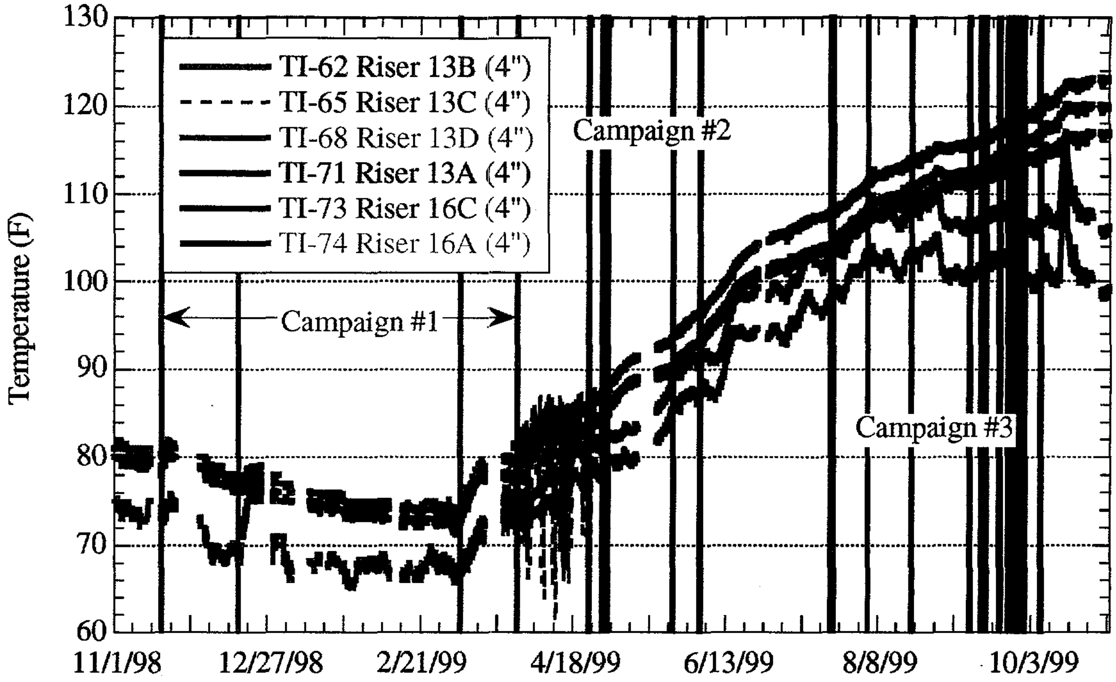

Figure 3.7. AY-102 Temperatures 4 in. above Tank Bottom (risers 13A-D, 16A, and 16C)

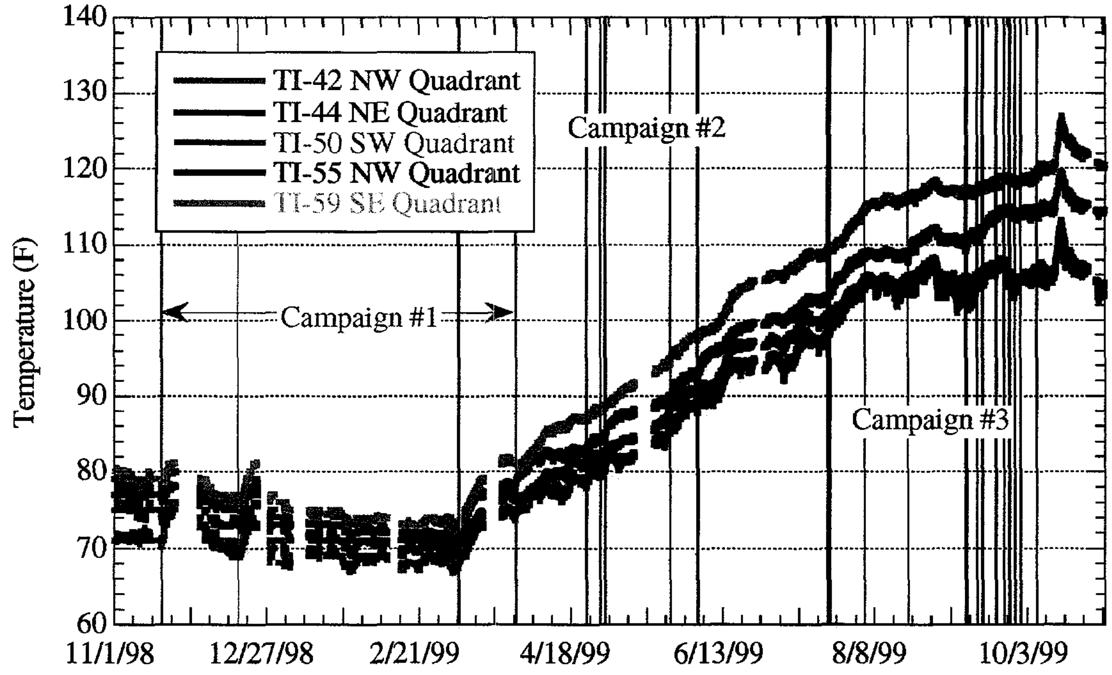

Figure 3.8. AY-102 Airlift Circulator Temperatures (3 in. above tank bottom)

cooling and operation of the annulus ventilation at high flow. Temperatures do not seem to be much affected by the transfer of approximately 10,000 gal of sludge to AY-102 in batch 1.1.1 and VOC test, Phase 1. With the sluicing operation of the VOC test, Phase 2 on March 7, 1999, however, all temperatures shown in these figures begin to climb. The rate of increase becomes slightly steeper for a time following each major sluicing campaign, but the overall rate of increase is relatively steady.

The riser 13 thermocouples, which are on the periphery of the tank, show temperatures that increase at approximately the same rate, with only a slight increase in the spread of temperatures. This indicates that the C-106 sludge, which was added to AY-102 through four opposing nozzles that distributed the slurry horizontally below the liquid surface, did a reasonably good job of spreading the incoming sludge uniformly. The sludge temperatures indicated by the riser 13 thermocouples by November 1, 1999 range from 117° to 123°F.

The temperatures nearer the center of the tank, on riser 16 and the airlift circulators (riser 3), also show a significant increase starting with the third sluicing operation of Campaign #1. The effect is mitigated, however, by cooling from below the tank due to annulus ventilation drawing air through channels in the concrete beneath the tank. The peak temperature reached by the riser 16 thermocouples is only about 100–110°F before the curves level off and even begin to show some slight downward trend. The airlift circulator temperatures show a similar pattern. (The sharp post-sluicing temperature spike seen on these plots is due to an interval when the annulus ventilation system was not operating.)

The 10 temperature measurements shown in Figures 3.7 and 3.8 give reasonably complete coverage of the tank bottom (refer to Figure A.2 for a radial map of the thermocouple locations). However, the loss of TI-65 and TI-50 in April 1999 greatly reduced the coverage of the southwest quadrant. After April 1999 there were only two measurement locations on the edges (the MIT in riser 5A and TI-73 on riser 16C) to represent the quadrant.

As of November 1, 1999, the range of temperatures across the bottom of the tank was 98–123°F, giving a radial variation in measured temperature of approximately 25°F. The range of variation has approximately doubled, from 10–12°F before sluicing began. Thermocouples in the same general region of the tank continue to give very similar readings, however. The local variation in temperature can be characterized by the comparisons in Table 3.2.

Table 3.2. Local Variation in Sludge Temperatures

Thermocouples in same general region	Temperatures
TI-73, TI-42	106° and 104°F, respectively
TI-74, TI-44	98° and 104°F, respectively
TI-68, TI-55	120° and 114°F, respectively

This comparison shows that the local variation in temperature within a region is relatively small (perhaps no more than about 5° to 6°F), and therefore the greatest part of the regional variation must be the result of active cooling through the channels in the concrete beneath the tank. The hottest region in the sludge appears to be the outer edge of the northwest quadrant, and the coolest region is the central area of the tank.

3.2.2 Supernatant Liquid Temperature in AY-102

Figure 3.9 shows temperatures measured on risers 13A–D with thermocouples located 158 in. above the bottom of AY-102. This instrument was initially submerged approximately 7 in. in the supernatant liquid layer and was 145–150 inches above the sludge layer. By the end of sluicing operations, increases in the liquid level have resulted in these instruments being about 67 in. below the surface of the supernatant liquid layer and only 85–90 inches above the new sludge layer. Risers 13A–D are near the periphery of the tank, and all four thermocouples at this level indicate essentially identical temperature changes throughout the entire year.

The temperatures decrease for the first four months (consistent with the observed behavior of the sludge temperatures noted above), reaching a low temperature of about 68°F just before sluicing operation VOC test, Phase 2. The temperatures increase steadily thereafter, with step increases of 2–4°F in response to each sluicing operation's bringing more material from C-106 to AY-102. The supernatant liquid temperature as of November 1, 1999 is approximately 92–93°F and shows a continued increasing trend.

3.2.3 Headspace Air Temperature in AY-102

Figure 3.10 shows the temperatures in the headspace based on the thermocouples on risers 13A–D at 300 in. Initially, this location was approximately 135 in. above the liquid surface in the tank. By the end of sluicing operations, the liquid level had risen so the instruments were only about 75 in. above its surface. Throughout the year, all four thermocouples showed essentially identical traces, which is to be expected. As with the thermocouples in the sludge and supernatant liquid layer, the air temperature shows a seasonal decrease through the winter months until VOC test Phase 2. At that point, the temperatures began to increase at a rate consistent with the observed behavior in the sludge and supernatant layers.

The headspace air temperature rises steadily from March through most of August, leveling off to an approximately constant value of about 86–87°F about halfway through Campaign #3. The temperature does not increase after this and shows a slight decrease over the remainder of Campaign #3, even though an additional 30,000 gal or so of sludge (containing about 18% of the total heat load transferred from C-106 to AY-102) was transferred to the tank in September and October. The sharp spike of 3–4°F post-sluicing is due to temporary shutdown of the tank headspace ventilation system (refer to Section 3.2.6).

The net change in headspace air temperature between November 1, 1998 and November 1, 1999 is about 10°F. Most of this rise can be attributed to the increased heat load added from C-106 rather than to differences in ambient conditions. The monthly average ambient air temperature for November 1999 was within 0.5°F of the value calculated for November 1998. Overall, the differences in daily average temperature ranged from less than half a degree to nearly 20°F, and differences in hourly temperatures were as large as 30°F, but these measurements are fluctuations about the same seasonal mean temperature of 46 to 47°F.

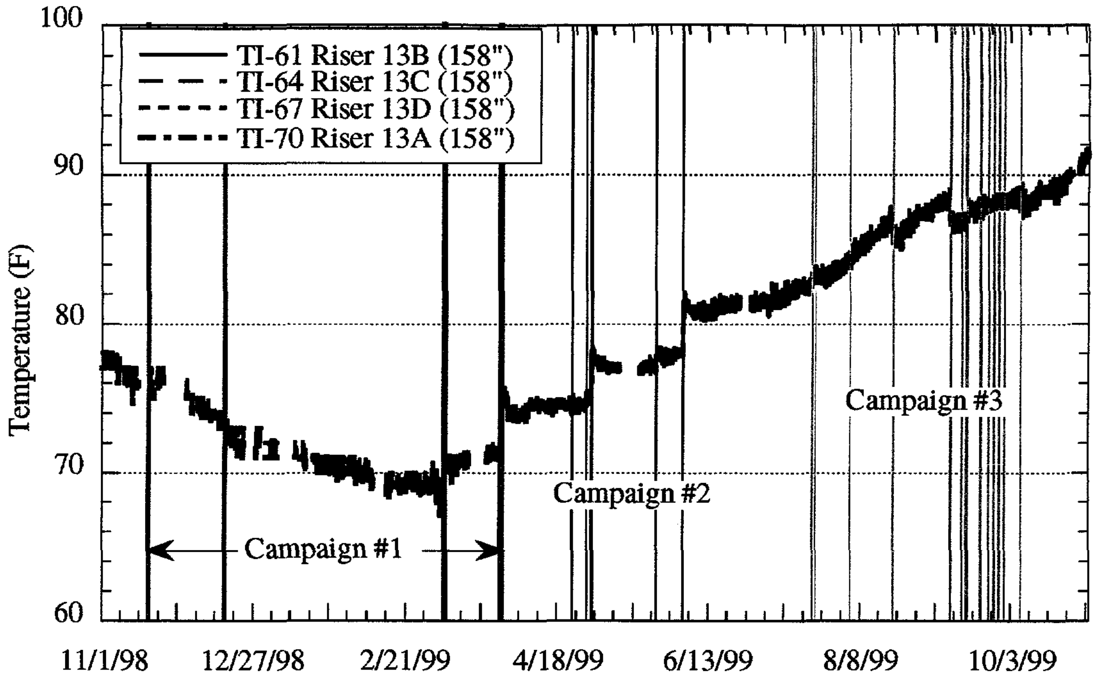

Figure 3.9. AY-102 Temperatures at 158 inches above Tank Bottom (risers 13A–D)

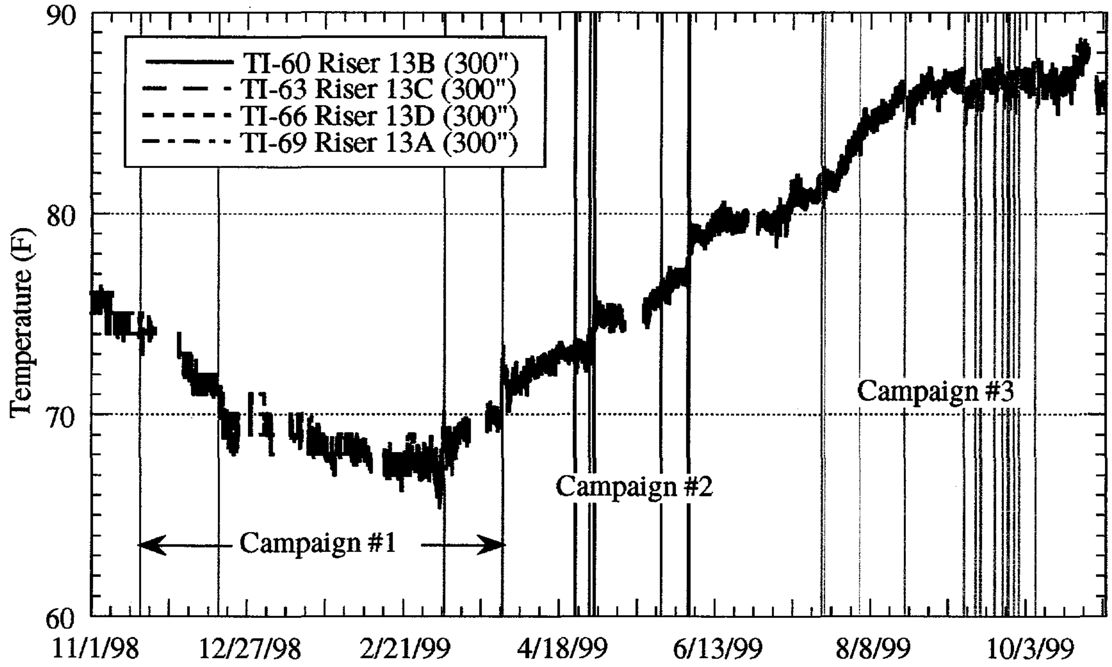

Figure 3.10. AY-102 Temperature 300 in. above Tank Bottom (risers 13A–D)

3.2.4 Tank Bottom Temperatures in Insulating Concrete Beneath AY-102

Thermocouples are installed in the insulating concrete beneath AY-102 at radii of 7 ft, 21 ft, and 36.5 ft to provide measurements of the tank bottom temperature. The venting arrangement is such that air is piped directly to the center of the tank and flows radially out from the center through channels spaced approximately 20 degrees apart (see Figure A.2 for a detailed map of the thermocouple locations and vent channels under the tank). Figures 3.11 through 3.13 show plots of these measured temperatures at radii of 7 ft, 21 ft, and 36.5 ft, respectively. For convenience, these plots show daily rather than hourly averages of the thermocouple readings. The curves are smoother than the hourly averaged data but have exactly the same shape.

In general, the variations in the tank bottom temperatures from November 1, 1998 to November 1, 1999 follow the same pattern as the waste temperatures in AY-102. There is an initial seasonal decrease during the winter followed by a steady increase as sluicing adds to the heat load. The temperature rise is also in part a response to the increasing ambient air temperature brought in by the annulus cooling system. (The sharp spikes in the temperatures, most noticeable in Figures 3.11 and 3.12, correspond to intervals when the annulus ventilation system was off-line.) The rate of temperature rise flattens out in the fall with the advent of cooler weather, even though new heat generating material was added to the tank in September and October.

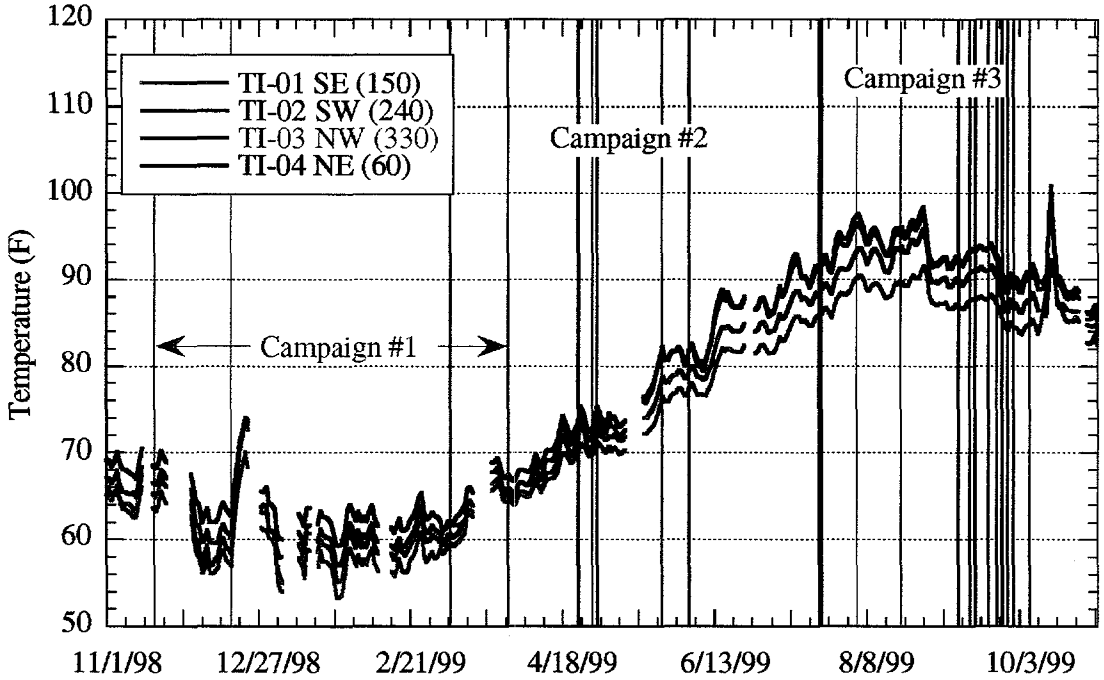

Figure 3.11. AY-102 Tank Bottom Temperatures at 7-ft Radius

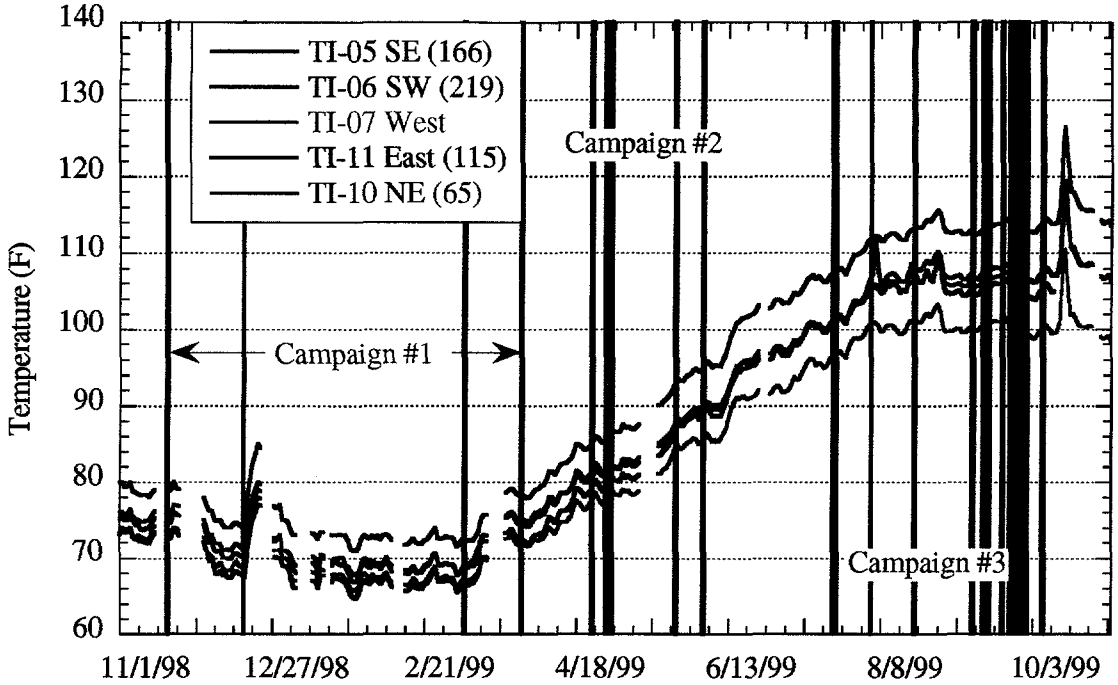

Figure 3.12. AY-102 Tank Bottom Temperatures at 21-ft Radius

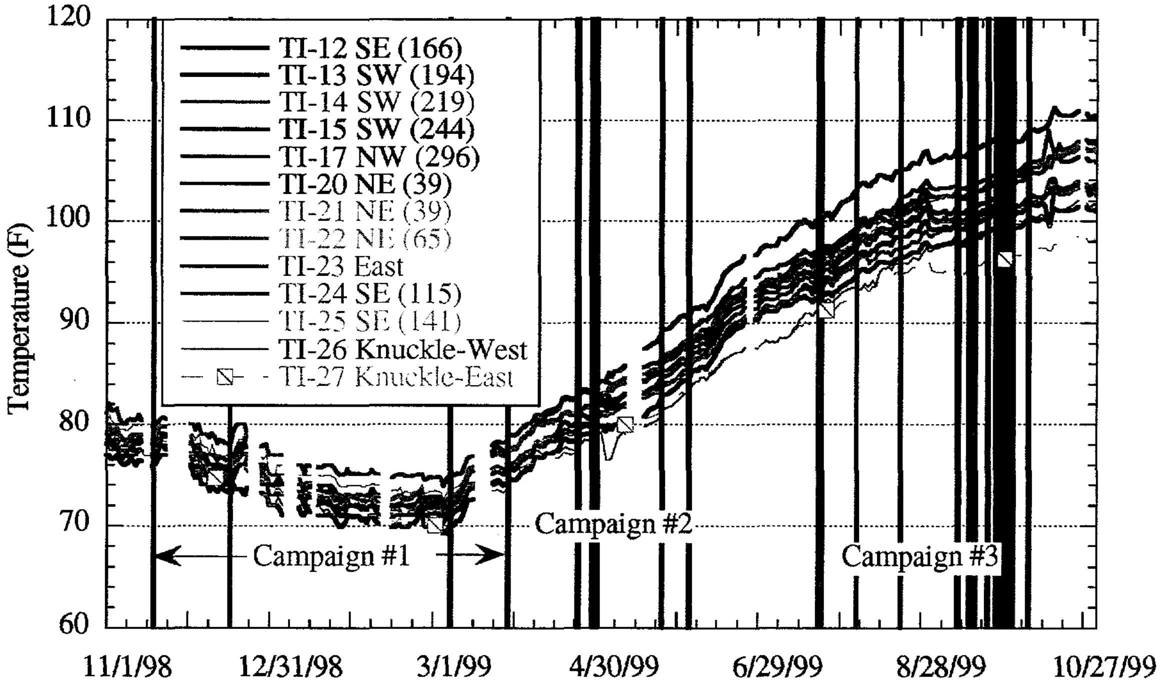

Figure 3.13. AY-102 Tank Bottom Temperatures at 36.5-ft Radius

The temperature plots in these figures show that the coolest temperatures are at the 7-ft radius and the hottest at the 21-ft radius. The periphery of the tank, at the 36.5-ft radius, is only slightly cooler. This is summarized in Table 3.3, comparing the average temperature and the range of temperatures at each radius.

This pattern is the result of the airflow from the annulus being delivered under the center of the tank and forced to flow radially outward through the vent channels. Whenever forced convection cooling is curtailed or cut off, the tank bottom temperatures at all locations rise rapidly.

Table 3.3. Tank Bottom Temperatures in Insulating Concrete (11/1/99)

Radius	Average temperature	Range of temperatures
7 ft	84°F	82–86°F
21.5 ft	106°F	98–113°F
36.5 ft	105°F	101–110°F

3.2.5 Vertical Temperature Profile in AY-102

The vertical temperature profile in the waste in AY-102 was monitored by periodically running a validation probe down the multifunction instrument tree (MIT) in riser 5A (at tank radius 32 ft, 180° azimuth). Profiles were obtained after nearly every sluicing batch, at the end of each campaign, and before the next campaign began. Measurements were recorded at elevations from 11 to 440 in. above the tank bottom. Figure 3.14 shows the evolution of the temperature profile as sluicing proceeded. It shows profiles before and after each campaign, including the first validation probe profile obtained in August 1998 during the hottest part of the year, before sluicing operations began.

These profiles reflect the seasonal temperature drop during the winter. The profile in March 1999, at the end of Campaign #1, has supernatant and headspace air temperatures 3–5°F lower than in August 1998. The highest measured sludge temperature, however, is nearly 5°F higher than the August temperature at the same level, and the slope of the profile shows the greater depth of the nonconvective layer. The profile obtained about four weeks later, just before the beginning of Campaign #2 in April, shows that the supernatant temperature continued to drop 1–2°F, but the sludge temperature continued to climb, increasing by about 6–7°F during the monitoring period between the two campaigns.

The profile obtained after Campaign #2 started shows that the temperatures in the headspace air, supernatant liquid, and sludge all continued to climb as sluicing operations proceeded. The profile at the end of Campaign #3 shows an increase of more than 10°F in the supernatant liquid layer and more than 20°F in the sludge. The latest profile obtained after the end of sluicing operations was performed almost a month after the end of Campaign #3, on November 2, 1999. This profile seems to indicate that a parabolic temperature distribution is being established within the nonconvective layer as heat is removed by natural convection in the supernatant liquid layer and by forced convection through the vent channels in the concrete beneath the tank.

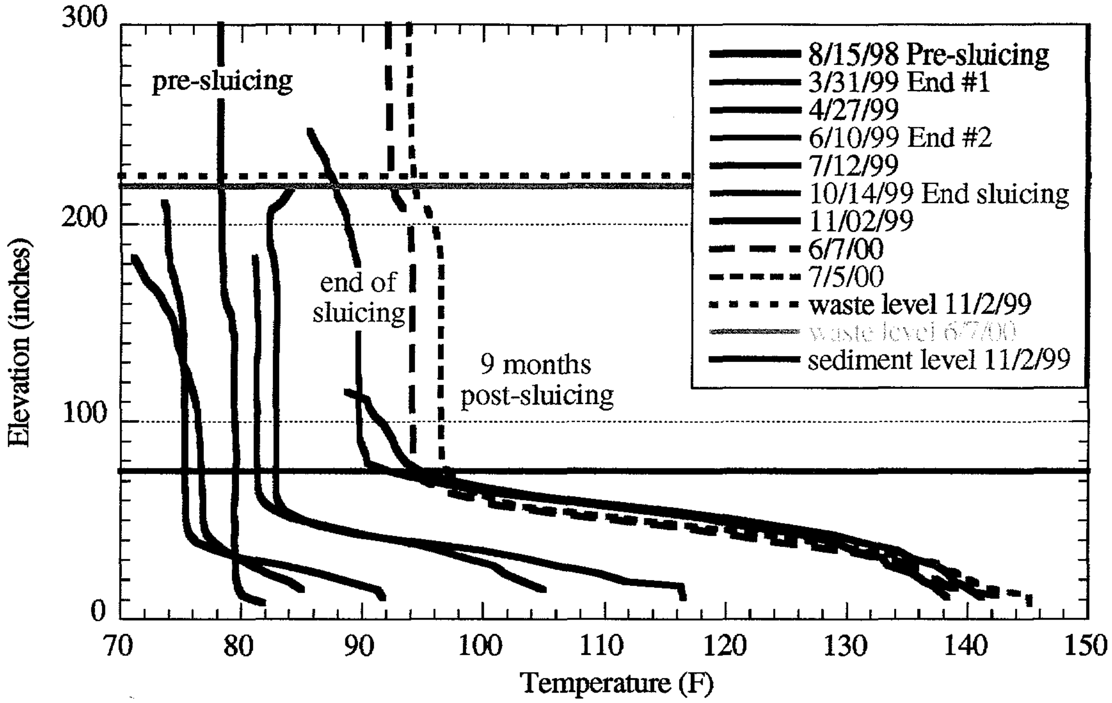

Figure 3.14. AY-102 Evolution of Temperature Profile During and after Sluicing

The very short length of the 11/2/99 profile that extends into the convective layer appears somewhat anomalous compared with earlier profiles. It has a different slope than the nonconvective layer, but it does not show the essentially uniform temperature characteristic of the convective layer. This may be due to operational procedures that did not allow sufficient time to establish thermal equilibrium at these levels, or it may be due to a settled layer of fine solids lying on top of the nonconvective layer and identified from Enraf densitometer measurements.

3.2.6 Ventilation System Performance in AY-102

Figure 3.15 presents data summarizing the performance of the annulus ventilation system during sluicing operations from November 1998 to November 1999. The exhaust fans ran at an essentially constant rate throughout the 12-month period with only a few relatively brief outages for maintenance or equipment modifications. Because of the seasonal variation in air temperature, the actual air flow rate varied from about 900 scfm in the winter months to 825–850 scfm during the summer months. The exhaust air temperature (indicated by TI-0620) follows a similar seasonal variation with a low of around 65°F in the winter to a high of approximately 85°F in the summer.

Figure 3.16 shows that the tank headspace exhaust airflow rate (indicated by FI-AY2K1-2) varied about 300 to 350 scfm during the approximately 12 months of sluicing operations. A headspace air recirculation system that included an evaporative cooler was operating part of the time, as can be seen from the headspace air temperature measurements shown in the figure. Glycol is the primary coolant in the system, with an evaporative spray cooler as the heat sink.

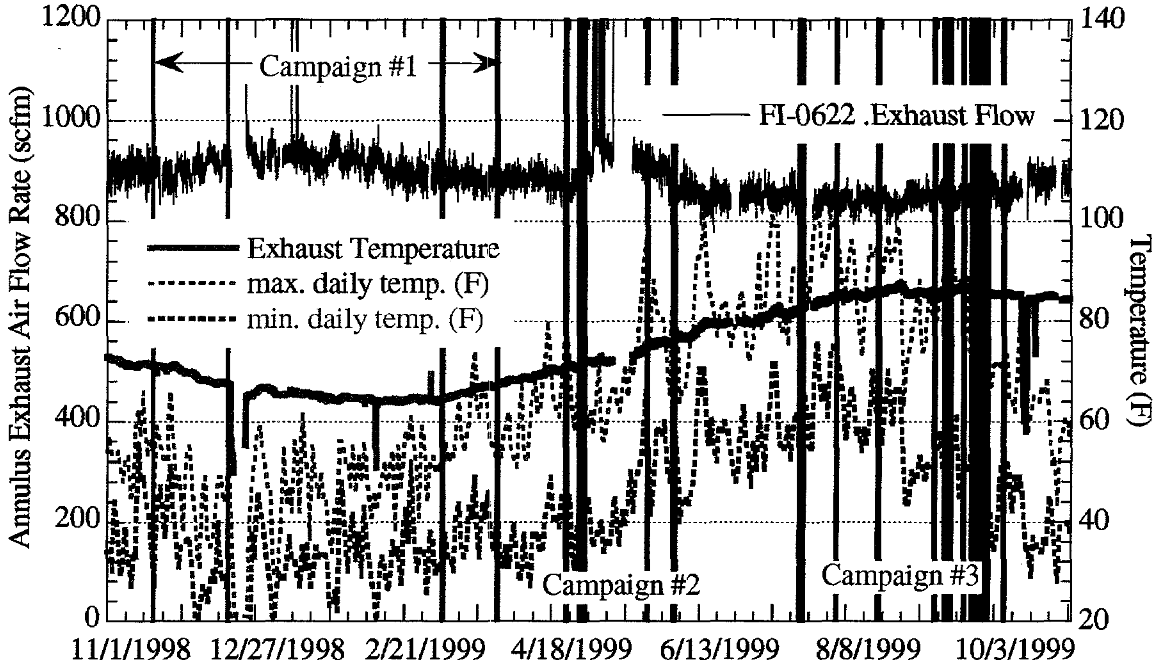

Figure 3.15. AY-102 Annulus Ventilation System Flow Rate and Temperatures

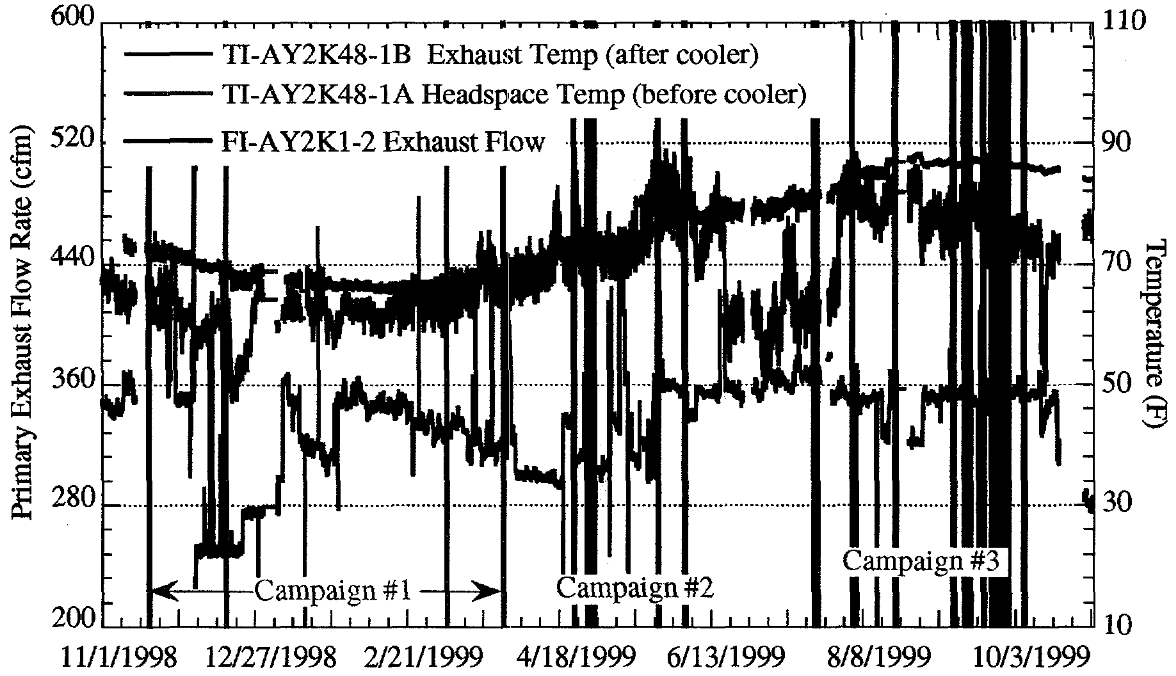

Figure 3.16. AY-102 Tank Headspace Ventilation System Flow Rate and Temperatures

The headspace air temperature before entering the cooling system (TI-AY2K48-1A) is virtually identical to that of the headspace air temperature measured by the riser 13 thermocouples 300 in. above the tank bottom (see Figure 3.10). This means that the air temperature above the liquid waste surface is essentially uniform throughout the headspace.

The air temperature after passing through the cooling system (TI-AY2K48-1B) shows somewhat erratic behavior. At times it is as much as 10–15°F below the temperature before the cooler. At other times, the temperature after the cooler is not significantly different from the temperature before the cooler. At all times, however, the temperature after the cooler varies in a diurnal cycle following that of the ambient air temperature. At one period in early June, this temperature was actually hotter by about 5–10°F than that the temperature before the cooler. This behavior indicates that the secondary side of the cooling system was not always operating, and even when it was working, it did not operate at a very high efficiency.

Figure 3.17 confirms this by showing the performance of the primary side of the cooler. The glycol coolant flow rate is essentially constant and so high that little temperature change occurs in the coolant from inlet to outlet. The glycol coolant temperature follows the diurnal temperature fluctuations, and there are intervals when the glycol coolant temperature is the same as the ambient temperature. These are intervals when the evaporative cooling system was deactivated for operational reasons, and in at least one case, the recirculation cooler was actually warming the air in the tank headspace, rather than removing heat from it.

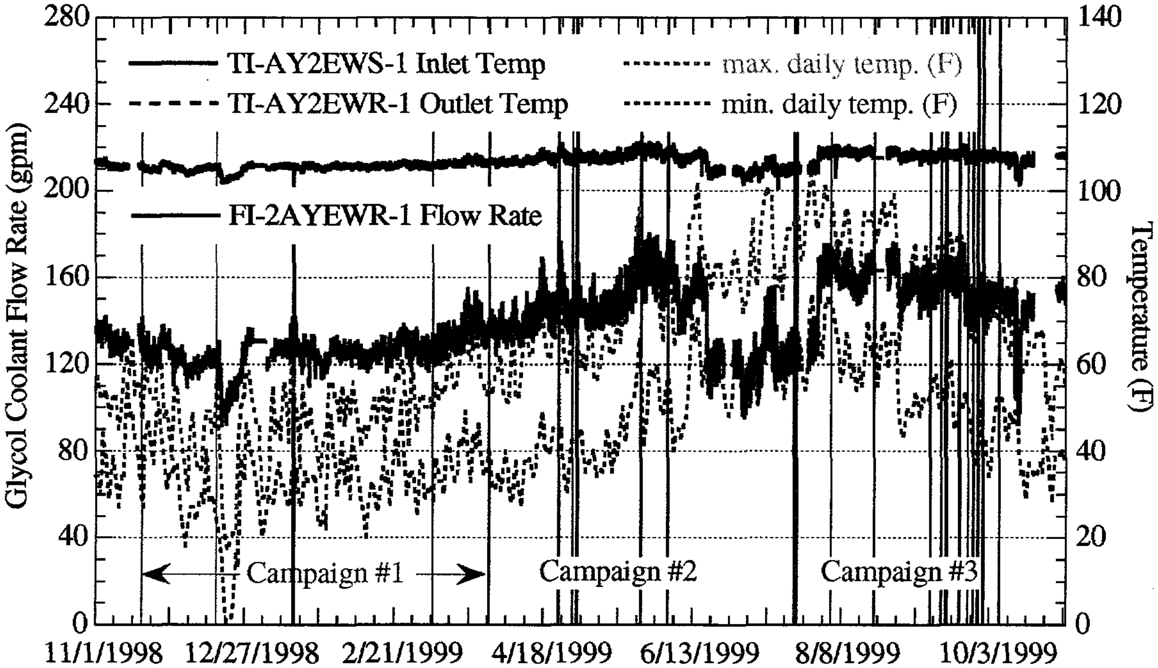

Figure 3.17. AY-102 Ventilation System Glycol Coolant Flow Rate and Temperatures

Despite the somewhat erratic performance of the headspace cooling system, the evaporation rate from the tank remained fairly constant all during sluicing operations. This is shown by Figure 3.18. The headspace exhaust air humidity was relative constant at 100% throughout most of the 12-month period, and the incoming ambient air was extremely dry. The amount of evaporation shows a distinct seasonal variation, tending to increase with the increasing temperature of the incoming ambient air during the summer and to decrease in the cool weather of the winter. The only significant exception to this trend occurred when the cooling system was operating with unprecedented efficiency for about six weeks, from mid-June to the end of July, recirculating and cooling the headspace air.

During this period, heat was being actively removed from the headspace air, and the amount of water carried out with the exhaust air was only slightly greater than the amount of water coming in with the ambient air. Recirculation cooling of the headspace air was effective enough for the exhaust air temperature to follow the minimum ambient air temperature (see Figure 3.17). This efficient cooling was not maintained, however, and at the end of July evaporation losses increased, and the coolant temperature returned to the previous pattern of following the daily ambient air temperature cycle. It appears that the spray cooling to the evaporator was turned off for some reason or severely curtailed from that point onward.

3.2.7 Hydrogen Release in AY-102

Figure 3.19 shows the hydrogen concentration (in ppm) measured on riser 15C in Tank AY-102 from November 1, 1998 to November 1, 1999. During sluicing operations, the hydrogen concentration in the tank headspace rose sharply due to gas release from the incoming C-106 waste. Between sluicing operations, the concentration tended to drop to a slightly lower level

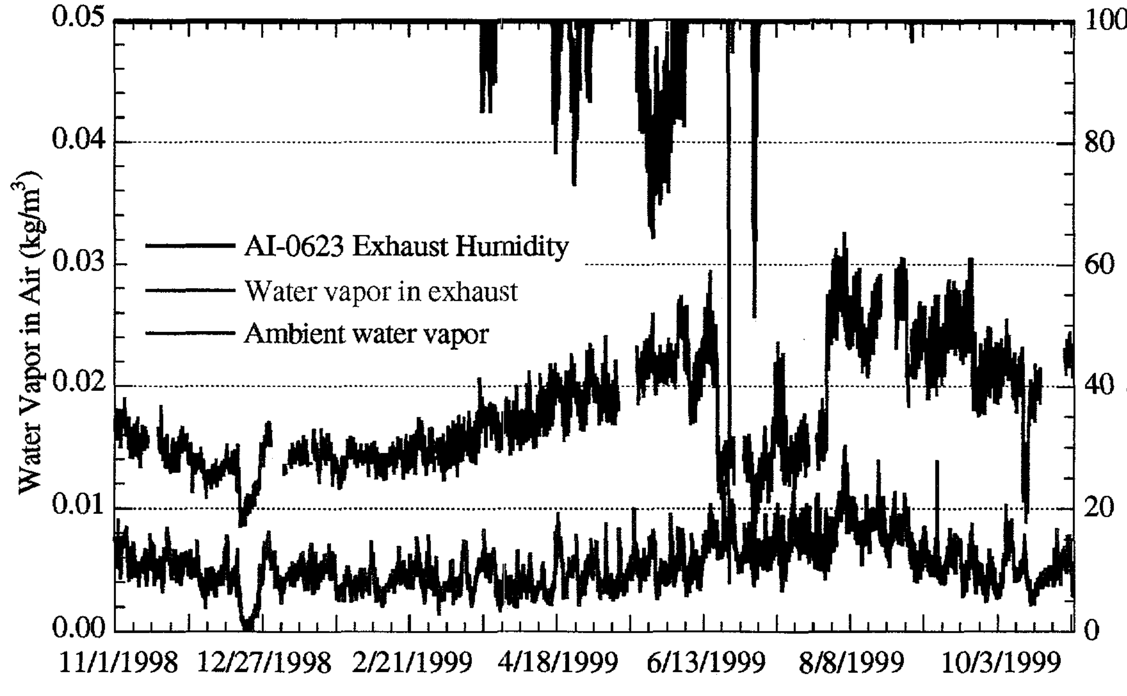

Figure 3.18. AY-102 Water Vapor in Inlet and Exhaust Air

than before a given operation, and by the end of sluicing, the nominal concentration was only about half of what it had been before the start of sluicing in November 1998. A short time after the end of Campaign #3, however, the concentration began to trend upward.

The ventilation flow rate for AY-102 was relatively constant all during the 12 months of sluicing operations, so the volumetric release rate of hydrogen followed much the same pattern as the concentration data shown in Figure 3.20. The release rate showed a tendency to drop as sluicing operations proceeded, raising the concern that flammable gas was being retained in AY-102 as the waste depth increased with transfers from C-106. This trend was seen by comparing the release rate with the baseline release rate determined before sluicing operations began.

The baseline for hydrogen release from AY-102 and C-106 was determined from the release rates measured prior to sluicing, from August 1, 1998 to November 6, 1998. (Appendix C contains a detailed description of the analysis used.) The mean release rate for AY-102 over this interval was 23.5 scfd, with a median of 23.7 scfd. The 95% confidence bounds for AY-102 release rates are 18.9–27.8 scfd. Therefore, the best estimate of hydrogen release rate for this tank before sluicing operations began is 24 scfd (upper bound 28 scfd and lower bound 19 scfd).

Monitoring of the level rise and hydrogen gas release rate during the intervals between campaigns showed no long-term trend of gas retention. The release rate was below the baseline value at the end of sluicing despite the increase in the amount of gas-generating material that had been added to AY-102. This was showing an upward trend by the end of November, however.

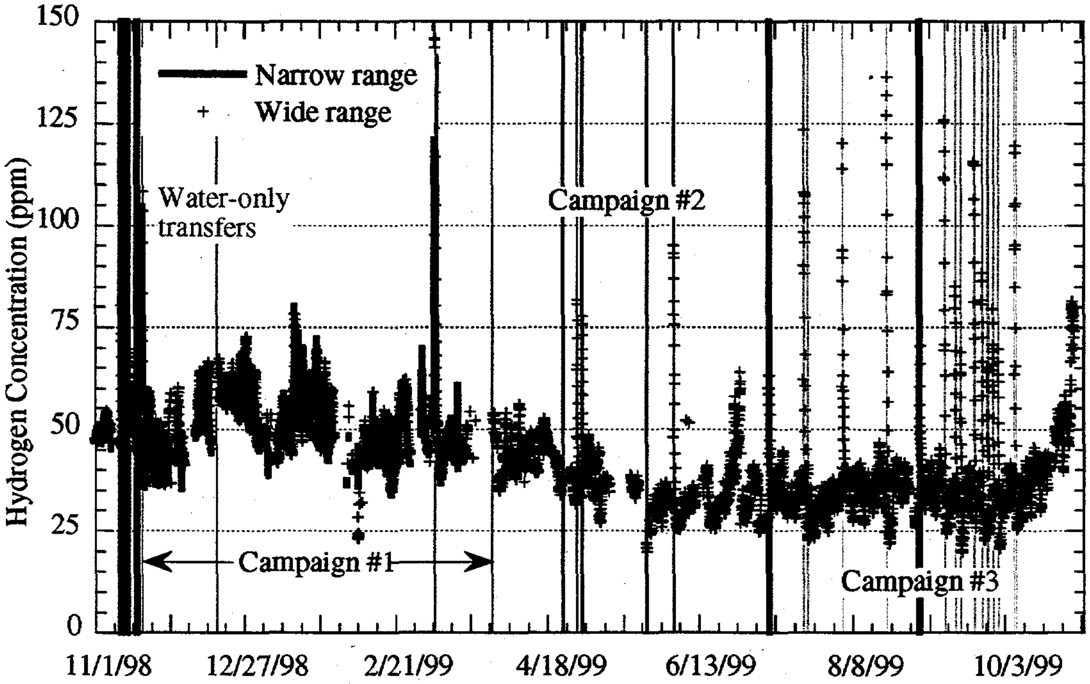

Figure 3.19. AY-102 Headspace Hydrogen Concentration (riser 15C gas chromatograph)

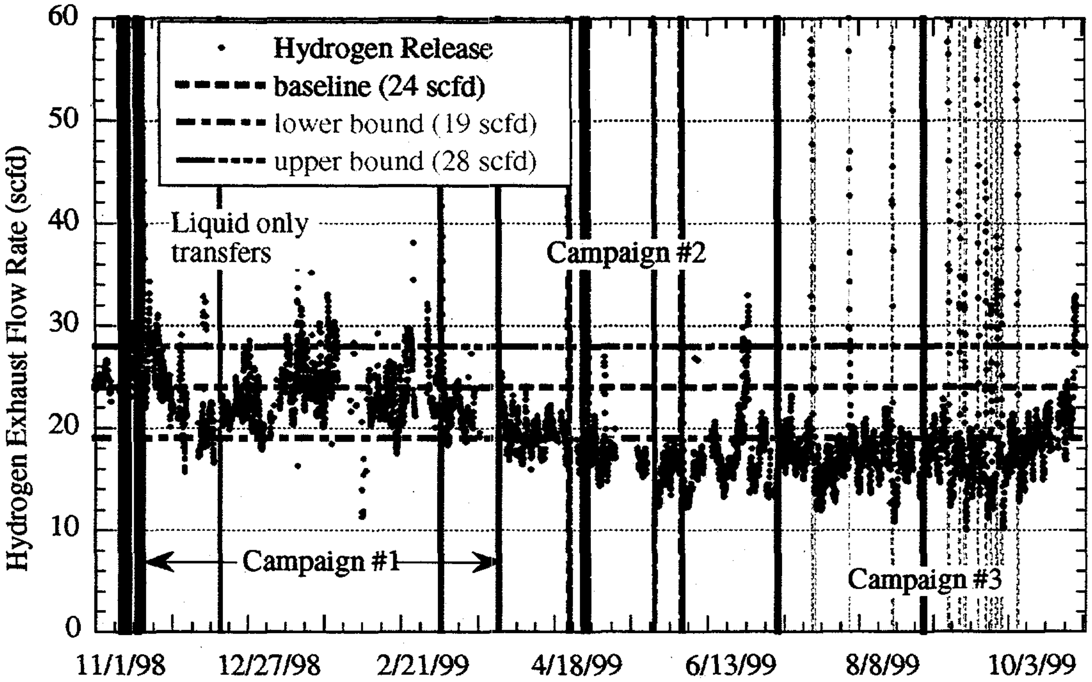

Figure 3.20. AY-102 Volumetric Flow of Hydrogen in Exhaust Air

The hydrogen concentrations measured in AY-102 during the 12 months of sluicing operations were far below the lower flammability limit (LFL) for hydrogen, which is 40,000 ppm. The highest measured hydrogen concentration between sluicing operations was approximately 75 ppm, which is less than 0.2% of the LFL. The highest concentration measured during sluicing was on the order of 150 ppm, which is less than 0.4% of the LFL.

3.3 Summary of WRSS Data for C-106

The following subsections present measured data from Tank C-106 during the 12 months of sluicing operations, presenting a broad overall picture of behavior in the tank and the response to waste transfer activities. Tank instrumentation for C-106 is relatively sparse compared with AY-102. Waste temperatures are measured in only two radial locations, by means of multiple instrument trees in riser 8 (at 33.3-ft radius) and in riser 14 (at 15.6-ft radius). Waste level, headspace ventilation flow rate, and hydrogen gas concentration in the headspace are the only other measured quantities in the tank.

3.3.1 Waste Temperatures in C-106

Figures 3.21 and 3.22 show the temperatures measured by the thermocouples on the instrument trees in risers 8 and 14. These instruments provide vertical temperature profiles in the tank at only two radial locations (15.6-ft radius for riser 14 and 33.3-ft radius for riser 8) and constitute a very incomplete picture of the waste temperature in the tank especially considering the non-uniform waste relocation involved with sluicing operations.

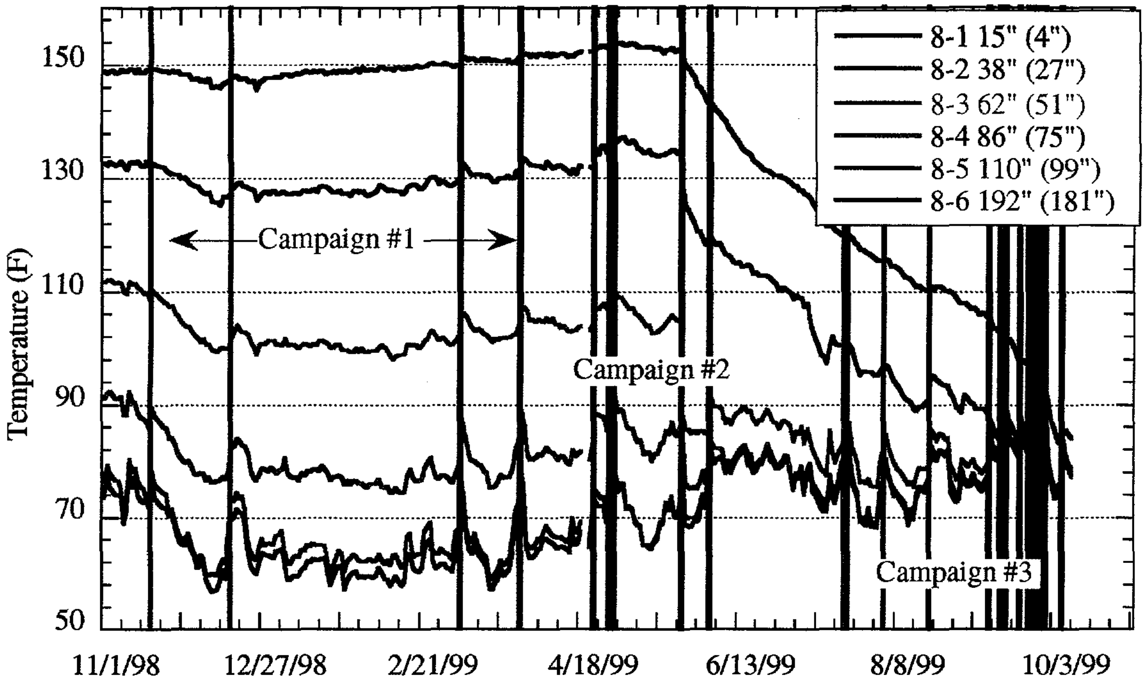

Figure 3.21. C-106 SACS Temperatures Measured in Riser 8

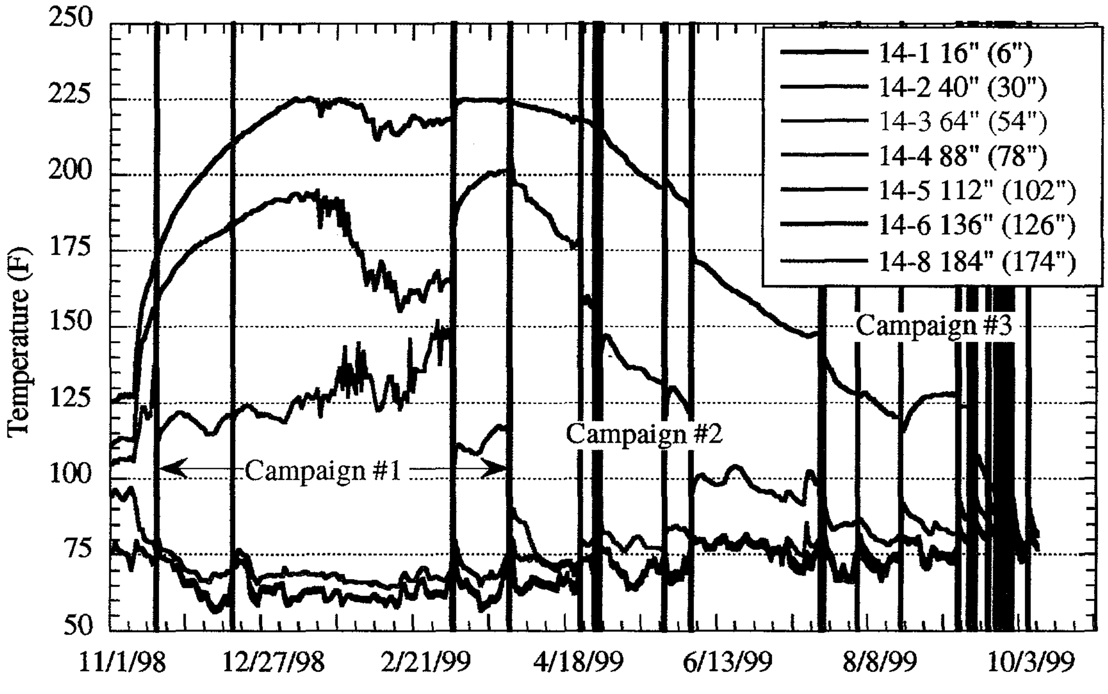

Figure 3.22. C-106 SACS Temperatures Measured in Riser 14

The temperatures on riser 8 in Figure 3.21 decrease until the sluicing operation on March 7, 1999. Subsequently, the temperatures at depths where sludge is probably still in contact with the thermocouples held relatively steady, with a slight increasing trend until enough sludge had been removed to uncover the instrument at a given level. After sluicing batch 2.2.1 on May 24, 1999, the temperatures indicated by thermocouples 8-1, 8-2, and 8-3 drop steadily. By the end of Campaign #3, all but 8-1 are indicating the headspace air temperature.

The behavior of the lower three thermocouples on riser 14 (shown in Figure 3.22) indicates that there must have been some unusual configuration of the waste near this riser. The temperatures were initially far lower than those indicated by riser 8, which suggests that the riser 14 thermocouples were not actually in contact with the solid waste. This is further borne out by the fact that as soon as the waste was disturbed by sluicing operations for the level adjustments prior to transferring batch 1.1.1, the temperatures began to rise rapidly. A proposed explanation is that sluicing filled in an annular natural convection path around the thermocouple tree.

Figure 3.23 shows evidence of local boiling near thermocouple 14-1 on riser 14. The temperature at thermocouple 14-1 from January 7–28 follows the variation in ambient pressure in the same way as the saturation temperature of pure water at ambient pressure which is 14°F lower due to hydrostatic pressure and the effect of dissolved salts. Over the 10-day period, the temperature ranged around 224–225°F, which is in a range consistent with estimates of the saturation temperature of the liquid in C-106. Evidence of boiling did not occur again around riser 14 after Campaign #1 ended. From that point on, the cooling due to reduction in heat load drove all temperatures well below saturation.

3.3.2 Waste Level in C-106

Figure 3.24 shows the waste level in C-106 as measured manually and by the Enraf level indicator in riser 1. Signal processing of the Enraf level indicator for the TMACS is not spanned for levels below 50.44 in., and after the end of Campaign #2, only daily manual readings are available from this instrument. The net decrease in waste level in C-106 during sluicing was 62.32 in. (from 78.24 in. on 11/09/98 to 15.92 in. on 10/07/99). Based on the level change alone, the volume of material removed from C-106 is 171,600 gal. However, operations logs show that, since the beginning of sluicing, at least 43,580 gal of water was added for line and instrument flushes in increments of a few gallons to a few thousand gallons at a time. This brings the total volume removed from C-106 to about 215,000 gal. Based on the net change in liquid level in AY-102, 158,000 gal of material was added to AY-102 during the course of sluicing. This amount includes 7,488 gal of known water additions for line and instrument flushes, so the net volume of material transferred from C-106 to AY-102 is 151,000 gal.

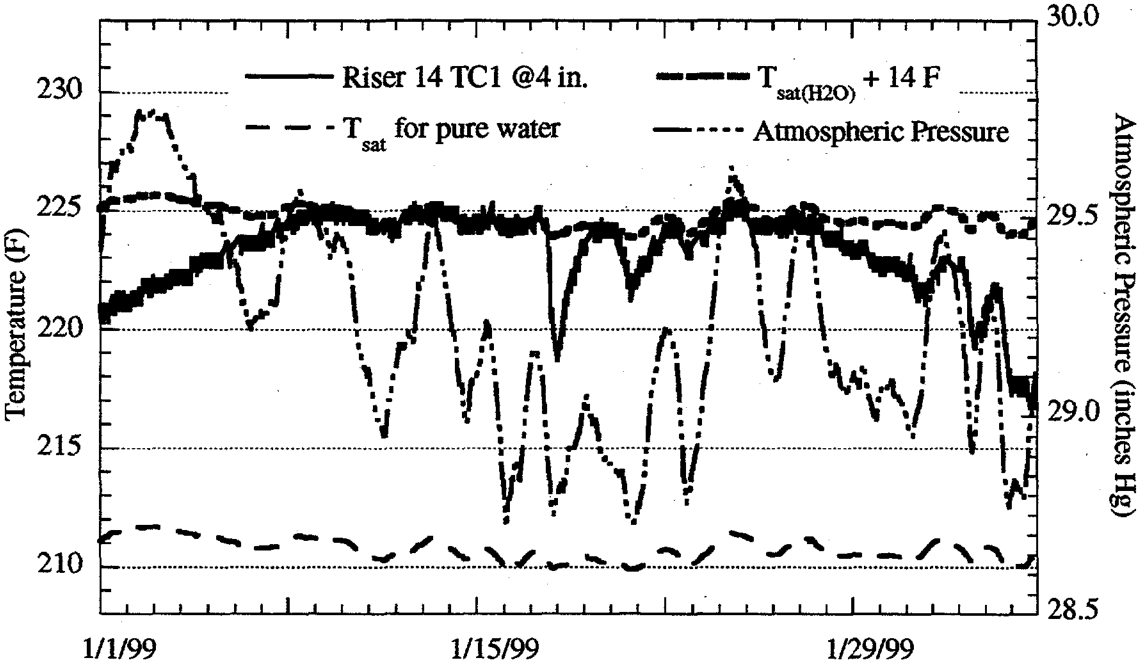

Figure 3.23. Evidence of Boiling near TC 14-1 on Riser 14

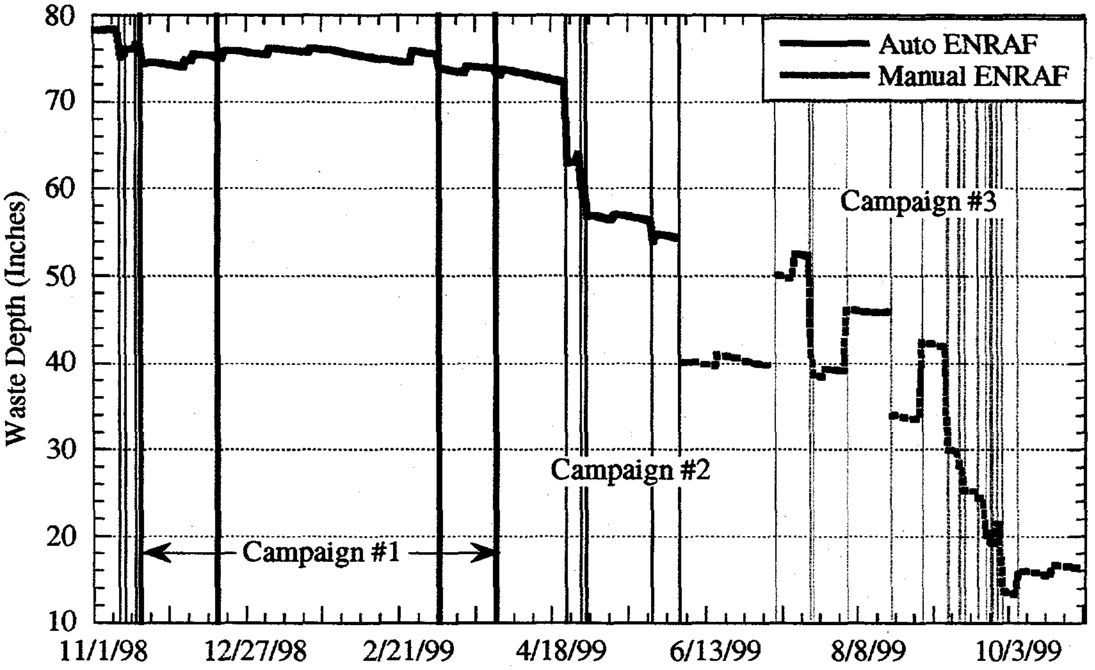

Figure 3.24. C-106 Waste Level (riser 1 Enraf level indicator)

The difference between these two figures suggests that approximately 64,000 gal was absorbed in dissolution of solids or lost to evaporation in the course of sluicing operations. About 16% of the sludge volume in C-106, or about 31,000 gal, was estimated to have dissolved based on grab sample analyses (Bailey 2000). If this dissolution occurred without adding to the liquid volume, 33,000 gal is left that must be attributed to evaporation. While there is some uncertainty in the estimated rates, evaporation from the two tanks would account for the 33,000-gal difference.

It is impossible to determine how much of the original sludge was removed from C-106 from the net volume transferred to AY-102. The data clearly show that sluicing operations moved sludge around within the tank, mobilizing, suspending, and dissolving solids for pumping over into AY-102. But some solids were left bermed up against the sides of the tank, as shown by the diagram in Figure 3.25 of the waste configuration after Campaign #2. Measurements based on the flow rate and solids loading in the sluicing line indicate that approximately 186,000 gal of

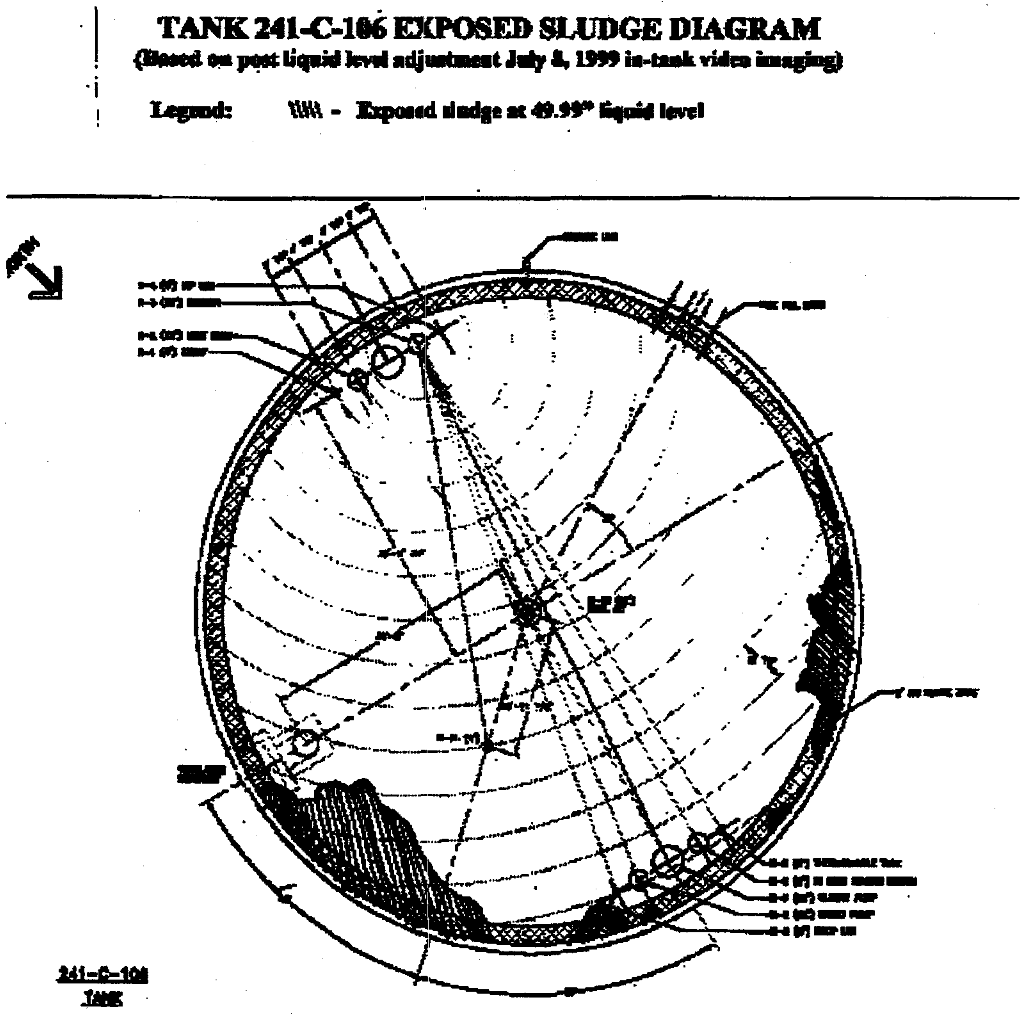

Figure 3.25. C-106 Exposed Sludge Diagram after Liquid Level Adjustment on 7/8/99

sludge were pumped from C-106 to AY-102. Changes in waste volume due to dissolution and 'fluffing' in transit, instrumentation uncertainties, and uncertainties in the amount of waste entrained or dissolved in the fluid volume returned to C-106 during sluicing make the calculation of net solids transferred extremely difficult. Section 4.3 explores this question further, making use of final settled solids measurements, thermal analyses, and gas release rates to assess the amount of mass transferred and the heat load that accompanied it.

3.3.3 Ventilation System Performance in C-106

Information on the operation of the ventilation system in C-106 is sparse because the measurements were recorded manually. During sluicing operations, the C-006 ventilation system was activated at 300–325 scfm; between sluicing operations, the original P-16 ventilation system was usually on. This system provides a very high ventilation rate of 2200–2600 scfm. The P-16 exhauster was used primarily to obtain the highest possible evaporation rate and thus heat removal rate in the tank. It has also been operating essentially continuously post-sluicing to minimize the time to dry out the tank to observe the remaining solids.

Figure 3.26 shows the measured flow rates recorded in the manual data files in the WRSS data archives. Approximately one measurement per month was recorded for the flow rate for the P-16 system. Measurements for the C-006 system were recorded two or three times a day whenever the system was operating. Since the end of Campaign #3, the P-16 system has operated continuously for ventilation of Tank C-106.

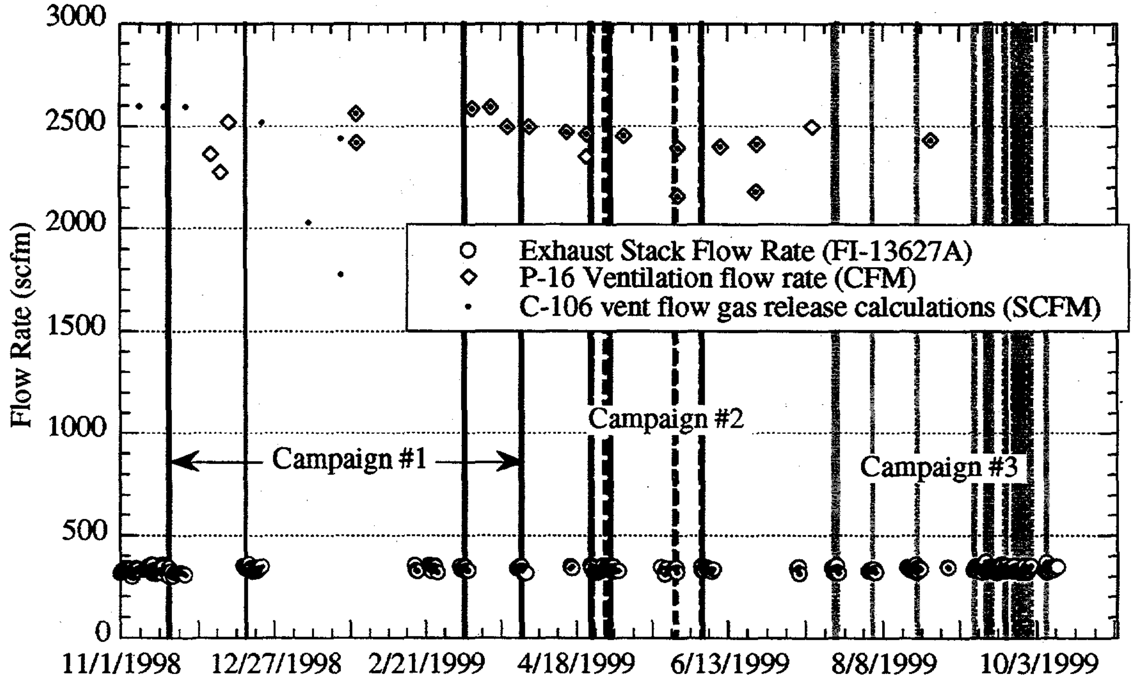

Figure 3.26. C-106 Tank Ventilation Flow Rate

3.3.4 Hydrogen Release in C-106

Figure 3.27 shows the hydrogen concentration (in ppm) measured on riser 2 in Tank C-106. The narrow range instrument was taken off-line on November 28, 1998 and was never successfully brought back on-line. The wide-range gas chromatograph (GC) was recalibrated to the same scale as the narrow range instrument in January 1999 and served as the main source of data on flammable gas concentrations in C-106 throughout the sluicing operations.

Between sluicing batches, the hydrogen concentration in the headspace of C-106 was so low that it was very difficult to measure. It remained less than 5 ppm most of the time, primarily because of the high volumetric flow rate of the headspace exhaust air when the P-16 ventilation system was operating. When the low flow rate C-006 system was in operation, the nominal hydrogen concentration in the headspace increased to 20–30 ppm. During sluicing operations, the concentration peaked at values as high as 400 to 500 ppm. Whenever the ventilation was switched back to the high flow rate P-16 system, however, the hydrogen concentration values dropped immediately back to about 5 ppm.

The volumetric release rate of hydrogen with the vent flow from C-106 is shown in Figure 3.28. When sluicing operations were actually under way, the release rate was as high as 300 scfd. When the waste was not being disturbed, however, the release rate was quite consistently in the range of 10 to 20 scfd. This rate is consistent with the baseline for flammable gas release from C-106 as determined from release rates measured over the 14-weeks from August 1, 1998 to November 6, 1998. (Appendix C contains a detailed description of the analysis used.) The best estimate of the mean release rate for C-106 is 12.5 scfd, with estimated lower bound of 9.4 scfd and upper bound of about 16.9 scfd.

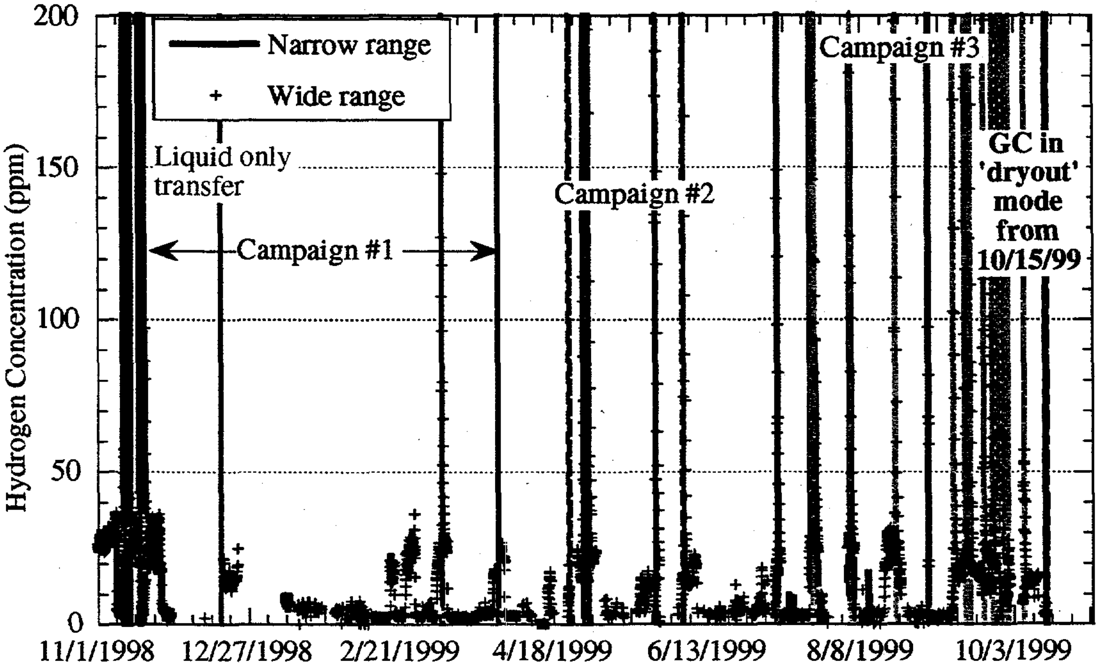

Figure 3.27. C-106 Headspace Hydrogen Concentration

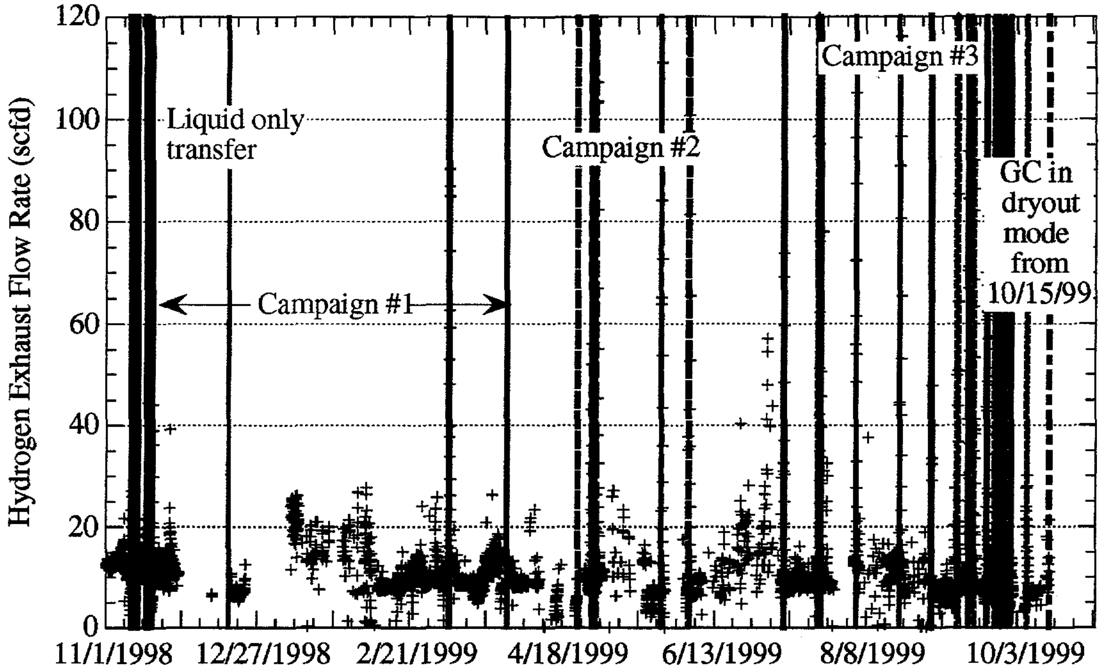

Figure 3.28. C-106 Volumetric Flow Rate of Hydrogen in Exhaust Air

The release rate does not appear to decrease by any significant amount as sluicing operations transferred waste from C-106 to AY-102. This may be partly because the very high ventilation flow rate with the P-16 system makes accurate measurement of the hydrogen concentration extremely difficult. It also suggests that a considerable amount of gas-generating material remains in C-106, even after the completion of sluicing operations.

The hydrogen concentration was very low in C-106 throughout the 12 months of monitoring, even when the waste was being disturbed by sluicing operations. When the waste was undisturbed and the high flow rate P-16 ventilation system was operating, the measured values represent a hydrogen concentration that is less than 0.02% of the LFL for hydrogen. At the very highest measured concentrations, the values represented less than 1.2% of the LFL.

3.4 External Environmental Conditions: Hanford Weather Station

External environmental conditions can affect conditions in the tanks in two significant ways. The ambient temperature of the incoming air for tank headspace ventilation and for annulus ventilation in AY-102 affects the rate of heat removal from the waste. The humidity of the ambient air affects the rate of evaporation of liquid from the tank, and therefore could also have a substantial effect on heat transfer due to the evaporative cooling rate. In addition, the evaporation rate affects the level rise and must be taken into account when evaluating surface level change for evidence of gas retention.

Figure 3.29 shows the daily maximum and minimum ambient air temperatures at the Hanford Weather Station from November 1, 1998 to November 1, 1999. The seasonal temperature ranges from 80 to 90°F, with daily extremes generally no more than about 30° apart. Prior to sluicing operations, the waste temperature in AY-102 showed distinct seasonal variations because the waste surface temperature was very close to the summer ambient air temperature. Thus, cooling the waste surface was extremely inefficient in summer and relatively effective in winter.

The waste in C-106 also showed degraded heat transfer rates during the summer but, because of higher temperatures in this tank, the effect was not so noticeable. As sluicing operations increased the heat load in AY-102, temperatures in the supernatant liquid became less sensitive to ambient temperature variations. But because of cooling from the annulus ventilation system, temperatures of the sludge in AY-102 became more sensitive to changes in ambient temperature.

The wide seasonal variation in relative humidity at Hanford is shown in Figure 3.30. It seems to suggest that a wide seasonal variation should exist in the evaporation rate from the tank. However, the ambient air generally contains very little water due to the extreme aridity of the environment. The plot of specific humidity on the figure shows that the actual amount of water in the air is relatively constant and very low all year. The rate of evaporation in the tank, therefore, is driven almost entirely by the temperature difference between the liquid waste surface and the headspace air and is only very slightly affected by the moisture content of the incoming ambient air.

Local variations in atmospheric pressure, which are shown for the 12 months of sluicing operations in Figure 3.31, have very little effect on heat transfer from the waste. They do, however, affect the rate of gas release from the waste, imparting diurnal and seasonal oscillations that must be considered when monitoring for flammable gas accumulation in the waste.

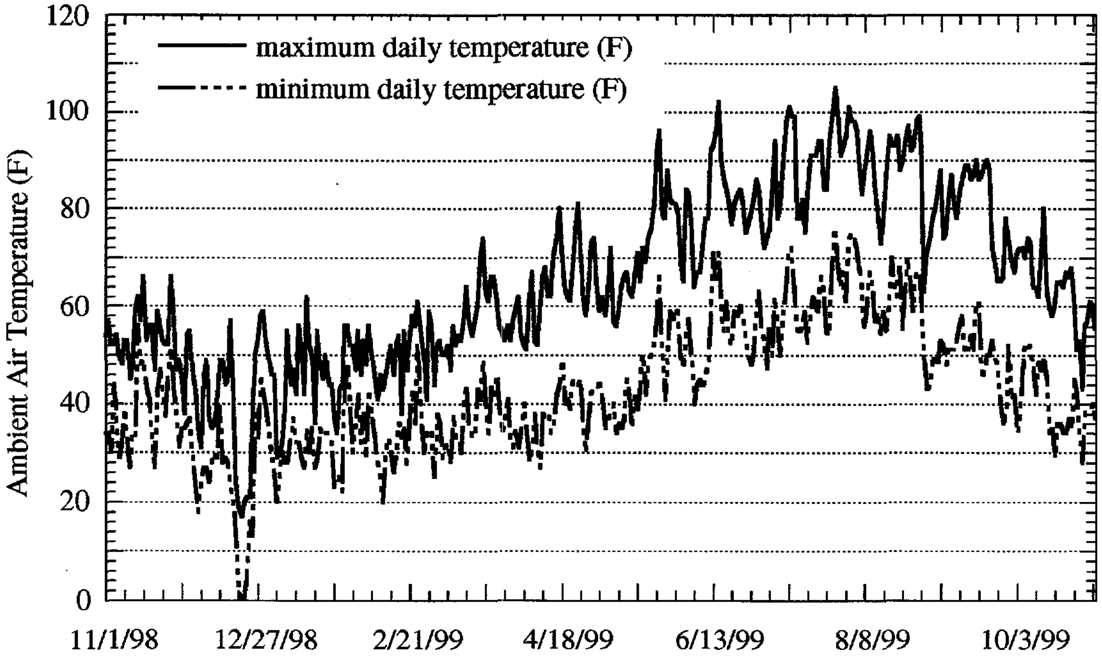

Figure 3.29. Hanford Meteorological Station Ambient Air Temperature

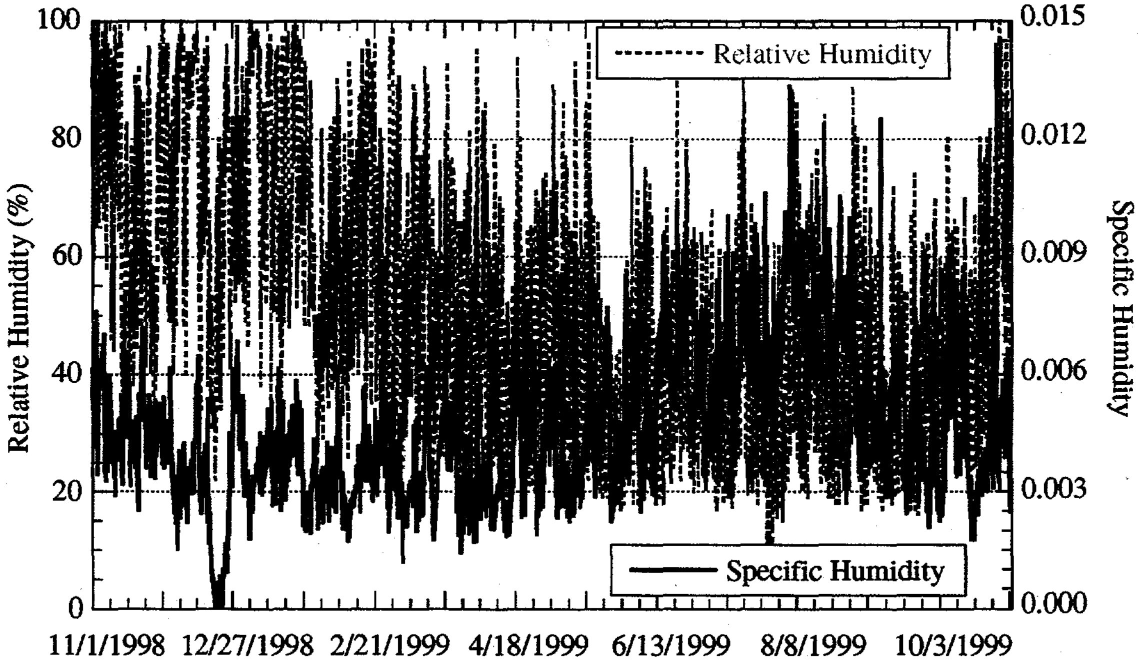

Figure 3.30. Hanford Meteorological Station Ambient Air Humidity

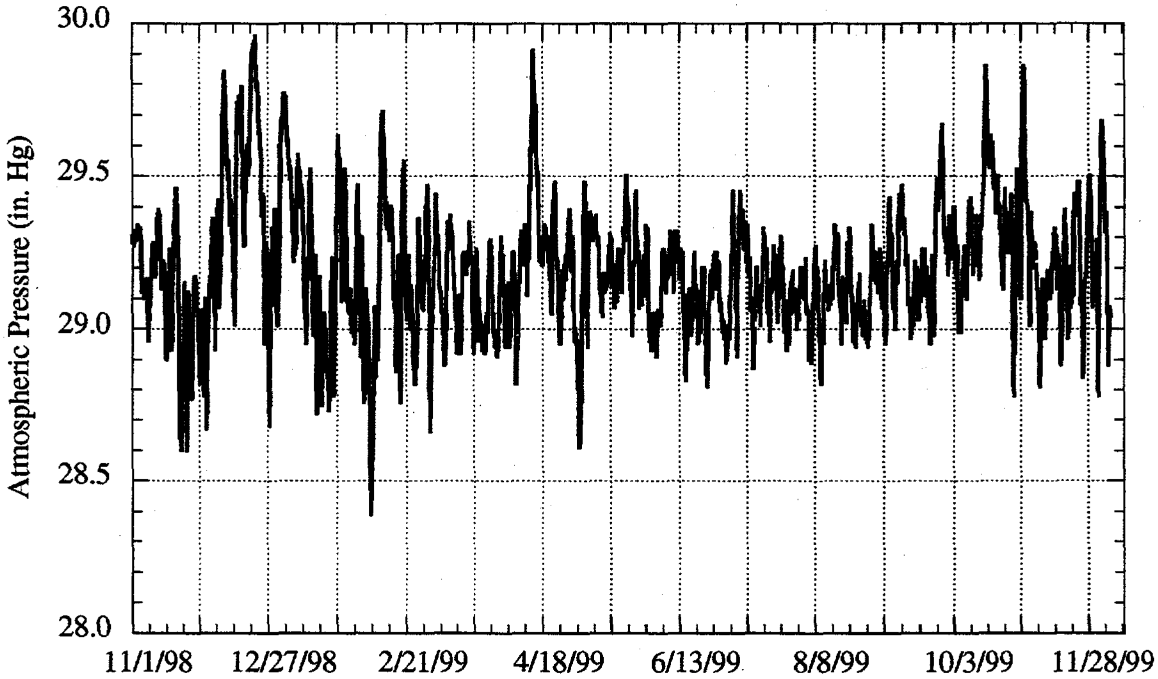

Figure 3.31. Hanford Meteorological Station Atmospheric Pressure

4.0 Post-Sluicing Conditions in AY-102 and C-106

After sluicing operations were completed, conditions continued to be monitored in AY-102 using the DAS instrumentation to determine the hydrogen release rate, verify that the thermal behavior of the tank would maintain conditions within acceptable temperature limits, and to evaluate the risk of flammable gas retention. Conditions were also monitored in C-106 to verify that the high heat condition in the tank had been successfully mitigated and to determine the quantity and character of waste remaining in the tank after sluicing.

Section 4.1 summarizes the current conditions and trends in AY-102. Section 4.2 describes the post-sluicing conditions in C-106. Section 4.3 presents an evaluation of the heat load and waste distribution in both tanks. An analysis of solids settling behavior between sluicing batches is presented in Section 4.4.

4.1 Current Waste Configuration in AY-102

The instrumentation for monitoring and system controls in AY-102 give a fairly complete picture of current conditions in the tank. Waste temperatures and liquid surface level are monitored using the DAS instrumentation along with headspace air temperature, humidity, pressure, and vent flow rates. Headspace hydrogen concentration is monitored by means of GC instrumentation. Ventilation flow rate and air temperatures in the annulus are also measured.

Post-sluicing monitoring of the waste temperatures was undertaken to evaluate the new thermal state of the tank. These results are discussed in Section 4.1.1. Waste level measurements and analysis to determine sediment level are described in Section 4.1.2.

4.1.1 AY-102 Temperatures

The waste temperatures in AY-102 continued to rise for about two months after the end of sluicing. This behavior was expected because the thermal time-constant of the system is relatively long. Figure 4.1 presents the sludge temperatures in AY-102 approximately 4 in. from the tank bottom through June 2000. Temperatures peaked in late November 1999, then gradually decreased until about mid-February, following the seasonal drop in ambient air temperature. Temperatures began to climb with the onset of warmer weather in late March and have not yet reached their summer peak, which usually occurs in late August or early September. Based on the waste temperatures recorded in June and July, the peak temperatures are expected to be in the range 130–140°F.

The riser 16 thermocouples, which are closer to the center of the tank, show the effect of forced convection cooling due to the annulus ventilation flow. Waste temperatures near the center of the tank are cooler than at the periphery except when the annulus ventilation flow is cut off for a time. Figure 4.1 also shows that cooling by means of annulus ventilation becomes much less effective as ambient air temperature rises, but even in the summer, this additional cooling is needed to prevent the waste temperature in the tank from rising.

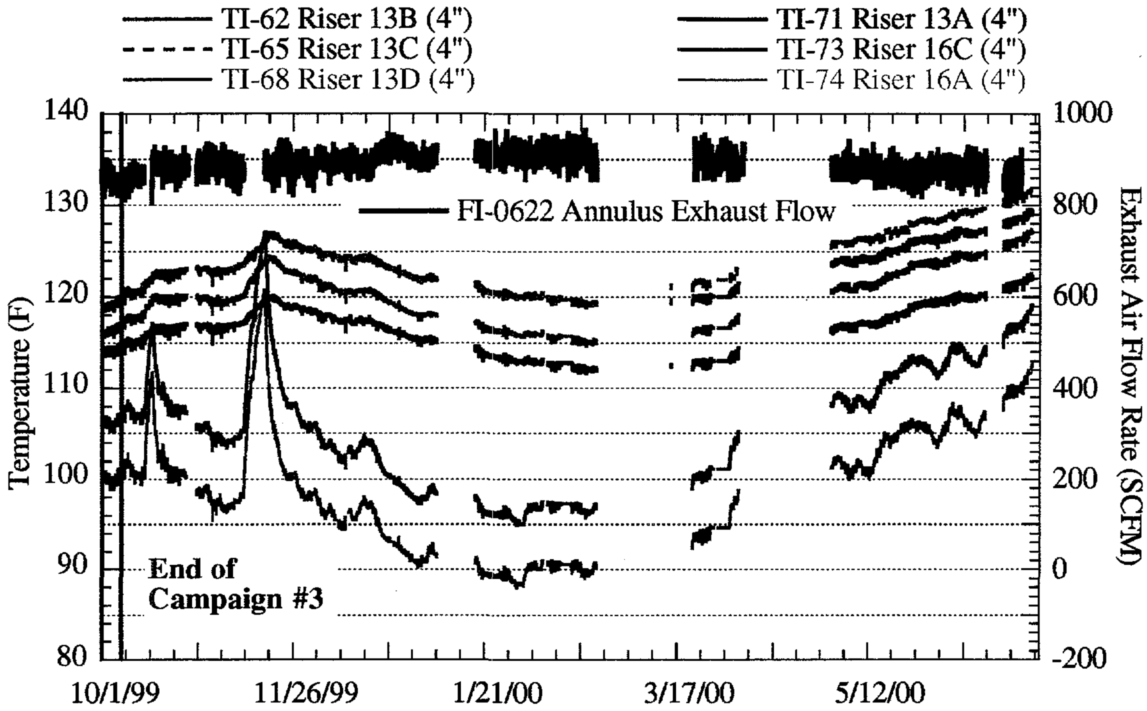

Figure 4.1. AY-102 Waste Temperatures and Annulus Ventilation Flow Rate

4.1.2 Gas Release Rate in AY-102

The relatively low level of gas release in AY-102 during sluicing operations, which was generally below the presluicing baseline and often below the lower bound of the baseline data, caused some concern that gas retention would be a problem as the waste depth increased in AY-102. However, the elevated hydrogen concentrations observed in both tanks during sluicing suggested that the waste was thoroughly degassed during the sluicing process, and it would be reasonable to suppose that release rates might drop for a time until a new equilibrium was reached. How long this might take, however, was not easy to characterize, and therefore the liquid surface level after the end of sluicing was monitored closely for signs of gas retention.

The post-sluicing level history in AY-102 through July 2000 is shown in Figure 4.2. After about mid-December 1999, the liquid level in AY-102 shows a steady decrease that is consistent with estimates of the loss due to evaporation. (The increase of approximately 0.26 in. on January 6, 2000 is assumed to be due to liquid addition to the tank for instrument or line flush.) The effect of gas retention immediately after the end of sluicing is illustrated by the graph in Figure 4.3. This plot compares the measured surface level for the first eight weeks post-sluicing with a hypothetical level determined by calculating the liquid evaporation rate and adding the effect of controlled water additions for instrument flushing operations.

Figure 4.3 indicates that immediately after the end of Campaign #3 there was a small level rise, on the order of 0.2 in., probably caused by gas retention in the degassed waste. However, the level rise of 0.2 in. indicates roughly 100 scf of gas retention at a pressure of 1.7 atm. This level rise coincides with the interval during which the hydrogen release rate was below the pre-

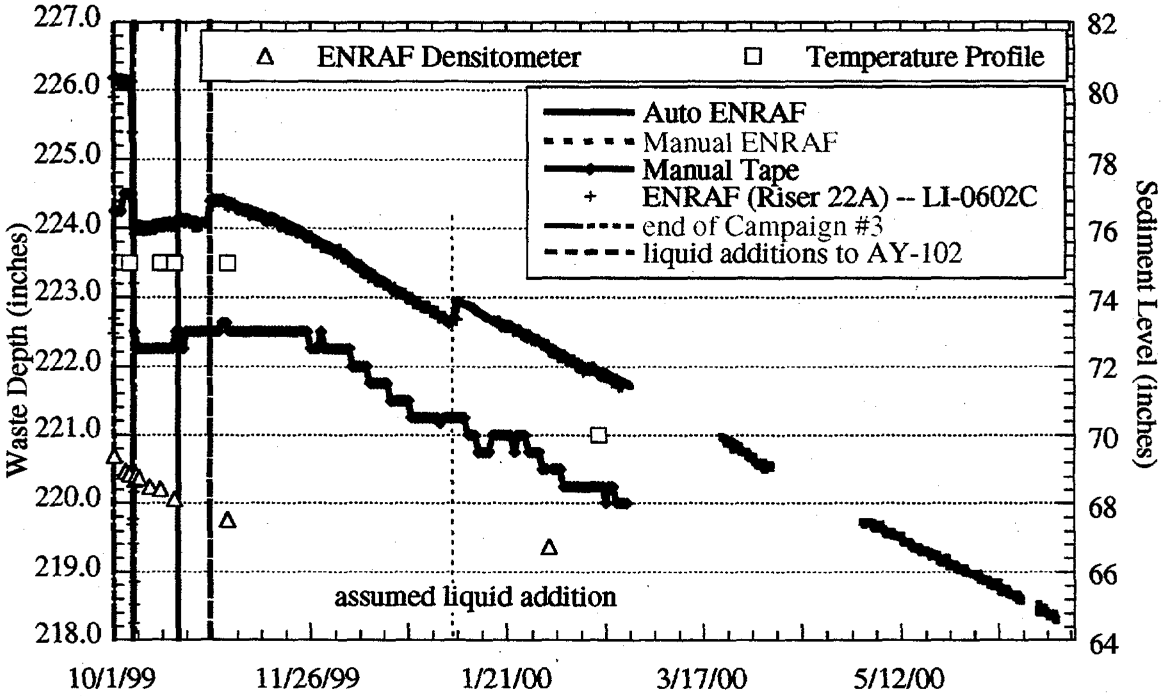

Figure 4.2. AY-102 Level History Post-Sluicing Through July 2000

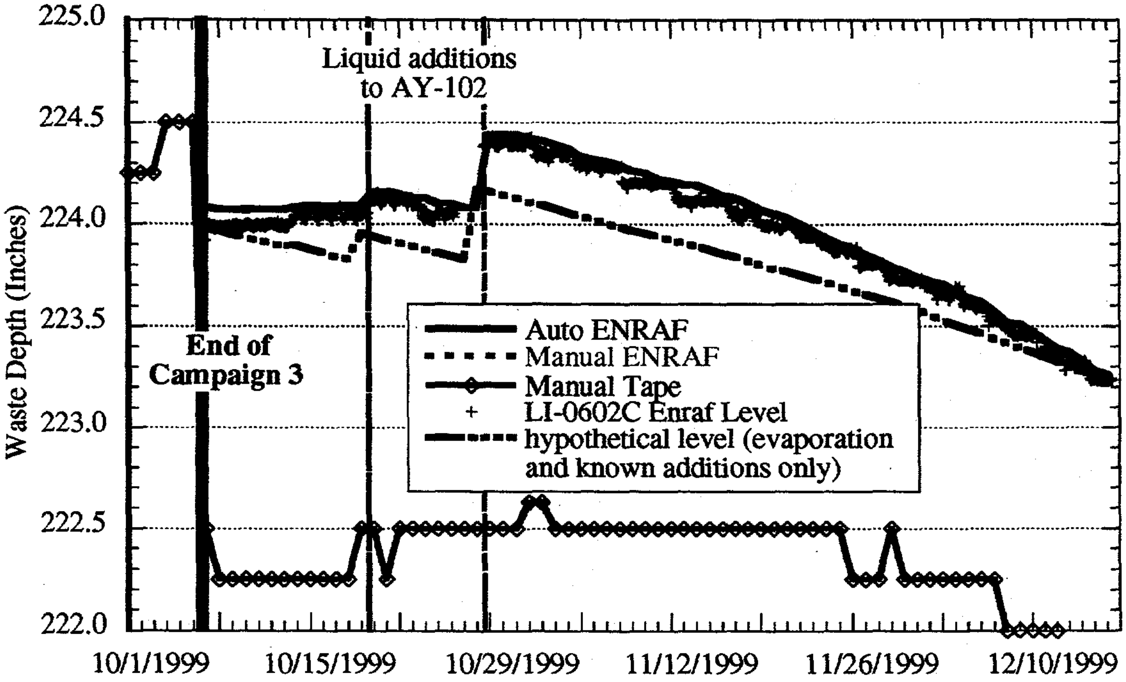

Figure 4.3. AY-102 Waste Level Eight Weeks after the End of Sluicing Operations

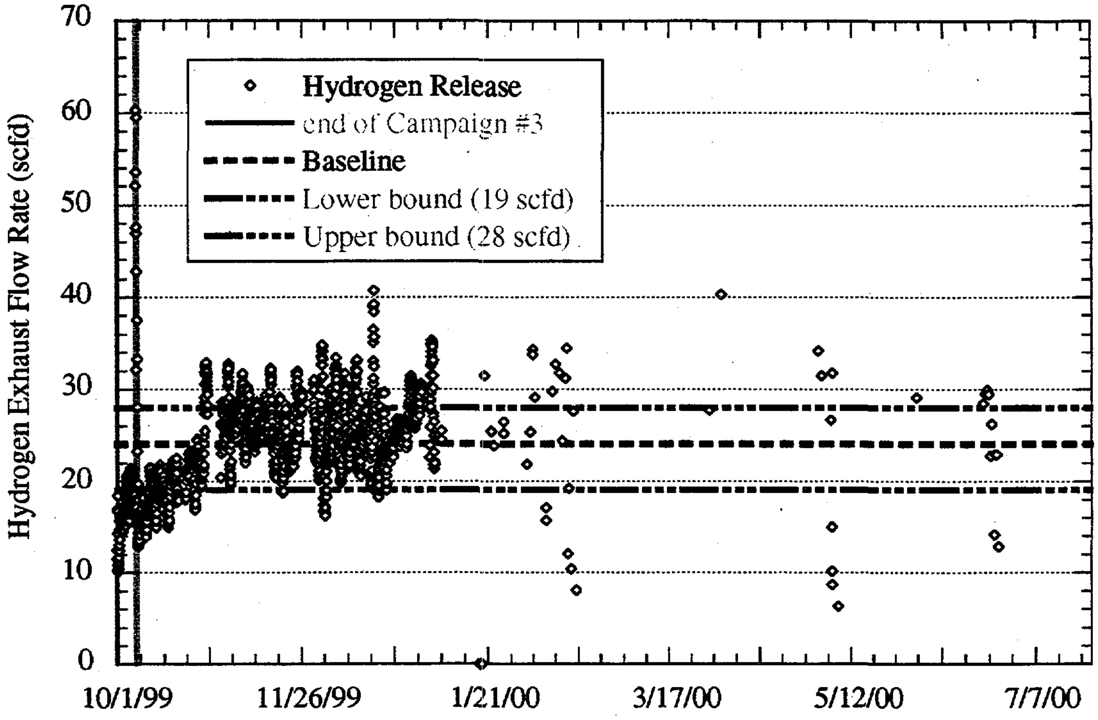

Figure 4.4. AY-102 Volumetric Flow of Hydrogen in Exhaust Air (post-sluicing)

sluicing baseline. This is illustrated in Figure 4.4, which shows the hydrogen release rate post-sluicing. As the hydrogen release rate increased, the liquid level gradually dropped slightly faster than the evaporation rate alone. After about eight to 10 weeks, the liquid level measurements show no evidence of gas retention. Figure 4.2 shows that there has been a steady decrease of about 0.028 in./day in the level since about mid-December 1999 that appears to be due entirely to evaporation.

Because the hydrogen data are relatively sparse after about mid-January 2000 and show considerable variability in the hydrogen release rate for the tank, the barometric pressure evaluation (BPE) method was used to provide an independent search for evidence of gas retention in AY-102. The BPE method is based on the correlation of barometric pressure swings with waste level fluctuations. A negative level-to-pressure correlation (level decreases with pressure increases) indicates gas compressing and expanding with changes in barometric pressure. While this method can provide good quantitative estimates in tanks with a deep liquid layer and weak waste as in AY-102, it has a relatively high detection limit and is not suited for assessing incipient gas retention (Meyer et al. 1997; Stewart and Chen 1998). In the case of AY-102 under winter 1999–2000 conditions, the detection limit is approximately 1,000 ft^3 of gas in situ. This corresponds to a void fraction of about 0.04.

The actual correlation of waste level to barometric pressure for November 1, 1999 through January 30, 2000 is -0.021 ± 0.008 cm/kPa, based on Hanford weather station pressure data and the Enraf level in AY-102. The in situ gas volume is computed from

$$V_G = -Ap\frac{dL}{dP}$$

where V_G is the gas volume, A is the waste surface area, p is the hydrostatic head at the midpoint of the nonconvective layer, and dL/dP is the level-to-pressure correlation. With an effective pressure of 1.7 atm, the gas volume is 500 ± 200 $ft^{3,}$ which corresponds to a void fraction of about 0.02. This is well under the detection limit so the value cannot be considered quantitative. However, the BPE analysis does confirm that no significant gas retention has occurred since the end of sluicing.

4.2 Current Waste Configuration in C-106

Sluicing operations have left only a small amount of waste in the bottom of C-106, and, as a result, the available instrumentation is not able to give a very complete picture of its condition. Views of the tank obtained by video camera scans on July 13–14, 2000 show that the remaining non-liquid waste in the tank is in the form of irregular chunks up to three or more inches in diameter. This material appears to be about the consistency crushed rock or coarse gravel and is distributed nonuniformly over the bottom of the tank. Two small irregular piles of this material are visible above the liquid level, lying against the wall on the periphery of the tank, one in the northwest quadrant, the other in the northeast quadrant. These piles are roughly semiconical in shape, extending 4 to 5 ft up the tank wall, and appear to have been pushed up at the extreme ends of the arc of the sluicer. There is also a relatively large shallow region of solids visible on the north side of the tank under the camera and submersible pump. A small fourth pile of material is visible above the liquid level between the northeast and northern piles.

It appears that nearly all of the fine particles have been removed by sluicing, leaving only the larger coarser material that cannot be suspended by the sluicing jets and are too large to pass through the 1/4-inch screen on the submersible transfer pump. A rough estimate of the amount of solid material present above the liquid level was obtained from geometric calculations based on the video images. These calculations indicate that there are possibly 4,450 gal of solids in the visible piles, of which about 2,450 gal. is above the liquid level.

The video images show that the float for the Enraf level gauge is suspended in liquid and is therefore giving valid readings. The post-sluicing liquid level measurements in C-106 through August 2000 are shown in Figure 4.5. This plot indicates that the level is dropping slowly due to evaporation, at a rate of about 0.02 in. per day, with intermittent increases in level due to liquid additions and instrument flushes. The zero datum reference for this instrument was changed on June 29, 2000. Previously, the liquid level was measured relative to the tank knuckle, which is 12 in. above the center of the bottom of the tank. The new reference is the bottom center of the tank. The effect of this change is to add 12 in. to the instrument indication. (See Appendix A for details and locations of all instrumentation in Tanks C-106 and AY-102.)

The ending liquid level of 23.5-in. indicates a waste volume of about 41,500 gal. Adding the 2,450 gal of solids above the liquid level, the total amount of waste (solid and liquid) remaining in C-106 is estimated to be on the order of 44,000 gal.

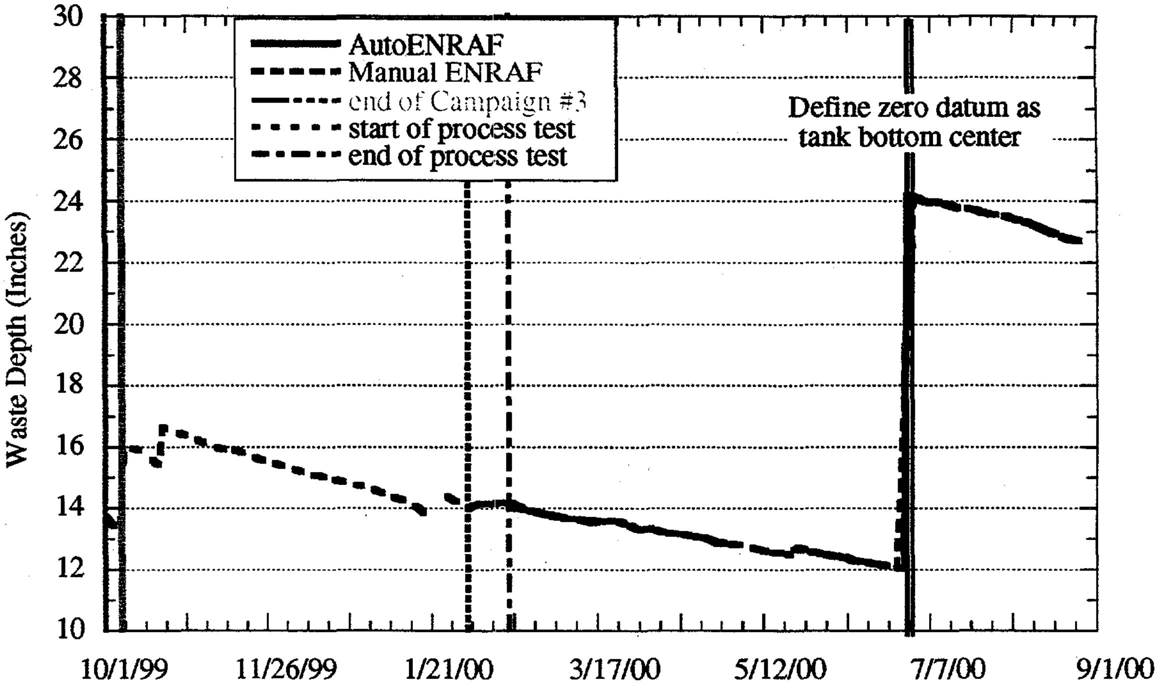

Figure 4.5. C-106 Liquid Level Measured with Enraf in Riser 1 (post-sluicing)

4.2.1 C-106 Temperatures

The waste level in C-106 is so low now that most of the thermocouples are no longer in contact with the waste. The video camera images show that the lowest thermocouple on riser 14 (TC14-1) is several inches below the liquid surface. All other thermocouples on riser 14 are measuring the air above the waste. The video images show dry solid waste surrounding the lower end of the riser 8 thermocouple tree. The surface of the solid material appears to be several inches above the liquid surface. The lowest thermocouple on riser 8 (TC8-1) is submerged in solid waste (which also presumably contains interstitial liquid at the level of TC8-1), but all other thermocouples on this riser are measuring the air temperature above the waste.

The measured liquid level in the tank also indicates that the bottom thermocouples on risers 8 and 14 (TC 8-1 and TC14-1) are in contact with the liquid waste. All other thermocouples on both risers are measuring the air above the liquid surface. The temperatures plotted in Figure 4.6 for riser 8 and in Figure 4.7 for riser 14 show that all but the bottom thermocouples on each riser indicate essentially the same temperature. The bottom thermocouples indicate temperatures slightly above that of the air, representing the waste temperature several inches below the liquid surface. The two temperatures are nearly the same, as shown in Figure 4.8 for TC8-1 and TC14-1 together. Thermocouple TC8-1 is consistently about 1–2 degrees warmer than TC14-1.

All thermocouples show a rising trend due to increasing ambient air temperatures during the summer. The sudden downturn in late August corresponds to a break in the weather, as shown by the maximum daily ambient air temperatures on Figure 4.8. This indicates that the remaining waste in C-106 is effectively cooled by headspace ventilation.

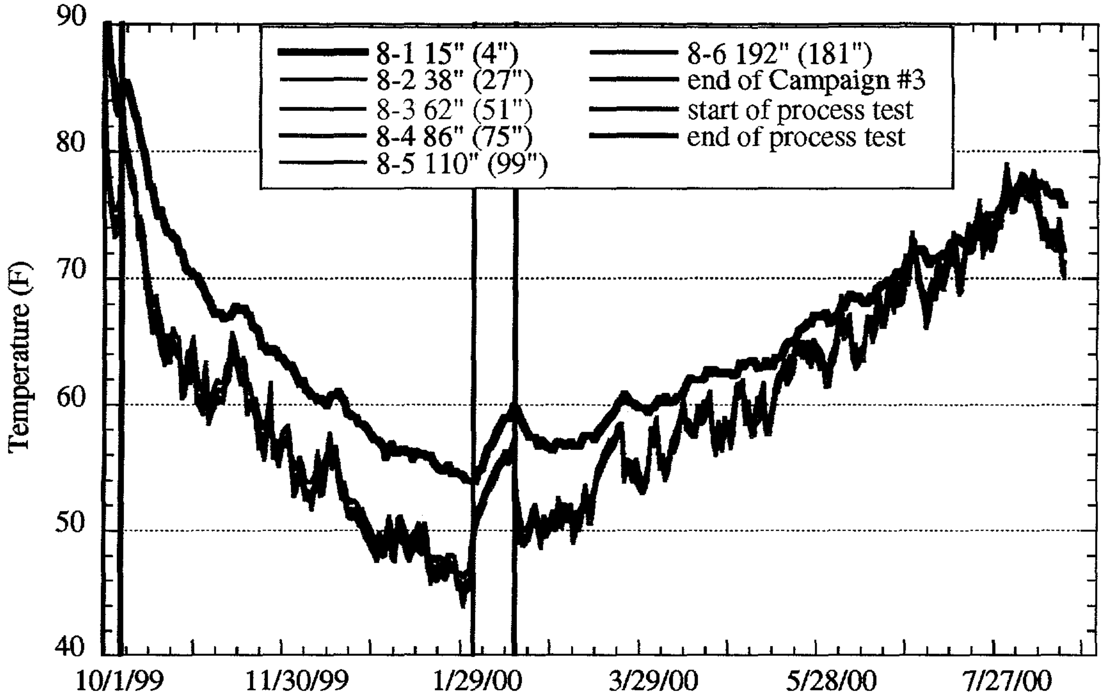

Figure 4.6. C-106 Temperatures Measured with Riser 8 Thermocouples (post-sluicing)

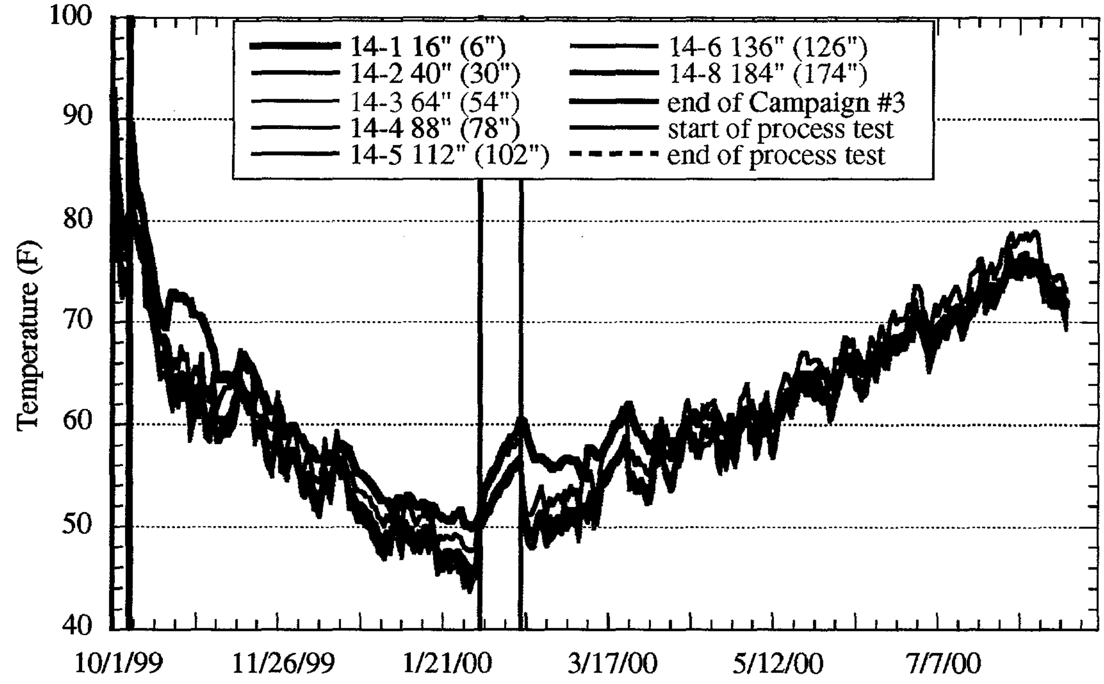

Figure 4.7. C-106 Temperatures Measured with Riser 14 Thermocouples (post-sluicing)

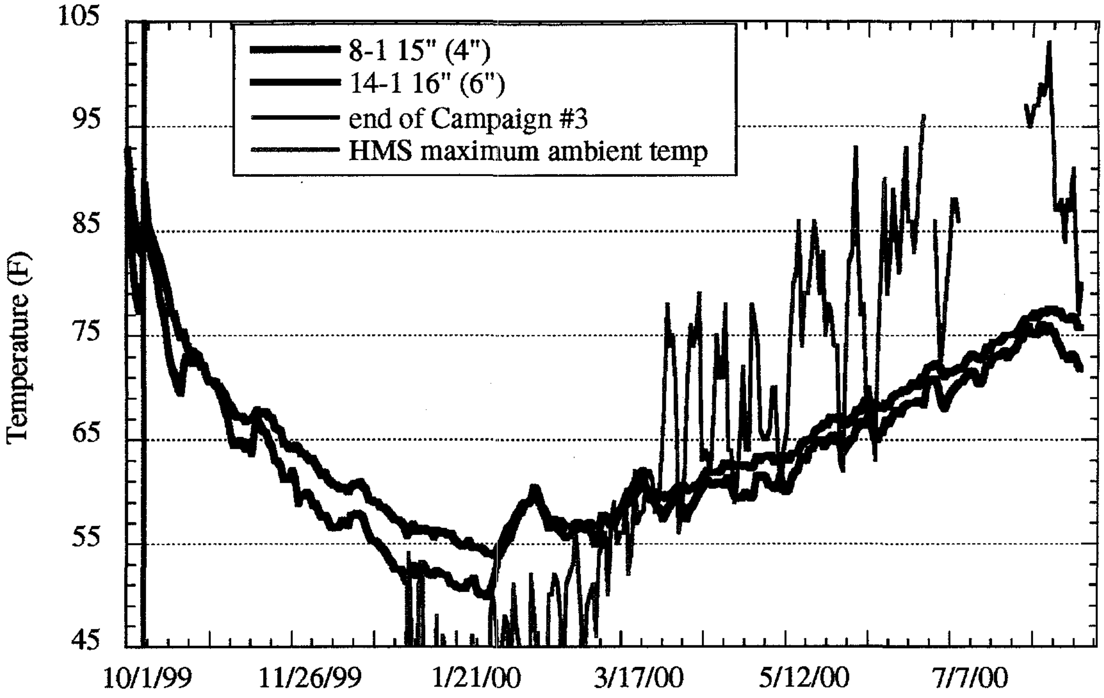

Figure 4.8. C-106 Waste Temperatures (post-sluicing)

4.2.2 Gas Release Rate in C-106

Gas retention and release are not issues in C-106 after sluicing because little waste remains in the tank. The headspace ventilation rate has been relatively high since the end of sluicing; as a result, the headspace hydrogen concentration has remained very low. When the P-16 system is operating, the headspace hydrogen concentration is generally below the detection threshold for the GCs in riser 2. However, when ventilation was shut down for a time, as in the process test on February 2–16, 2000 and during other outages, the hydrogen concentration rose rather dramatically. This is illustrated by the plot of hydrogen concentration in Figure 4.9. A process test was performed to help determine the actual heat load remaining in the tank. It also measured the rate of hydrogen release from the remaining waste in the tank. In this test, the P-16 ventilation system turned off at 14:00 on February 2, 2000, and there was no active tank ventilation for 14 days, until the system was turned back on at 09:43 on February 16.

Figure 4.10 shows the hydrogen concentration in the tank during the process test. Analysis of the transient concentration indicates the passive ventilation rate was about 30 cfm for the first half of the test but dropped to about 16 cfm for the second half. A simple exponential model assuming constant gas release and ventilation rates was used to estimate the release rate that would produce the measured concentrations. The model indicates the new steady-state hydrogen release rate in the tank is about 3.4 scfd, or 27% of the pre-sluicing baseline rate of 12.5 scfd.

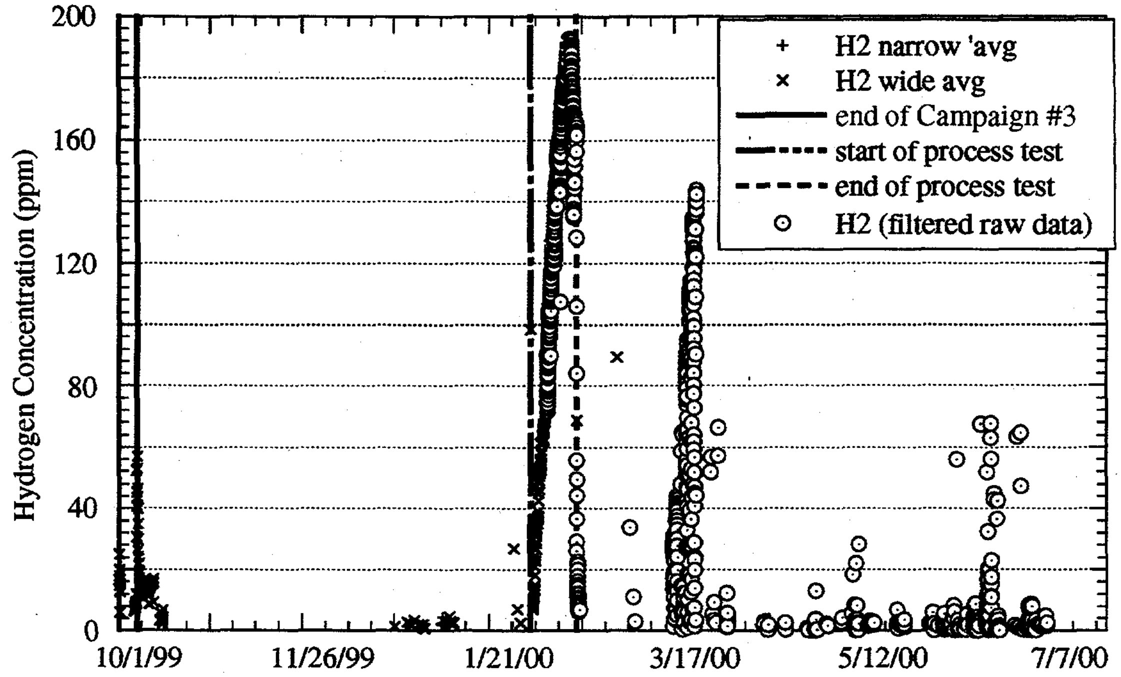

Figure 4.9. C-106 Headspace Hydrogen Concentration Post-Sluicing Through June 2000

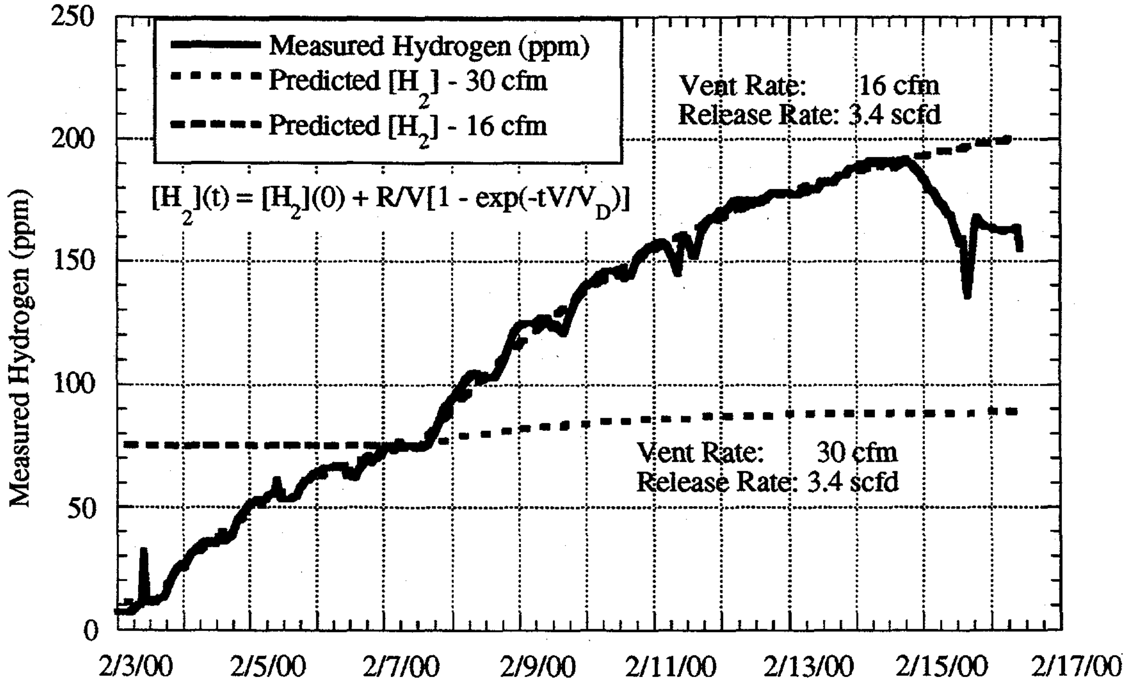

Figure 4.10. C-106 Headspace Hydrogen Concentration During the Process Test

4.3 Total Material Transfer Estimates

The original volume of sludge in C-106 was determined to be 192,000 gal. Mass balance calculations (Adams 1999) based on the mass flow meter summarized in Table 3.1 indicated that 186,000 gal, or 97% of the original sludge, was removed from C-106. Approximately 44,000 gal of material (liquid and solid) is estimated to remain in C-106 based on the current waste level and video evidence described in Section 4.2. It is not known what fraction of this volume is solid or liquid, but, based on the visible material, at least 4,400 gal of solids remain in the tank. If the other 39,600 gal is all liquid, a maximum of 188,000 gal, or 98% of the sludge, was removed from C-106. If, contrary to the appearance of the video and other evidence, all 44,000 gal were equivalent to original sludge, it would indicate that minimum of 148,000 gal, or 77% of the sludge, was transferred. These percentages represent the absolute upper and lower bounds on estimates of the amount of material removed from C-106. However, the actual amount transferred is much closer to the upper bound. The following discussion presents alternative estimates based on different assessment methods.

In addition to estimating the volume of material remaining in C-106, the ending sludge volume in AY-102 can also be considered. The AY-102 sludge depth indicated by the most recent densitometer measurement on July 27, 2000 was 66 in. The depth estimated from the most recent validation probe temperature profile on June 7, 2000 was approximately 64 in. These measurements represent a net gain of 55–57 in. over the original 9 in. of sludge in AY-102 and are equivalent to 151,000–157,000 gal of sludge. Approximately 16% of the original C-106 sludge volume, or 31,000 gal, are estimated to have been lost to solids dissolution (Bailey 2000). Adding this to the estimates of sludge volume in AY-102 and assuming the new sediment has essentially the same volume fraction as C-106, the total amount removed from C-106 is 182,000 to 188,000 gal or 95 to 98% of the original 192,000 gal initially in the tank.

A pre-sluicing energy balance analysis performed for both tanks using the benchmarked thermal models determined that the initial heat load in 1997 was approximately 41,200 Btu/hr in AY-102 and 118,000 Btu/hr in C-106 (see Appendix B). Radioactive decay would have reduced this to 38,800 and 111,000 Btu/hr, respectively, as of February 2000. At the end of Campaign #3 (October 1999) analyses of grab sample results (Table 3.1) indicated that only about 46,740 Btu/hr, or about 42%, of the heat load had been removed from C-106. This suggested that up to 111,000 gal or 58% of the sludge might remain in C-106. However, post-sluicing thermal analyses (Ogden and Bratzel 2000) determined that the earlier heat load calculation had used an simplifying assumption on the concentration of cesium and strontium in the waste, which made the estimates low by about a factor of two. The final thermal analyses indicates that 7,000 to 11,000 Btu/hr remains in C-106, suggesting that at least 90% of the heat load had been transferred to AY-102. This would leave the equivalent of about 19,000 gal of sludge in C-106, assuming that the heat load was distributed uniformly, which is probably not true.

Analysis of the hydrogen data from the process test in Section 4.2.2 showed that the post-sluicing release rate is about 3.4 scfd in C-106. This represents 73% of the original 12.5 scfd baseline C-106 hydrogen release rate. It can be inferred that roughly 73% of the waste in C-106 has been transferred to AY-102 under the assumption of constant and uniform gas generation rate per unit volume, which is almost certainly not true.

Table 4.1 summarizes the results of the different approaches to estimating the amount of material transferred by sluicing operations from C-106 to AY-102. Discounting the estimates based on thermal analysis and gas release rates, the preponderance of the evidence suggests that sluicing operations transferred at least 95% and as much as 98% of the original sludge volume from C-106 to AY-102. The "best estimate" is taken to be 97% which suggests that 6,000 gal of solids equivalent to original sludge remains in C-106 which is quite consistent with the video observation.

Table 4.1. Summary Waste Transfer Volumes Inferred from Analysis of Post-Sluicing Conditions in C-106 and AY-102

Analysis Time frame	**Volume transferred to AY-102 (gal)**	**Fraction of sludge transferred**	**Sludge volume remaining in C-106 (gal)**
Mass balance based on mass flow meter and grab samples (Table 3.1)	186,000	97%	6,000
Video analysis of material left in C-106	148,000–188,000	77–98%	4,400–44,000
Analysis of sediment level in AY-102	182,000–188,000	95–98%%	4,000–10,000
C-106 thermal analysis (Ogden & Bratzel 2000)[(a)]	173,000–180,000	90–94%	12,000–19,000
H_2 release rate in C-106 Process Test (Feb. 2000)[(b)]	140,000	73%	52,000
Best overall estimate	186,000	97%	6,000

(a) Requires assumption of uniform heat load distribution.
(b) Requires assumption of constant and uniform gas generation per unit volume.

4.4 Solids Settling Analysis

Settling of solids occurred repeatedly in AY-102 during the numerous sluicing events. In this analysis, each event is assumed to have agitated the liquid in the tank, thereby creating an approximately homogenous mixture from which particles settled and raised the level of the solids. The variation of the level of the top of the solids and top of the liquid from March to October 1999 is shown in Figure 4.11.

An expanded view of the variation of the solid level in inches is shown in Figure 4.12 with a number of the sluicing events labeled. For each settling event, the top of the solids layer first rises as solids settle onto it and then descends slightly as the newly settled solids compact under their own weight. This information provides an opportunity to infer the rate of settling of particles and from this to infer the size of the particles.

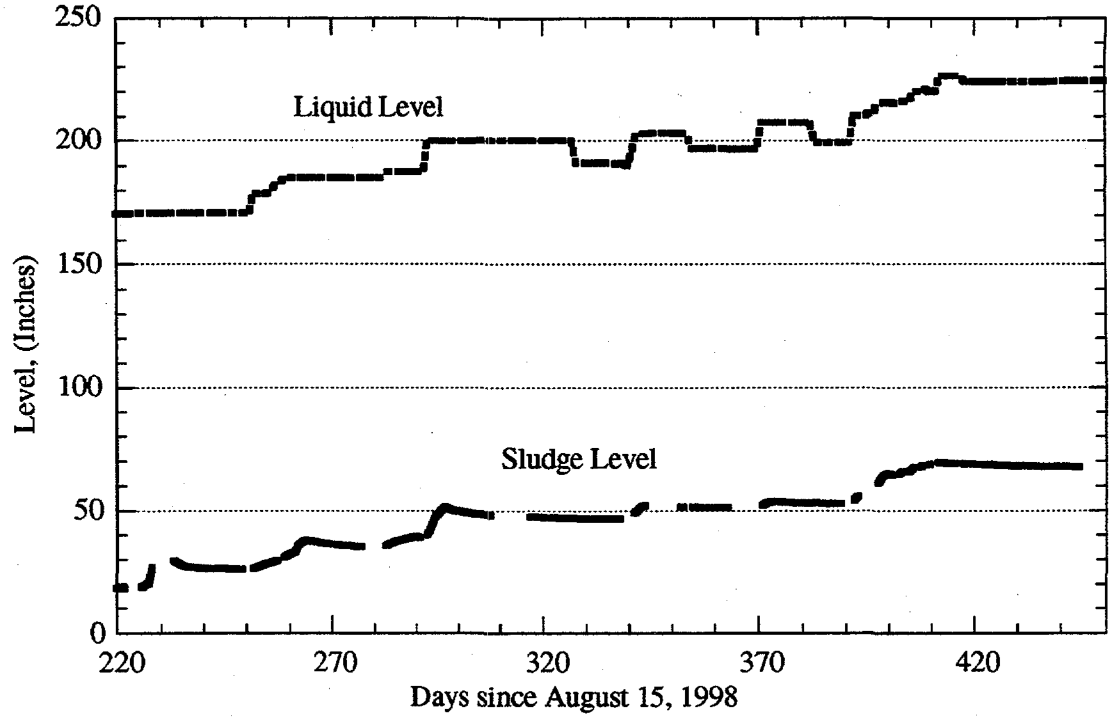

Figure 4.11. Liquid and Solids Layer Surface Level During Sluicing Operations

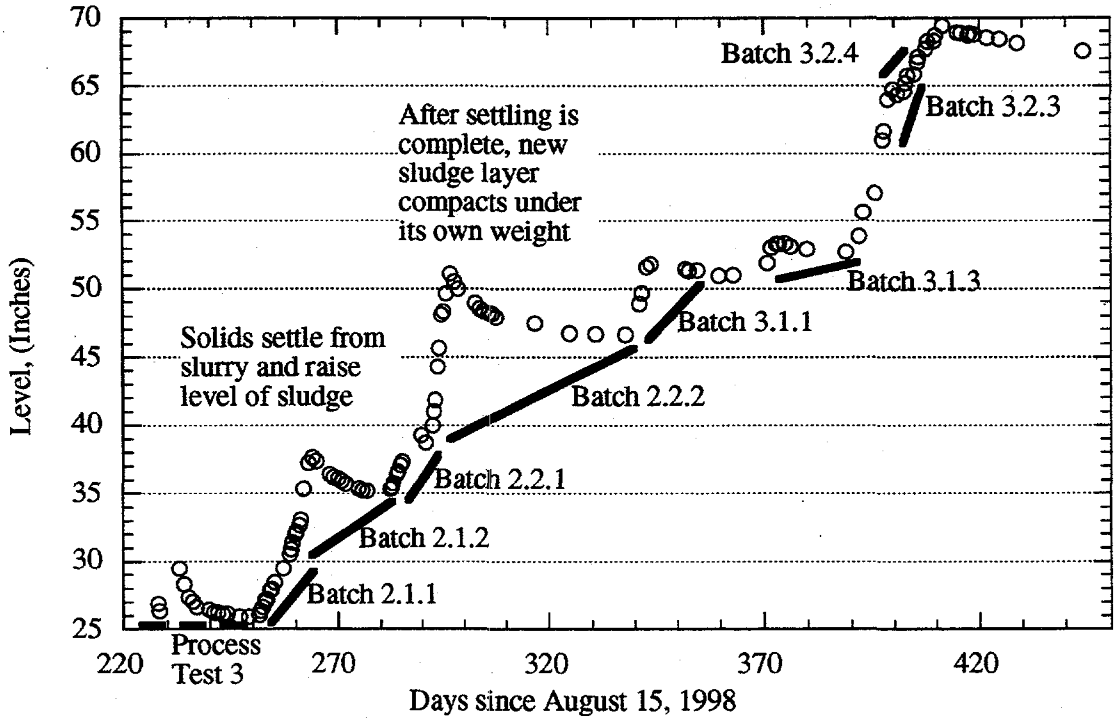

Figure 4.12. Detail of Liquid and Solids Layer Surface Level During Sluicing Operations

The presumed physical situation is shown in Figure 4.13. The particles are assumed to be uniform in size and hence settle at the same rate. In that case, the settling particles occupy a region with a distinct upper interface. The distance "L" traveled by this interface from the beginning of the settling to the time it reaches the simultaneously rising surface of the solids is the distance traveled by the particles that started out at the top of the liquid. The end of settling corresponds also to the maximum height of the solids surface. Dividing the settling distance by the time "t-max" to reach the maximum solids height gives the settling velocity U_1 for the slurry.

Subsequently, the newly settled solids arrive at thickness "S," the difference between the height of solids before and after settling. The volume of solids settled can be estimated relative to the volume of liquid from which they settle. The volume of liquid transferred into AY-102 was reported for each sluicing event. From the cross-sectional area of the tank, the height "V" of the liquid can be inferred from which the solids settle and from this the apparent solids volume fraction, S/V. However, this is for the settled solid/liquid layer. If the solids are close-packed, e.g., 64% by volume for the settled layer, the volume fraction of solids ϕ in the initial slurry can be inferred. The results of this simplified analysis are shown in Table 4.2.

If the particles are all assumed to be spherical and of the same size, the rate of settling of particles embedded in the slurry is related to the rate of settling of the constituent particles individually in the same interstitial liquid by Stokes law, as shown in Equation 1:

$$U_0 = \frac{2\Delta\rho g}{9\mu d^2} = f(\phi)\, U_1 \tag{1}$$

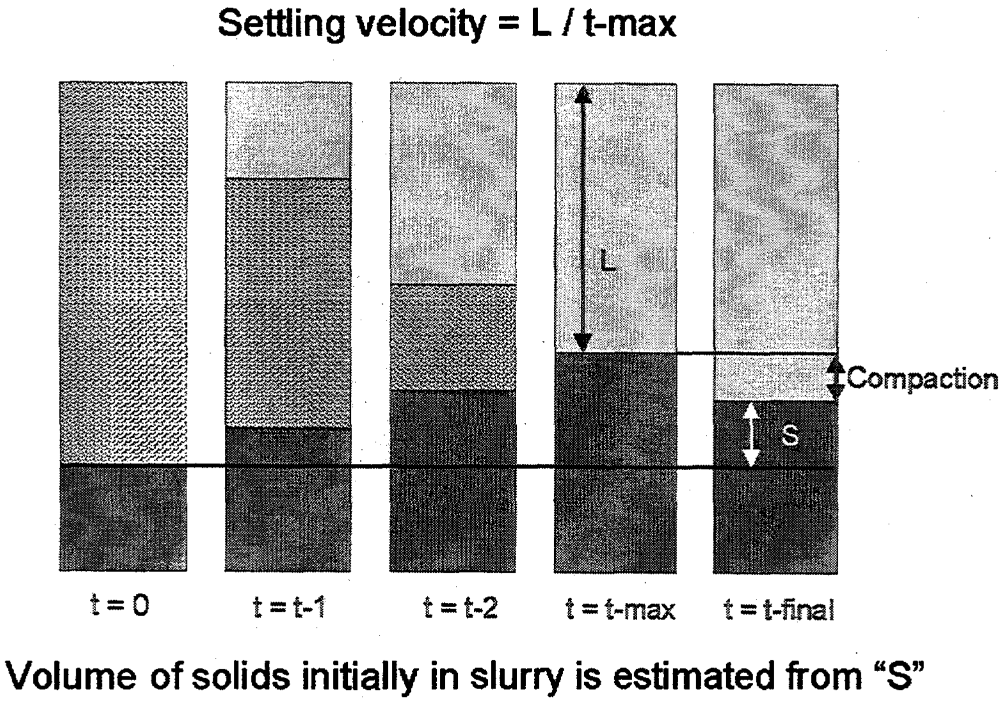

Figure 4.13. Diagram of Assumed Settling Process

Table 4.2. Batch by Batch Evaluation of Volume Fraction of Solids

Batch	**Process Test 3**	**2.1.1**	**2.1.2**	**2.2.1**	**2.2.2**	**3.1.1**	**3.1.3**	**3.2.3**	**3.2.4**
L, in.	141.1	149.3	147.6	148.3	148.8	151.2	154.3	150.6	149.5
t-max, days	7.27	5.55	5.33	7.33	5.32	2.61	2.15	2.29	0.83
S, in.	7.14	3.42	4.67	3.40	6.69	2.39	0.86	3.34	1.17
V, in.	32.7	70.5	45.9	61.4	46.7	78.7	25.8	50.1	220.5
U_1, in./day	19.4	26.9	27.7	20.2	28.0	57.9	71.9	65.6	180.9
ϕ	14.0%	3.1%	6.5%	3.5%	9.2%	1.9%	2.1%	4.3%	0.3%

where U_0 is the velocity for an individual particle, U_1 is the velocity for a particle in the slurry, $f(\phi)$ is a function of the volume fraction ϕ of the particles in the slurry, $\Delta\rho$ is the difference in density between the particles and the interstitial liquid, μ is the viscosity of the interstitial fluid, g is the acceleration of gravity, and d is the diameter of the particles.

The function $f(\phi)$, shown in Equation 2, describes both the upwelling of the interstitial fluid as the particles fall and the effect of interactions between the particles that increase the apparent viscosity of the fluid:

$$f(\phi) = \frac{\left(1 - \frac{\phi}{\phi_{ref}}\right)^4}{(1-\phi)} \tag{2}$$

where ϕ_{ref} is a reference volume fraction, taken to be the volume fraction of close packed spheres, i.e., 0.64.

The apparent diameter of the particles can then be inferred by inverting Stokes law to give Equation 3:

$$d = \left(\frac{9 U_0 \mu}{2 \Delta\rho\, g}\right)^{1/2} \tag{3}$$

where U_0 is found from U_1 and Equations 1 and 2. The result is shown in Table 4.3, where we assume the interstitial fluid has the viscosity and density of water and the specific gravity of the solids is 2.

Table 4.3. Batch by Batch Analysis of Settling Velocity

Batch	Process Test 3	Batch 2.1.1	Batch 2.1.2	Batch 2.2.1	Batch 2.2.2	Batch 3.1.1	Batch 3.1.3	Batch 3.2.3	Batch 3.2.4
U_1 (cm/s)	5.71E-04	7.90E-04	8.14E-04	5.95E-04	8.22E-04	1.70E-03	2.11E-03	1.93E-03	5.32E-03
U_0 (cm/s)	2.48E-04	6.69E-04	5.67E-04	4.91E-04	4.87E-04	1.53E-03	1.89E-03	1.53E-03	5.22E-03
dia, µ	1.07	1.75	1.61	1.50	1.50	2.65	2.94	2.65	4.90

The results are plotted with date in Figure 4.14. Also plotted are the measured specific gravities of the interstitial fluid and centrifuged solids, for comparison to the above assumptions, and the partial composition of the solids in terms of Fe and Al. The compositions and volume fractions are read on the right scale. The particles apparently were in the micron range and showed a slight increase as the sluicing came to an end.

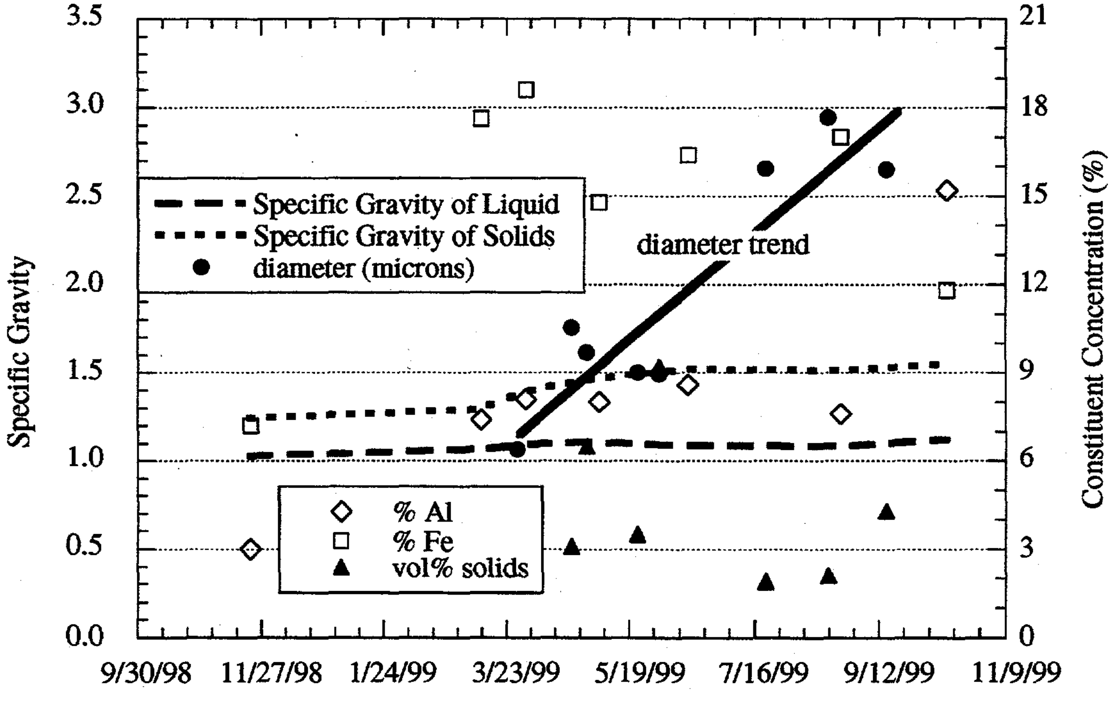

Figure 4.14. Model Predictions of AY-102 Sludge Layer Changes During Sluicing

5.0 Conclusions and Recommendations

The current analysis based on tank data for the six-month period following completion of sluicing firmly supports the conclusion that significant gas retention is not occurring in AY-102. In fact, gas retention is undetectable based on the data available through June 2000. There are three important indications that gas is not being retained in significant quantities:

- The waste level is not rising, even after accounting for evaporation.
- Analysis of the barometric pressure effect shows a retained gas volume below the detection limit for this method.
- The sum of current hydrogen release rates from AY-102 and C-106 is approximately 92% of the pre-sluicing total, well within the uncertainty resulting from changes in waste temperature and salt concentration.

Gas generation and release in C-106 are no longer issues. Only 3–4 scfd of hydrogen is being produced by this tank, which can be diluted below 25% of the LFL of 10,000 ppm with a ventilation rate of 14 scfh, or less than 1 scfm. AY-102 currently generates approximately 30 scfd of hydrogen, which requires at least 2 scfm of ventilation to remain below 10,000 ppm of hydrogen in the headspace.

The results of several independent calculation methods indicate that 97% or 186,000 gallons of the original C-106 sludge were transferred to AY-102, leaving the equivalent of about 6,000 gallons in C-106. However, the video inspection performed in C-106 in July 2000 clearly shows that remaining solids cannot be removed by further sluicing.

6.0 References

Adams MR. 1999. *River Protection Project Process Engineering Desk Instruction and Guidance Manual.* HNF-SD-WM-PROC-021 Rev. 3, Lockheed Martin Hanford Corp., Richland, Washington.

Bailey JW. 1998a. *System Description for the 241-C-106 Waste Retrieval Sluicing System Data Acquisition System.* HNF-2115, Numatec Hanford Corporation, Richland, Washington.

Bailey JW. 1998b. *Project W320 SAR and Process Control Thermal Analyses.* HNF-SD-W320-ER-004 Rev. 1, Numatec Hanford Company, Richland, Washington.

Bailey JW. 2000. *Waste Retrieval Sluicing System (WRSS) and Project W-320, Tank 241-C-106 Sluicing, Lessons Learned.* RPP-5687, CH2M Hill Hanford Group, Inc., Richland, Washington.

Carothers, KG, D Estey, NW Kirch, LA Stauffer, JW Bailey. 1998. *Tank 241-C-106 Waste Retrieval Sluicing System Process Control Plan.* HNF-SD-WM-PCP-013, Lockheed Martin Hanford Corporation, Richland, Washington.

Ogden DM, and DR Bratzel. 2000. *Thermal Analyses for Tanks 241-AY-102 and 241-C-106.* RPP-6463 Rev. 0, CH2MHill Hanford Group, Inc., Richland, Washington.

Reynolds DA. 1997. *Chemical and Chemically Related Considerations Associated with Sluicing Tank C-106 Waste to Tank AY-102.* HNF-SD-WM-TI-756 Rev 2, Lockheed Martin Hanford Corporation, Richland, Washington.

Stauffer LA and LM Stock. 1999. *Origins of Volatile Organic Compounds Emerging from Tank 241-C-106 during Sluicing.* HNF-4261 Rev. 1, Lockheed Martin Hanford Corporation, Richland, Washington.

Stewart CW and G Chen. 1998. *Baseline Estimate of the Retained Gas Volume in Tank 241-C-106.* PNNL-11890, Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Locations of Instrumentation for WRSS Data in Both Tanks

Appendix A

Locations of Instrumentation for WRSS Data in Both Tanks

Figure A.1 is a diagram of the tank showing the locations of the instrumentation in the waste in AY-102. Figure A.2 shows the locations of the thermocouples between the insulating concrete and the tank bottom in relation to the vent channels in the concrete bottom. The four 4-in. vent channels introduce air that is mixed in the small central plenum beneath the tank bottom and then flows radially outward through the air return channels and annular ring channels shown on the diagram. The radial locations of risers 13A–D, risers 3a–f, and risers 16A and 16C are also mapped onto this diagram. Figure A.3 is a diagram of C-106 showing the locations of the various instruments in the tank.

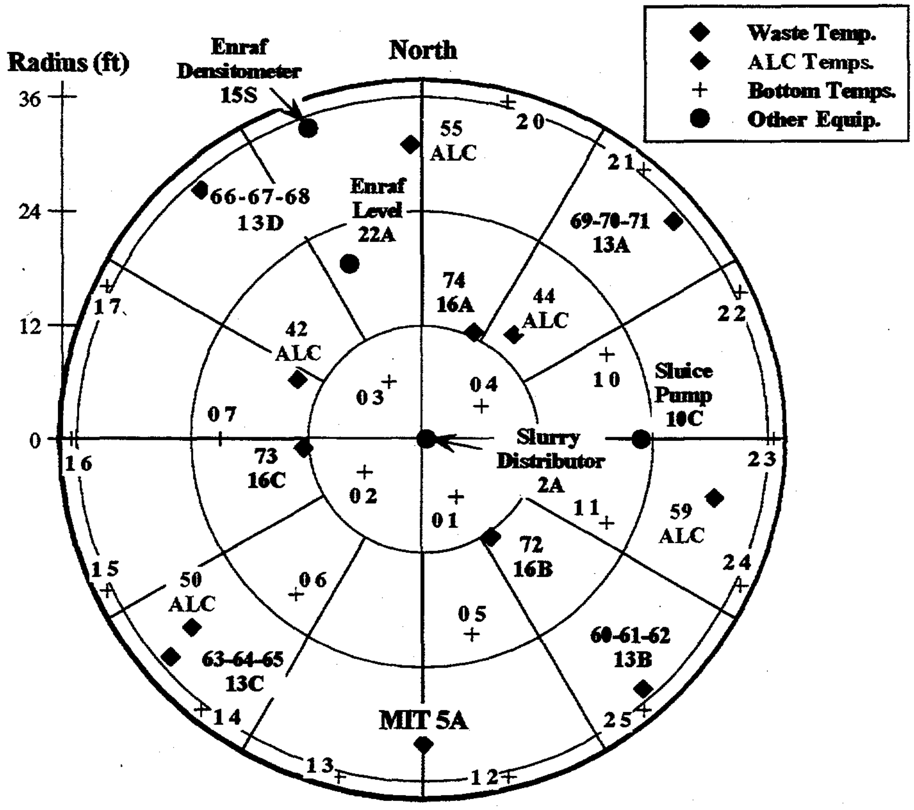

Figure A.1. AY-102 Instrumentation Map

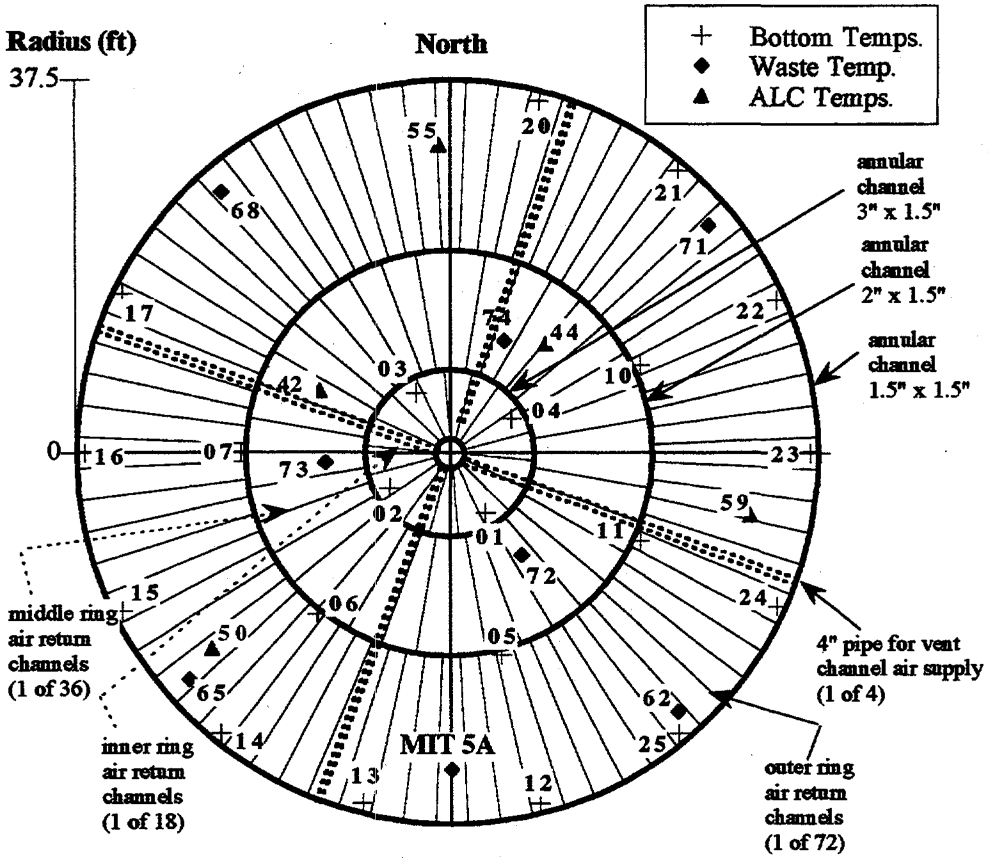

Figure A.2. AY-102 Floor Channel Map

Tables A.1 through A.6 summarize the locations and types of measurements obtained using the DAS and non-DAS data collection for WRSS referenced in this report for evaluation and monitoring of the behavior of AY-102 and C-106. In Tables A.2 through A.6, radial locations are given by distance from the center of the tank and azimuthal angle relative to north, as indicated on the tank diagrams. Vertical locations are given by distance from the tank bottom. For AY-102, this is straightforward because the double shell tanks have a flat bottom. For C-106, the matter is more complicated because the tank bottom is not flat; it has a slope of 1:37.5—that is, it drops 1 ft in the 37.5 feet from the tank edge to the center. The zero datum for vertical distances in this tank is a horizontal plane 12 in. above absolute bottom at the center of the tank. The distance from the zero reference datum to the local tank bottom, therefore, varies with riser location, as listed in Table A.1. (These values are calculated assuming a uniform slope of approximately 1.5 degrees.)

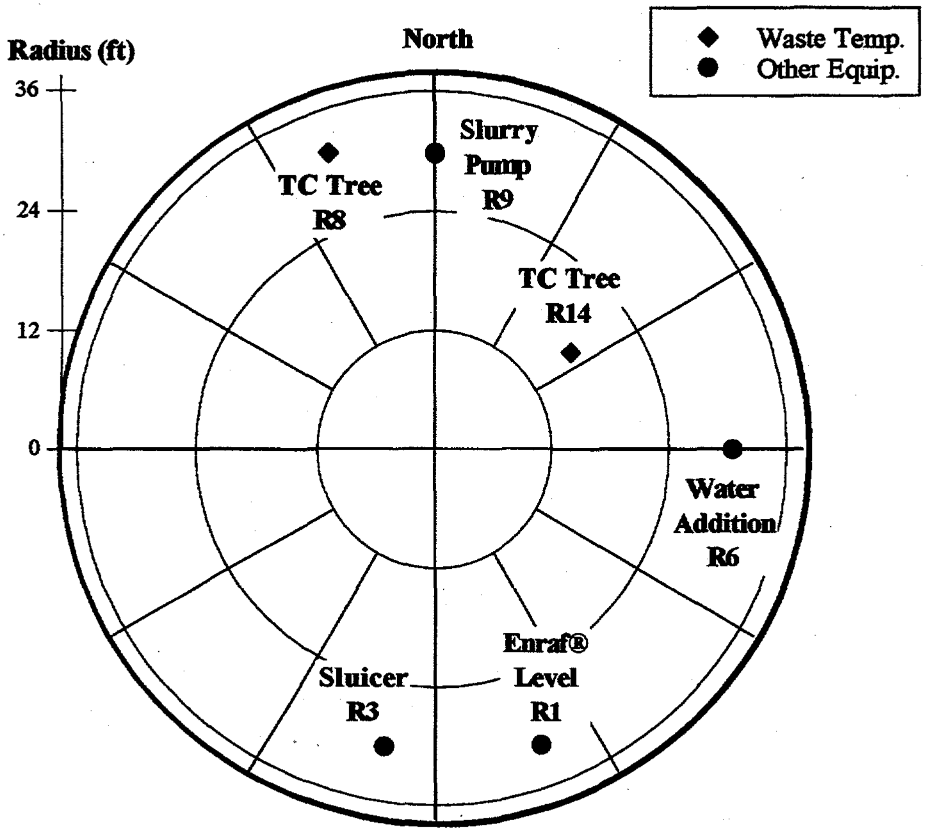

Figure A.3. C-106 Instrumentation Map

Table A.1. Distances in Tank C-106

Tank	Riser	Radial location (feet)	Local tank bottom, relative to zero datum (inches)
C106	1	31.7	-1.9
C106	3	30.4	-2.3
C106	6	30.4	-2.3
C106	8	31.7	-1.9
C106	9	29.7	-2.5
C106	14	17.0	-6.6

Table A.2. Instrumentation for Monitoring Waste Temperature in AY-102

Instrument	DAS tag name	Riser	Radial location (feet)	Vertical height (inches)	Azimuth (degrees)
thermocouple	TI-71	13A	34.75	4	48.8
thermocouple	TI-62	13B	34.75	4	138.8
thermocouple	TI-65	13C	34.75	4	228.8
thermocouple	TI-68	13D	34.75	4	318.8
thermocouple	TI-74	16A	12.50	4	25.4
thermocouple	TI-73	16C	12.50	4	265.4
thermocouple	TI-70	13A	34.75	158	48.8
thermocouple	TI-61	13B	34.75	158	138.8
thermocouple	TI-64	13C	34.75	158	228.8
thermocouple	TI-67	13D	34.75	158	318.8
thermocouple	TI-69	13A	34.75	300	48.8
thermocouple	TI-60	13B	34.75	300	138.8
thermocouple	TI-63	13C	34.75	300	228.8
thermocouple	TI-66	13D	34.75	300	318.8

In addition to the thermocouples on risers 13A-D, 16A, and 16C at 300 in., the MIT in riser 5A (which is located at radius 32 ft, 180-degree azimuth) also contains thermocouples at approximately 10- to 20-in. intervals from 434.2 in. to 11.2 in. above the zero datum. This provides a vertical profile of temperature in the tank, including sludge, supernatant, and air in the headspace above the waste level.

Table A.3. Instrumentation for Monitoring Airlift Circulation Temperature in AY-102

Instrument	DAS tag name	Riser	Radial location (feet)	Vertical height (inches)	Azimuth (degrees)
thermocouple	TI-44	3a	14.50	3	40.6
thermocouple	TI-59	3b	31.00	3	101.6
thermocouple	TI-50	3c	31.00	3	230.4
thermocouple	TI-42	3d	14.50	3	295.6
thermocouple	TI-55	3e	31.00	3	357.8

Table A.4. Instrumentation for Monitoring Insulating Concrete Bottom Temperature in AY-102

Instrument	DAS tag name	Radial location (feet)	Azimuth (degrees)
thermocouple	TI-01	7.0	150
thermocouple	TI-02	7.0	240
thermocouple	TI-03	7.0	330
thermocouple	TI-04	7.0	60
thermocouple	TI-05	21.0	166
thermocouple	TI-06	21.0	219
thermocouple	TI-07	21.0	270
thermocouple	TI-10	21.0	65
thermocouple	TI-11	21.0	115
thermocouple	TI-12	36.5	166
thermocouple	TI-13	36.5	194
thermocouple	TI-14	36.5	219
thermocouple	TI-15	36.5	244
thermocouple	TI-16	36.5	270
thermocouple	TI-17	36.5	296
thermocouple	TI-20	36.5	14
thermocouple	TI-21	36.5	39
thermocouple	TI-22	36.5	65
thermocouple	TI-23	36.5	90
thermocouple	TI-24	36.5	115
thermocouple	TI-25	36.5	141

Table A.5. Other Instrumentation of Interest in Both Tanks

Instrument	Tag name	Riser	Radial location (feet)	Azimuth (degrees)
Enraf level indicator; AY-102	LI-602C	22A	21.50	338
Enraf 854 level gauge; C-106	N/A	1	31.7	160
gas chromatograph; AY-102	N/A	15C	12.50	275
gas chromatograph; C-106	N/A	2		
Enraf densitometer; AY-102	DI-602A-1 through DI-602A-N	15S	34.75	340
MIT verification probe; AY-102	TI-06230 through TI-06251	5A	32.00	180

For risers 8 and 14 in Tank C-106, in addition to giving the vertical heights in Table A.6 relative to the zero datum, the distance relative to the absolute bottom at the center of the tank is also listed, in parentheses. At a radius of 17 ft, the local bottom of the tank under riser 14 is 6.56 in. below the zero datum reference plane. At a radius of 31.7 ft, the local bottom of the tank under riser 8 is 1.86 in. below the zero datum reference plane.

Other measurements of interest include the exhaust airflow rates and temperatures for both tanks, including the air exhaust from the annulus of AY-102. This information is used in conjunction with the mass transfer information to estimate the rate of heat removal from the tanks over the reporting period. Full documentation of the data management plan is available in HNF-2318 Rev. 0, "Management of Data for Tank 241-C-106 Retrieval."

Table A.6. Instrumentation for Monitoring Waste Temperature in C-106

Instrument	Tag name	Riser	Radial location (feet)	Vertical height (inches)	Azimuth (degrees)
thermocouple	C106-TI-R014-01	14	17.0	4 (15.96)	55
thermocouple	C106-TI-R014-02	14	17.0	28 (39.96)	55
thermocouple	C106-TI-R014-03	14	17.0	52 (63.96)	55
thermocouple	C106-TI-R014-04	14	17.0	76 (87.96)	55
thermocouple	C106-TI-R014-05	14	17.0	100 (111.96)	55
thermocouple	C106-TI-R014-06	14	17.0	124 (135.96)	55
thermocouple	C106-TI-R014-07	14	17.0	148 (159.96)	55
thermocouple	C106-TI-R014-08	14	17.0	172 (183.96)	55
thermocouple	C106-TI-R008-01	8	31.7	3.38 (14.64)	340
thermocouple	C106-TI-R008-02	8	31.7	27.38(38.16)	340
thermocouple	C106-TI-R008-03	8	31.7	51.38 (62.16)	340
thermocouple	C106-TI-R008-04	8	31.7	75.38 (86.16)	340
thermocouple	C106-TI-R008-05	8	31.7	99.38 (110.16)	340
thermocouple	C106-TI-R008-06	8	31.7	181.38(192.16)	340

Appendix B

Energy Balance for Tanks 241-AY-102 and 241-C-106

Appendix B

Energy Balance for Tanks 241-AY-102 and 241-C-106

B.1 Pre-sluicing Energy Balance

An energy balance analysis will be performed to estimate the amount of heat source removed from Tank 241-C-106 and transferred into Tank 241-AY-102 as the waste retrieval and transfer operation proceeds. The heat load estimate is required to predict the thermal behavior of Tank 241-AY-102 and demonstrate that the maximum waste temperatures will not exceed established temperature limits. The thermal hydraulic models used for the energy balance analyses have been benchmarked using data for the pre-sluicing operating conditions for C-106 and AY-102.

Tank 241-AY-102

A pre-sluicing energy balance was performed for Tank 241-AY-102 using the benchmarked thermal models. The tank heat load was estimated to be 41,200 Btu/hr. These analyses used the primary and annulus ventilation system flow data and measured meteorological data from June 1, 1998. The energy balance established through the thermal analyses is shown in Figures B.1 and B.2. Figure B.1 shows the primary and annulus system heat removal. The energy storage is the difference between the total tank heat load and the sum of the primary and annulus heat removal. Figure B.2 shows the components of the primary system heat removal, which include latent heat, sensible heat and soil conduction. It can be seen from the figure that during period of July through the middle of September, the total heat removed by the tank ventilation system alone is

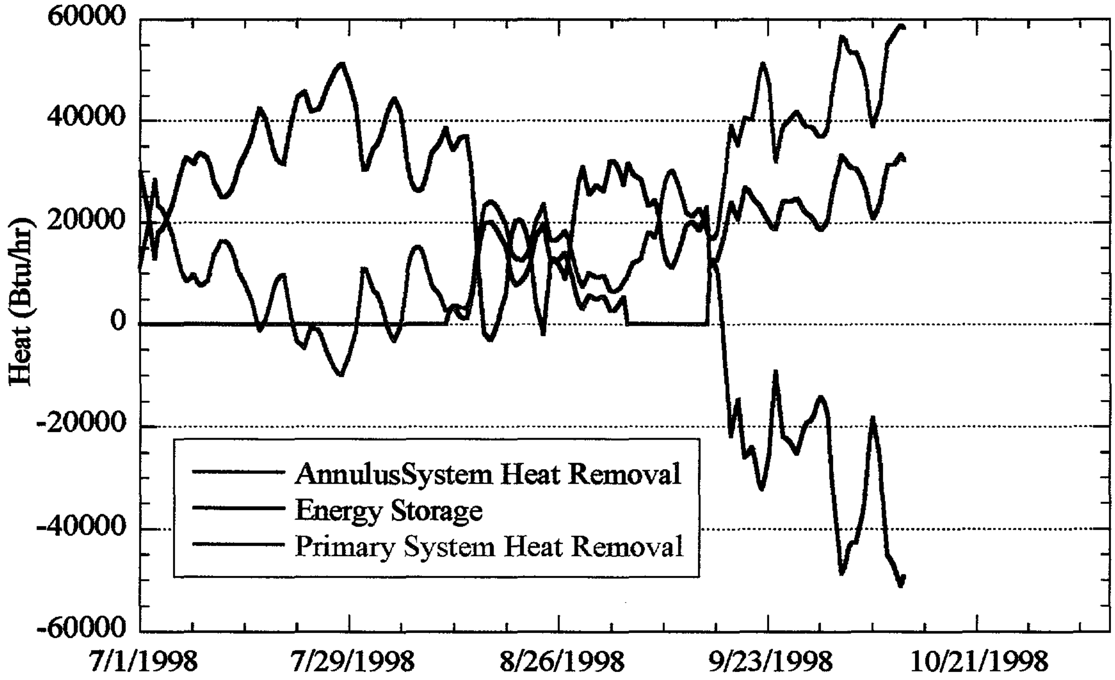

Figure B.1. Energy Balance for 241-AY-102; 41,200 Btu/hr Heat Load

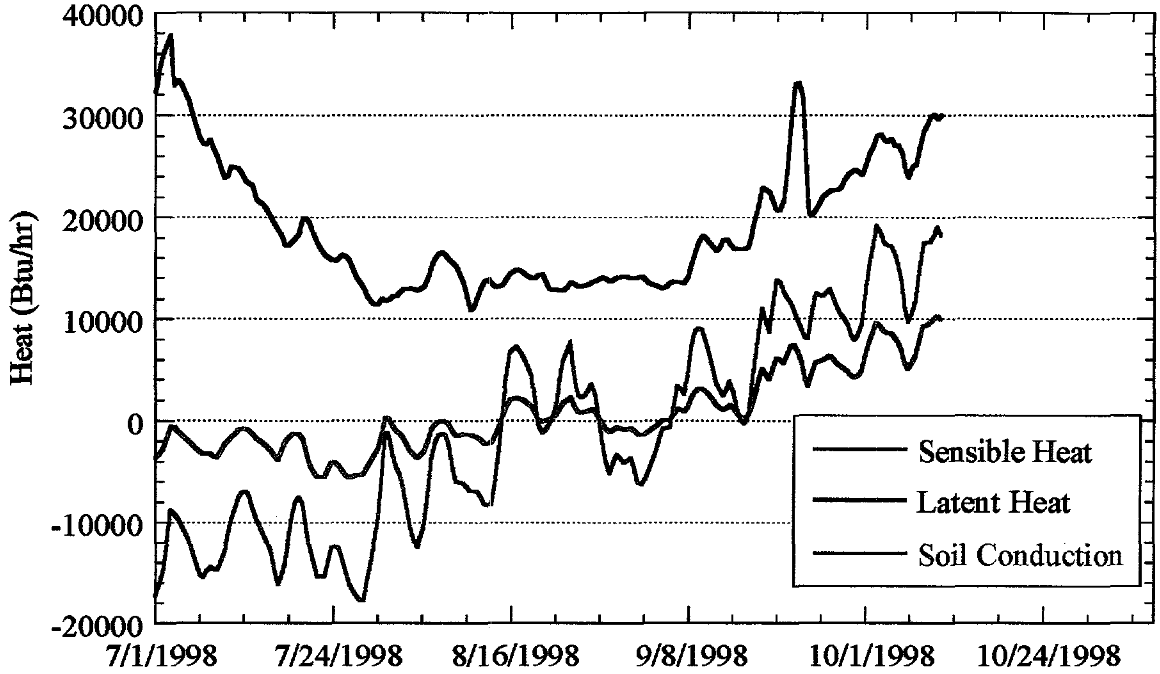

Figure B.2. AY-102 Primary System Heat Removal Components

less than the tank heat load, resulting in energy storage in the tank waste. However, during the month of August with the annulus exhaust system also in operation, the heat stored in the waste was reduced significantly. When the annulus system was shut off at the end of August, the energy stored in the waste increased again. From the middle of September, with the restart of the annulus system and with the decreasing ambient temperatures, the heat removal rate exceeds the heat generation rate, which results in energy removal from the waste (seen as negative energy storage in Figure B.1). This effect can also be seen in the tank temperatures (see Figures B.1, B.5, B.6, and B.7). Reduced temperatures are most pronounced in the bottom waste and the insulating concrete due to the proximity of cooling channels.

Tank 241-C-106

The heat load of the Tank 241-C-106 was determined by thermal analyses to be 118,000 Btu/hr. The measured data for P-16 exhauster was used along with the ambient temperature, humidity and pressure conditions for the ventilation flow. The effect of the air chiller and 296-C-006 ventilation system operations were included in the analyses. Figure B.3 shows the energy balance for this tank. The heat is removed from the tank by evaporation, sensible heat and conduction through the soil. In Tank 241-C-106, the dome air temperature remains above the ambient temperature, resulting in heat removal by conduction through the dome soil throughout the year. The dominant part of heat loss is through the liquid evaporation. From March through August, heat removal is less than heat generation and the remaining heat energy is stored in the tank, leading to increased waste temperatures. From September through February, more heat is removed from the tank than generated by the waste, resulting in energy removal from the waste

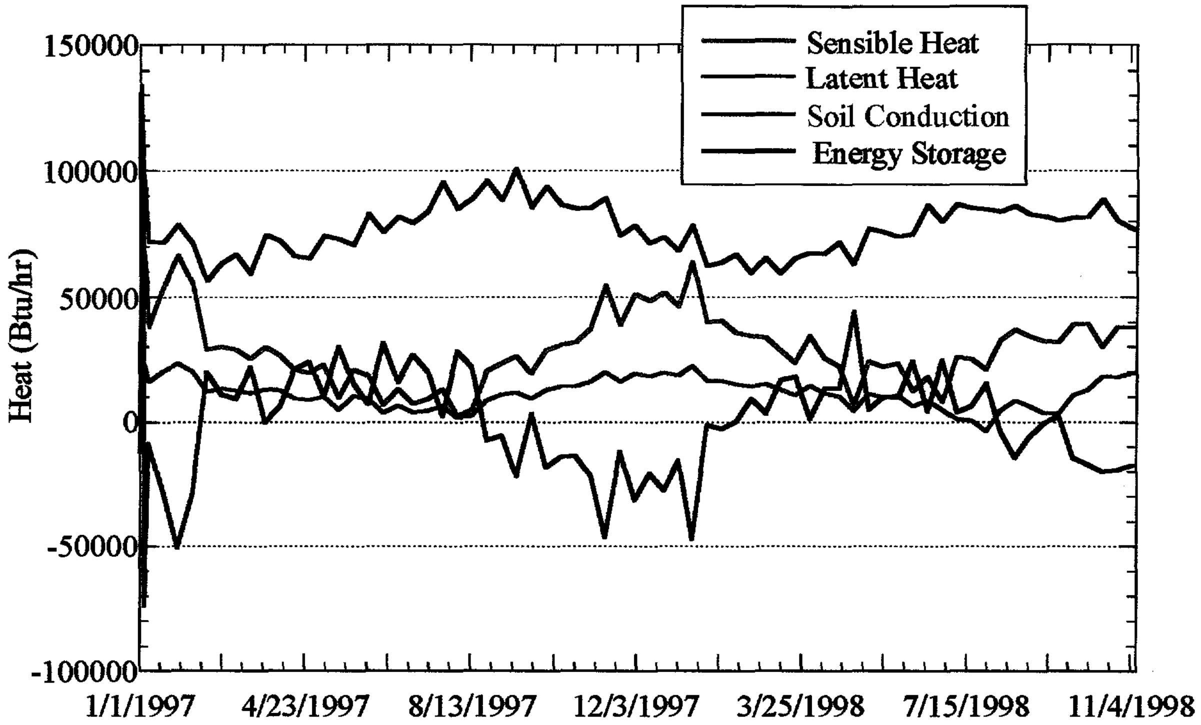

Figure B.3. Energy Balance for 241-C-106, 118,000 Btu/hr Heat Load

and reducing waste temperatures. The chiller in the ventilation flow path was activated at end of June 1998. The chiller operation increased the sensible heat removal and thus reducing the net energy stored in the tank waste. However, shutting down the P-16 exhauster (which provided about 2600 cfm ambient ventilation flow) and activating the C-006 system (which has about 350 cfm ambient flow and 800 cfm recirculation flow) significantly reduced the primary ventilation flow heat removal capacity.

B.2 Energy Balance as of April 30, 1999

Tank 241-AY-102

An energy balance analysis has been performed to estimate and verify the amount of waste containing the heat source has been removed from C-106 and transferred into AY-102 as of April 30, 1999. First, the heat load of the tank was estimated using the measured data for AY-102 and compared with the heat load estimated using the radiolytic heat content of the transferred waste. The results of this calculation shows that the radiolytic heat content estimate of the waste transferred by Process Engineering Group is more reasonable than the conservative estimate calculated using the best estimate parameters.

Figure B.4 provides the results for the heat removed by the primary ventilation flow both in the form of sensible heat and latent heat and through heat conduction to the surrounding soil.

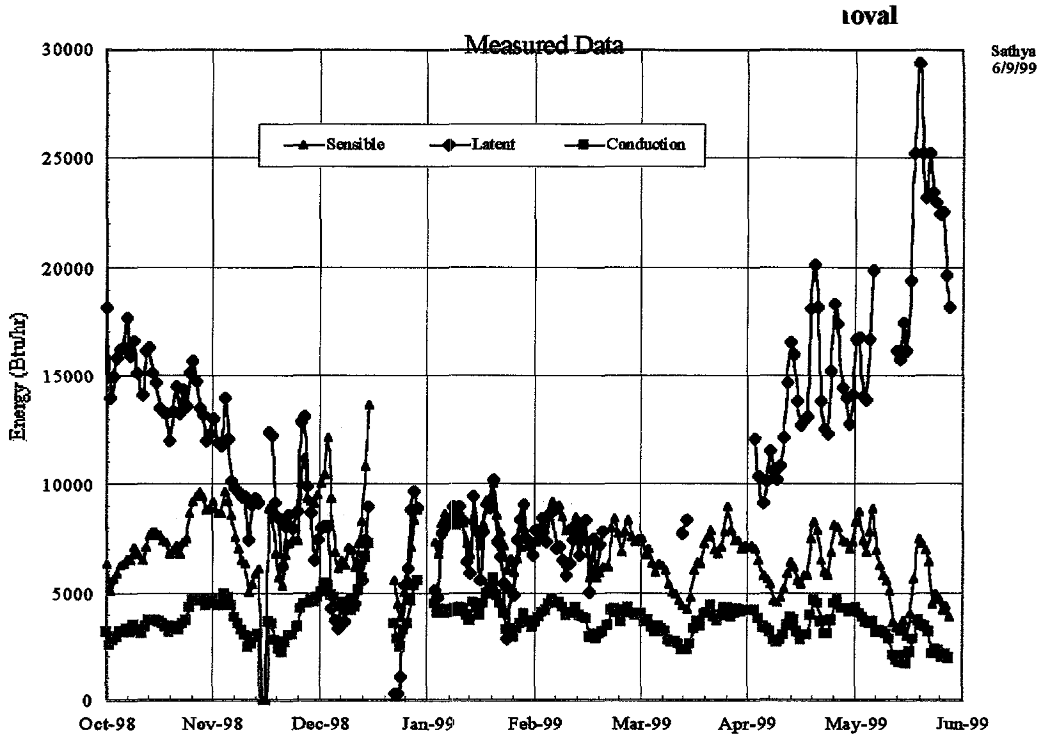

Figure B.4. Tank 241-AY-102 Primary Ventilation Heat Removal

Figure B.5 shows the results for the heat loss through primary ventilation flow and soil conduction as well as the annulus ventilation flow sensible heat removal. Also shown in the Figure B.5 is the total heat removal from the tank.

Figure B.6 describes the total heat stored in the waste including the individual component of supernate and sludge sensible heat values. The heat storage and heat removal values and the derived tank waste heat load are shown in Figure B.7.

Figure B.8 shows the comparison of the tank heat load evaluated using the measured temperatures, humidity and primary and secondary ventilation flows and that estimated using radiolytic content of transferred waste from C-106 to AY-102. Also shown in the Figure B.8 is the heat load value that derived using best estimate waste parameters as given in PCP and thermal analysis reports.

The results suggest that process engineering estimates of heat load for the transferred waste seems more reasonable. The measured sludge volumes and the estimated radiolytic heat load values are used for the transferred sludge in GOTHIC AY-102 models.

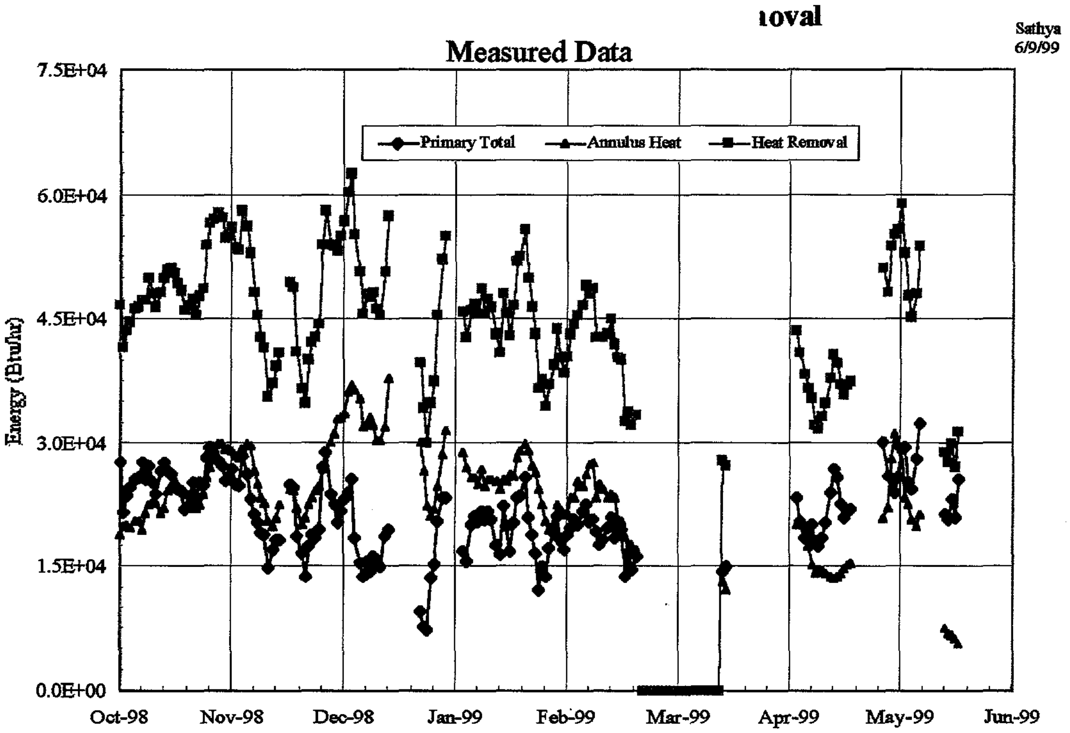

Figure B.5. Tank 241-AY-102 Heat Removal

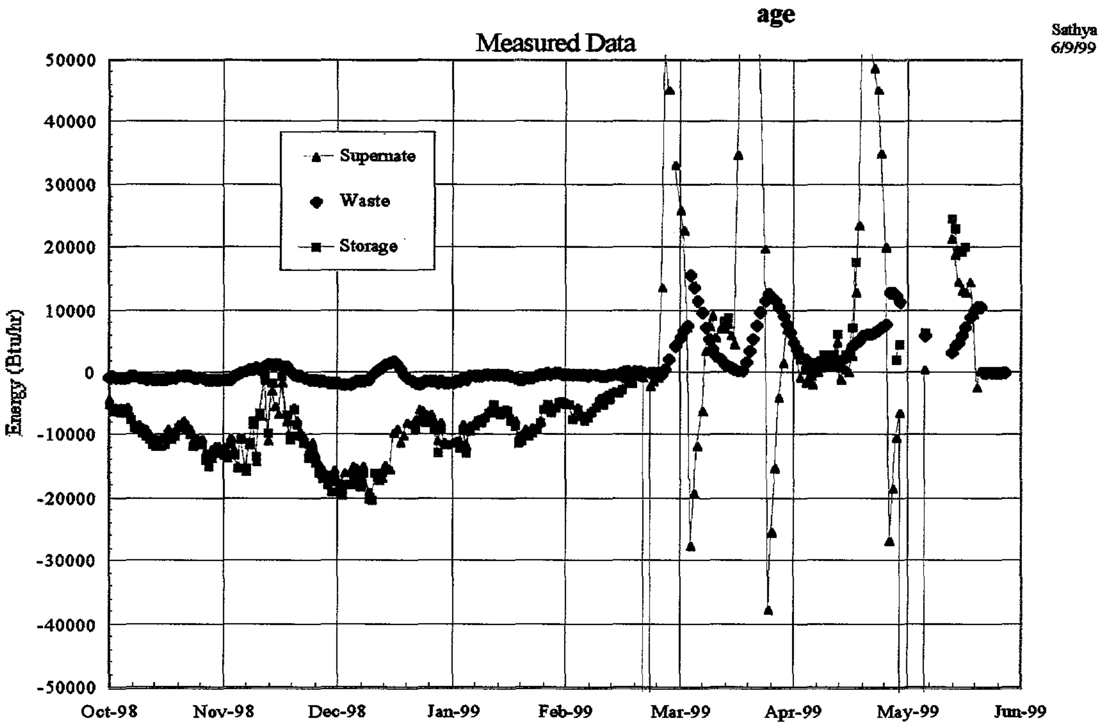

Figure B.6. Tank 241-AY-102 Heat Storage

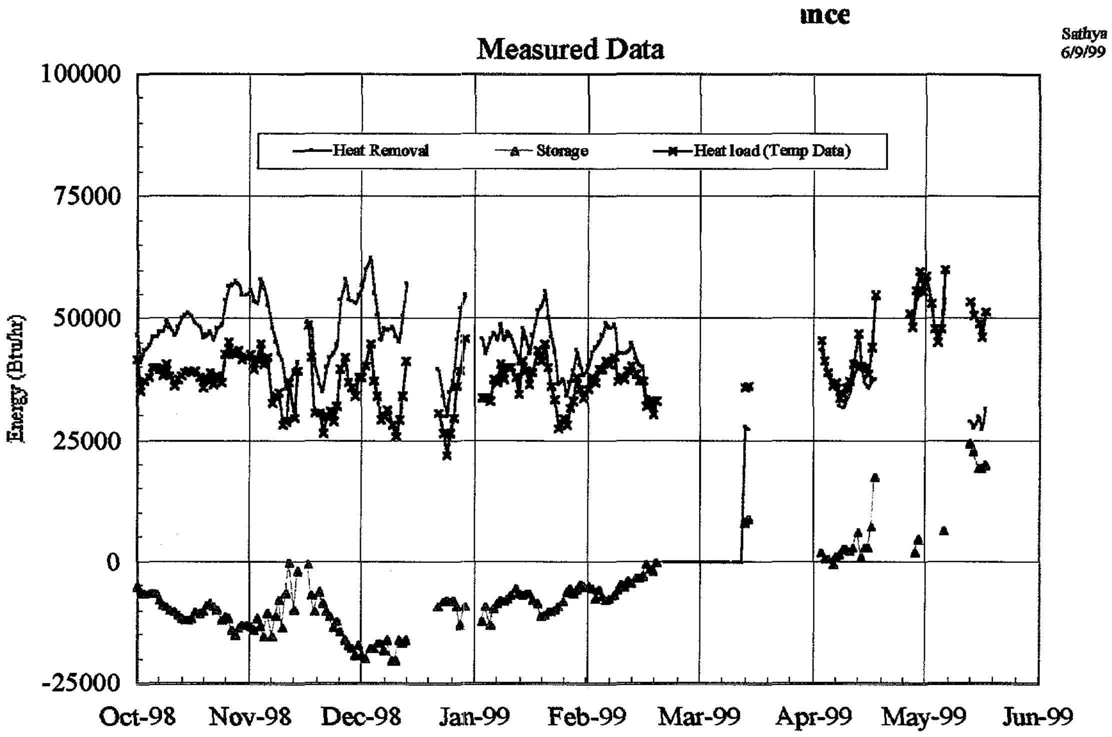

Figure B.7. Tank 241-AY-102 Heat Balance

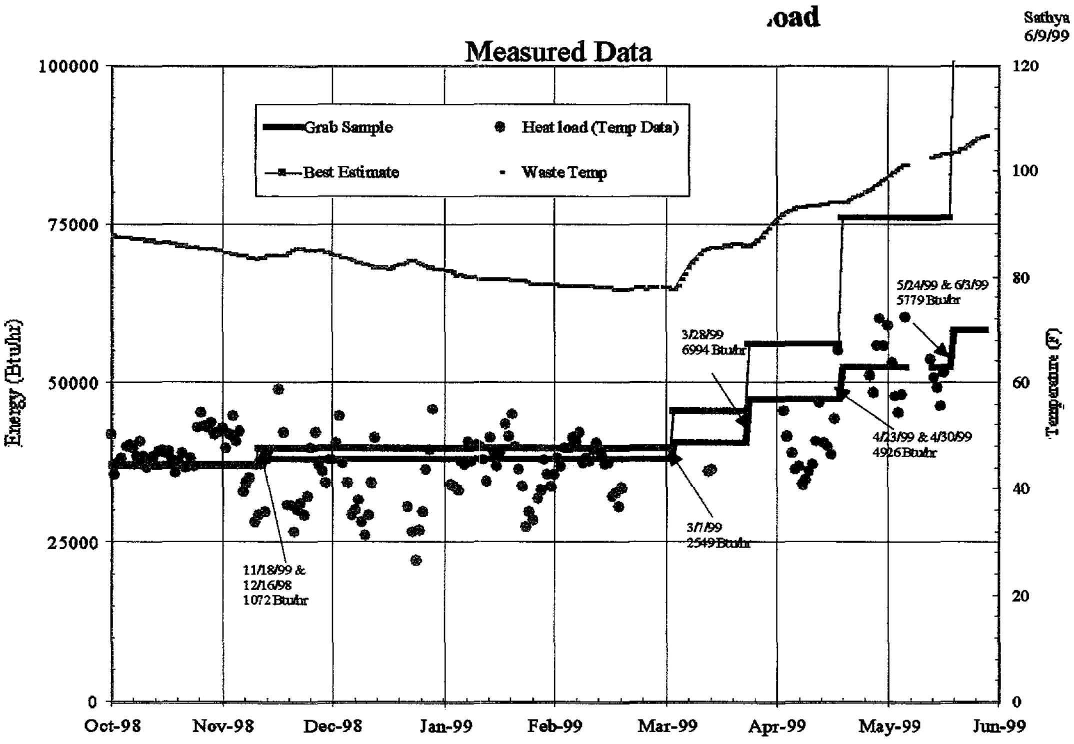

Figure B.8. Tank 241-AY-102 Heat Load

Appendix C

Baseline Hydrogen Release in AY-102 and C-106

Appendix C

Baseline Hydrogen Release in AY-102 and C-106

The WRSS Process Control Plan (PCP) gives the expected hydrogen release rates for C-106 and AY-102 as 6.5 ± 0.2 scfd and 14 ± 6 scfd, respectively (Carothers et al. 1998, Table 3-10). The release rate for C-106 was derived from the headspace hydrogen concentration transient when the ventilation system was shut down for 48 hours in June 1997. The AY-102 expected value was established shortly after the SHMS was installed in February 1998.

The baseline hydrogen release rates are important in assessing flammable gas accumulation in AY-102 after sluicing. A reasonable first-order assumption is that, if there is no gas retention, the hydrogen release rate from AY-102 after sluicing should be equal to the sum of the baseline AY-102 release rate and the product of the fraction of sludge transferred and the baseline C-106 release rate. The baseline release rate is also useful in evaluating the flammable gas decision map in the PCP (Carothers et al. 1998, Table 4-8).

The PCP requires the baseline to be established over a minimum four-week period before sluicing. The period considered here is 14 weeks, from August 1 to November 6, 1998. This is the longest period during which no significant waste disturbance occurred in either tank. In AY-102, the airlift circulators ran for nine days (June 28–July 6). The waste level (and thus hydrostatic head) was reduced to 167 in. at the end of July. In C-106 makeup water additions occurred August 20 (2010 gal), September 18 (3000 gal), and October 5 (3599 gal). A transfer line flush on October 29 added 3465 gallons.

The hydrogen release rate is equal to the flow rate of hydrogen in the headspace exhaust under the assumption that no significant retention or release is occurring in either tank. The hydrogen flow rates for AY-102 and C-106 for the baseline period are shown in Figures C.1 and C.2, respectively. The boxes outlined in red represent the 95% confidence limits derived from the cumulative distribution of the measurements. A flow rate calculation (headspace concentration ventilation rate) is made every 10 minutes, one for each headspace hydrogen concentration measurement recorded by the gas chromatograph. The baseline period contains 7708 data points for AY-102 and 11654 data points for C-106.

The baseline is taken as the mean of the data set. The mean release rate is 23.5 scfd for AY-102 and 12.5 scfd for C-106; the medians are 23.7 scfd and 12.2 scfd, respectively. The uncertainty is derived from the cumulative distribution of the data sets, which is shown with the probability density for AY-102 and C-106 in Figures C.3 and C.4, respectively. This uncertainty is assumed to contain all the random errors associated with the measurement system. The 95% confidence bounds for AY-102 and C-106 release rates are 18.9–27.8 scfd and 9.4–16.9 scfd, respectively. Thus the best estimate of hydrogen release rates for each tank can be stated as 24 (+4, -5) scfd for AY-102 and 12.5 (+4, -3) scfd for C-106.

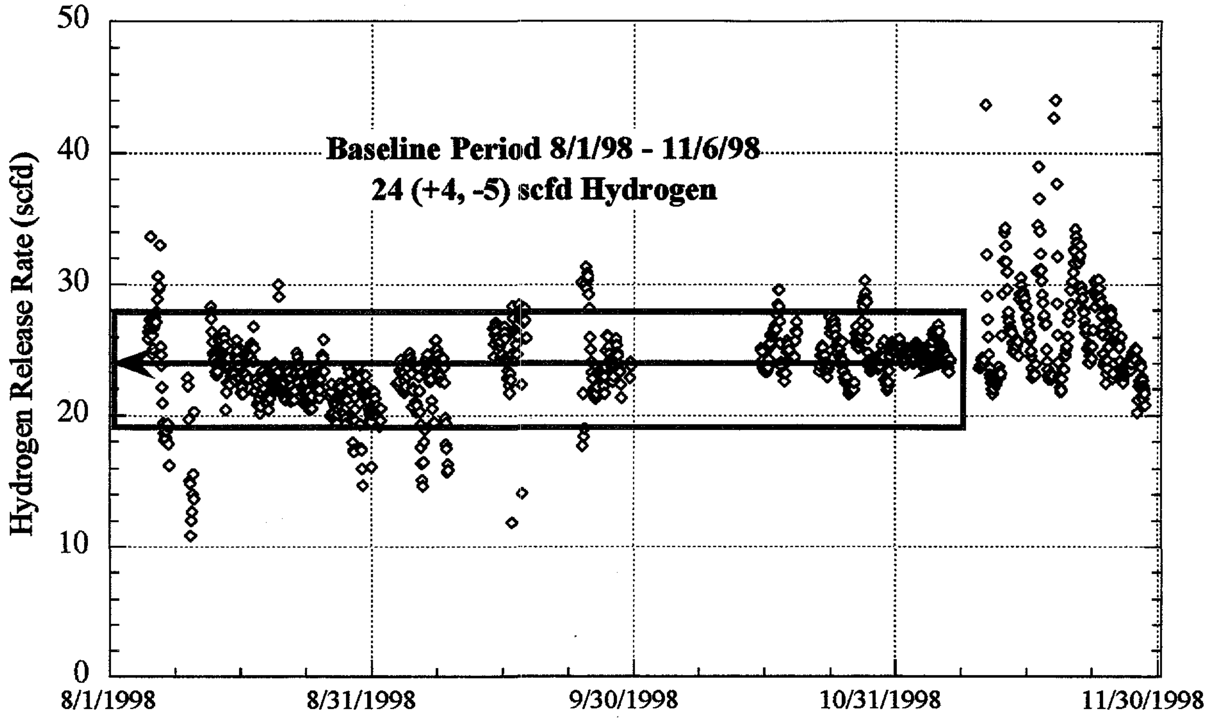

Figure C.1. AY-102 Baseline Hydrogen Release Rate

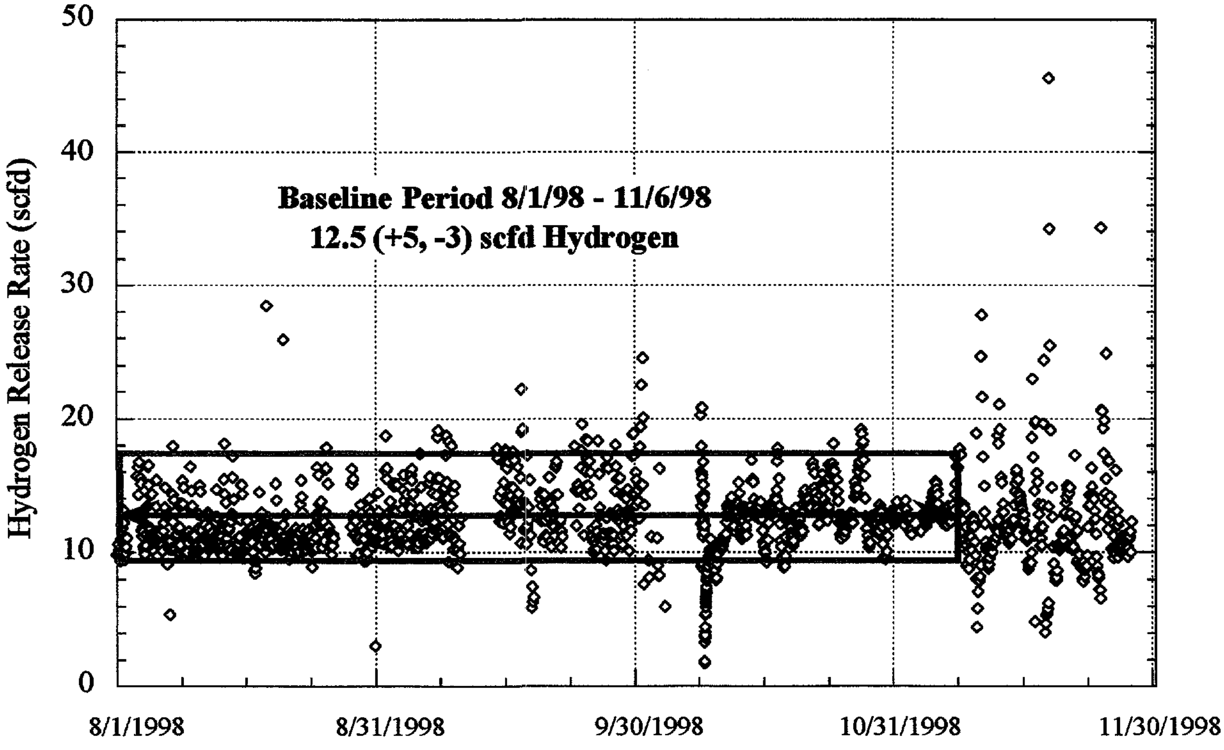

Figure C.2. C-106 Baseline Hydrogen Release Rate

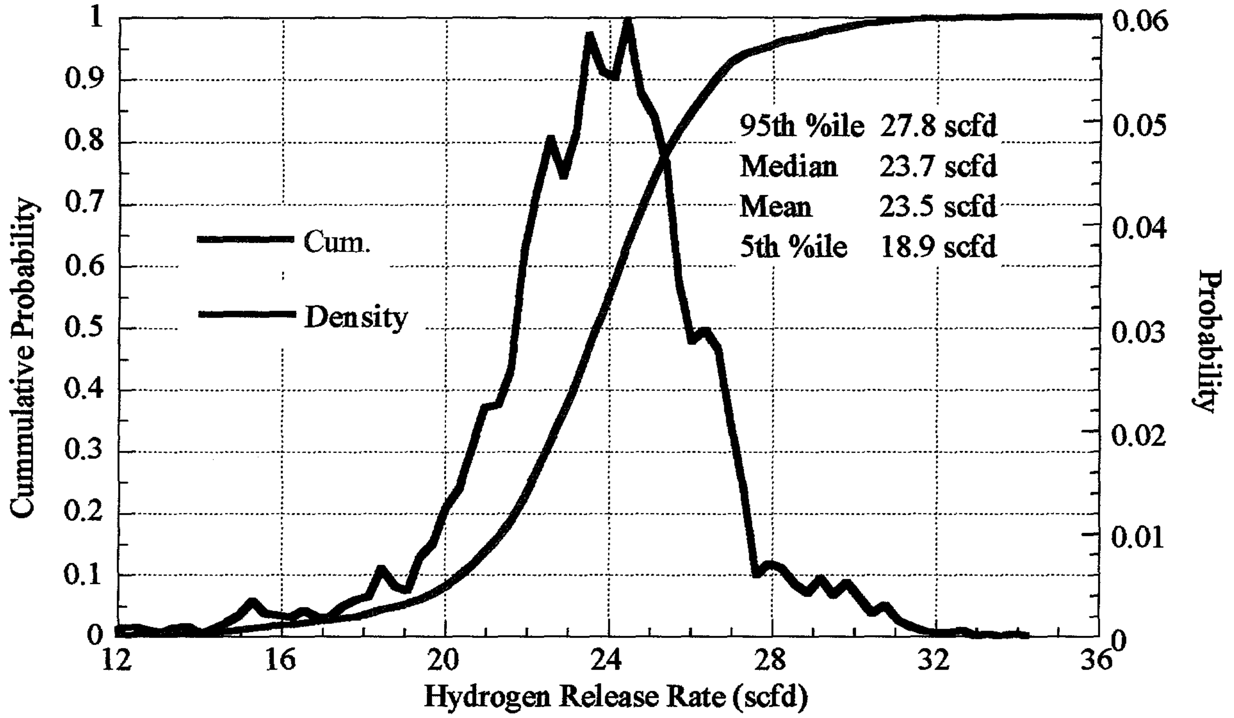

Figure C.3. AY-102 Hydrogen Release Rate Distributions

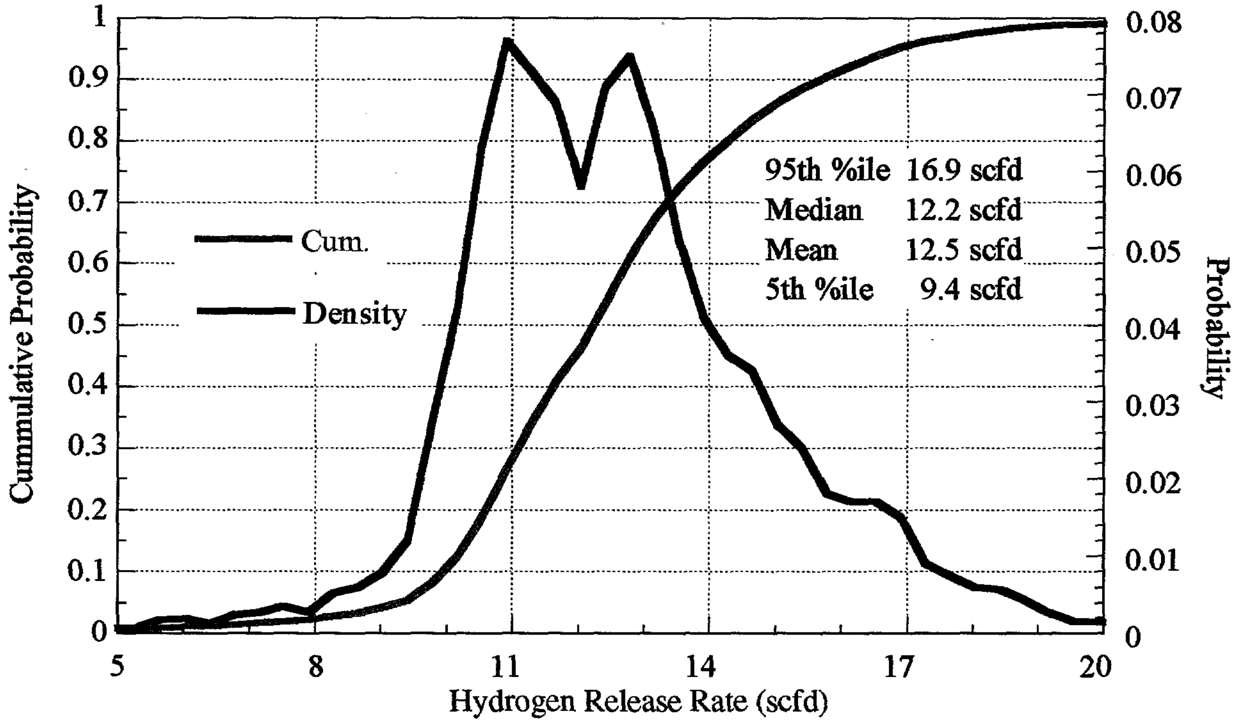

Figure C.4. C-106 Hydrogen Release Rate Distributions

Reference

Carothers, KG, D Estey, NW Kirch, LA Stauffer, and JW Bailey. 1998. *Tank 241-C-106 Waste Retrieval Sluicing System Process Control Plan.* HNF-SD-WM-PCP-013 Rev. 1, Lockheed Martin Hanford Corporation, Richland, Washington.

Distribution

No. of Copies		
Offsite		
2	DOE Office of Scientific and Technical Information	
Onsite		
1	DOE Richland Operations Office	
	W. Abdul	H6-60
8	PHMC Team	
	K. J. Anderson	S4-44
	J. W. Bailey	S2-40
	D. R. Bratzel	R1-44
	K. G. Carothers	R2-11
	M. R. Landon	R2-89
	D. B. Parkman	S5-13
	R. E. Raymond	S7-70
	R. G. Stickney	R1-43
9	Pacific Northwest National Laboratory	
	J. M. Bates	K7-15
	J. W. Brothers	K5-22
	J. M. Cuta	K7-15
	F. F. Erian	K7-15
	W. L. Kuhn	K7-15
	C. W. Stewart	K7-15
	Information Release (3)	K6-06