COMPLETE

ENGINEERING CHANGE NOTICE

Page 1 of 2

1. ECN 186732

Proj. ECN

2. ECN Category (mark one) Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	3. Originator's Name, Organization, MSIN, and Telephone No. T. J. Bander/PEA/H0-34/376-7143	3a. USQ Required? [] Yes [X] No	4. Date July 8, 1996
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12. Description of Change

Missing table entries in Table 6-2 were inserted. Also editorial types of changes were made.

13a. Justification (mark one)

Criteria Change	[X]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

13b. Justification Details

To complete document.

14. Distribution (include name, MSIN, and no. of copies)

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ENGINEERING CHANGE NOTICE	Page 2 of 2	1. ECN (use no. from pg. 1) 186732

15. Design Verification Required
[] Yes
[X] No

16. Cost Impact

	ENGINEERING		CONSTRUCTION	
Additional	[] $		Additional	[] $
Savings	[] $		Savings	[] $

17. Schedule Impact (days)

Improvement []
Delay []

18. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 12. Enter the affected document number in Block 19.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]		[]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

19. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision

20. Approvals

Signature	Date	Signature	Date
OPERATIONS AND ENGINEERING		**ARCHITECT-ENGINEER**	
Cog. Eng. T. J. Bander/B. A. Crea	7/10/96	PE	
Cog. Mgr. D. M. Ogden	7/11/96	QA	
QA		Safety	
Safety		Design	
Environ.		Environ.	
Other J. C. Conner	7/11/96	Other	
G. T. Dukelow	7/10/96		
J. P. Harris, III	7-11-96		
		DEPARTMENT OF ENERGY	
		Signature or a Control Number that tracks the Approval Signature	
		ADDITIONAL	

Tank 241-C-106 Sluicing Evaluation

T. J. Bander/B. A. Crea/D. M. Ogden
Westinghouse Hanford Company
Richland, WA 99352
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Abstract: The Process Engineering Analyses group performed a thermal evaluation of the Project W-320 retrieval process. The objective of this study was to characterize the thermal response of the tank 241-C-106 waste during the sluicing operation and to define operating limits (defined with measurable tank data), which will maintain the waste subcooling required by the operational controls.

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RECORD OF REVISION	(1) Document Number WHC-SD-WM-ER-588	Page 1

(2) Title
Tank 241-C-106 Sluicing Evaluation

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release (5) Cog. Engr.	 (6) Cog. Mgr. Date
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TANK 241-C-106 SLUICING EVALUATION

T. J. Bander
B. A. Crea
D. M. Ogden

June 1996

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7/9/96
Date

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7/9/96
Date

D. M. Ogden, Team Leader
Process Engineering Analysis

7/11/96
Date

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RICHLAND OPERATIONS OFFICE
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ABSTRACT

T. J. Bander
B. A. Crea
D. M. Ogden

A thermal evaluation of the Project W-320 retrieval process was performed by the Process Engineering Analysis group. The objective of the study was to evaluate the thermal behavior of tank 241-C-106 waste during retrieval of Project W-320 to establish operational limits to maintain waste subcooling throughout the retrieval process. Several computer models and subsequent analyses were used for the evaluation. The computer analyses included multi-dimensional thermal analyses with the P/THERMAL computer code and one-dimensional analyses accounting for phase change and evaporation performed with the GOTH computer codes. Analyses were performed both for the sluicing operation and the post sluicing waste dry out period. Conclusions of the evaluation included:

- *Rapid sluicing can eliminate the waste subcooling resulting in steam generation in the waste.*
- *An incremental retrieval of waste, followed by cooling periods, can eliminate the possibility of a steam bump.*
- *Water additions for tank 241-C-106 can be eliminated with about 0.6 m (2 ft) of the waste removed if active ventilation is maintained.*
- *Active ventilation can be eliminated with approximately 1.2 m (4 ft) of waste removal.*

It is recommended that the Project W-320 retrieval be performed in incremental steps followed by hold periods for cooling.

EXECUTIVE SUMMARY

A thermal evaluation of the Project W-320 retrieval process was performed by the Process Engineering Analysis group. The objective of the study was to evaluate the thermal behavior of tank 241-C-106 waste during retrieval to establish operational limits to maintain waste subcooling (non-boiling) throughout the retrieval process.

Several computer models and subsequent analyses were used for the evaluation. The computer analyses included multi-dimensional thermal analyses with the P/THERMAL computer code and one-dimensional analyses accounting for phase change and evaporation performed with the GOTH computer codes. Both computer codes have been used extensively for thermal-hydraulic analyses.

The following is a summary of important conclusions of the thermal evaluation:

- Rapid sluicing can eliminate the waste subcooling resulting in steam generation in the waste.
- An incremental retrieval of waste, followed by cooling periods, can eliminate the possibility of a steam bump.
- Water additions for tank 241-C-106 can be eliminated with about 0.6 m (2 ft) of the waste removed if active ventilation is maintained.

- Active ventilation can be eliminated with approximately 1.2 m (4 ft) of waste removal.

It is recommended that the Project W-320 retrieval be performed in incremental steps followed by hold periods for cooling. The sluicing should be performed with a constant level liquid pool for each step to ensure good waste level monitoring and promote uniform sluicing.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

TANK 241-C-106 SLUICING EVALUATION

1.0 *INTRODUCTION*

1.1 OBJECTIVE

The Process Engineering Analyses group performed a thermal evaluation of the Project W-320 retrieval process. The objective of this study was to characterize the thermal response of tank 241-C-106 waste during the sluicing operation and to define operating limits (defined with measurable tank data), which will maintain the waste subcooling required by the operational controls.

1.2 BACKGROUND

Tank 241-C-106 is a 2.0-million-liter (530,000 gal) capacity single-shell tank (SST) located in C Farm in the 200 East Area. The tank has been in an inactive status since 1979 and is considered to be sound (non-leaking). The calculated heat load in tank 241-C-106 currently exceeds 29 kW (100,000 Btu/h), the highest of any SST. Since mid-1971, water has been added periodically (every 30 to 60 days) to keep the waste wet and promote heat transfer by evaporation to the dome space. Tank 241-C-106 was identified as a Watch List Tank (Harmon 1991), in accordance with Public Law 101-510, Section 3137 (the Wyden Amendment). Should tank 241-C-106 begin to leak, continued water additions would be required to prevent temperature increases. The continued water additions would, however, promote further tank leakage and a subsequent insult to the environment. If the current methods of cooling the tank are stopped, the sludge and concrete structure will heat to temperatures greater than the established limits and may cause structural damage, leading to possibly an unacceptable radioactive release to the environment. The Project W-320 mission need was prepared and approved in August 1993 with a goal to retrieve the soft waste, and thereby mitigate the high heat and environmental hazards.

A process test was conducted in March 1994 to decrease the liquid level in order to minimize the environmental impact of a tank leak. The results of that test are reported (Bander 1995). During the process test, the waste temperatures measured at the riser 14 thermocouple (TC) tree increased significantly and exceeded the 11 °C/day (20 °F/day) temperature limit. This temperature increase resulted in measured temperatures at riser 14 which approached calculated temperatures at this location in the tank. Subsequent evaluations indicated that a steam or saturation region had formed in the waste, causing sludge motion to close a convective gap around the TC tree leading to the unexpected temperature behavior (Thurgood et al. 1995). This raised safety concerns related to the potential for spontaneous or mechanically induced steam releases ("bumps").

Project W-320 has addressed the concern for steam bump events through operational controls by requiring that a tank chiller system be installed in tank 241-C-106 prior to sluicing. The chiller system is needed to subcool the waste at the tank bottom to near-winter conditions (64.4 °C [148 °F] at TC-1 of riser 8) and to require that the waste remain subcooled at all times during waste retrieval (Conner 1996). While temperature will be monitored during waste retrieval, the thermal response time of the riser 8 temperatures and the unreliability of riser 14 temperatures (due to local convective gap) preclude a direct measurement of waste subcooling. Analyses are then required to provide a monitoring strategy for compliance with the operational controls.

2.0 SYSTEM DESCRIPTION

2.1 SLUICING SYSTEM

The major components of the sluicing system/loop for tank 241-C-106 are shown in Figure 2-1. The sluice submersible pump in tank 241-AY-102 is located near the surface in tank 241-AY-102 to allow maximum particle settling. It feeds the sluice booster pump at tank 241-AY-102 that pressurizes the sluicer assembly in tank 241-C-106 through approximately 518 m (1,700 ft) of buried double-wall pipe. The sluicer nozzle supplies supernate with low particle loading to dilute the waste in tank 241-C-106. The kinetic energy of the nozzle stream from the sluicer can also be directed to erode waste that does not readily become fluid just from simple dilution. The slurry submersible pump in tank 241-C-106 feeds the slurry booster pump to transport the slurry through approximately 518 m (1,700 ft) of buried double-wall pipe to tank 241-AY-102. Tank 241-AY-102 acts as a settling tank for the particulates in the recovered slurry and is a double-shell tank (DST) with an annulus ventilation system, which can help to reduce the maximum temperature of the tank contents. The thermal aspects of this system are the subject of this report.

2.2 SLUICING VENTILATION SYSTEM

The tank 241-C-106 ventilation system can be placed in three potential configurations, shown in Figure 2-2. The normal configuration (Configuration A) is a once-through system that draws air through an inlet filter (as well as some infiltration air from the risers), and the cascade line from tank 241-C-105.

It has been determined that before sluicing can begin, the tank contents should be cooled to a close approximation of winter conditions (Conner 1996). To accomplish this, an air cooler coil has been placed in the inlet duct for the tank. When this coil is activated, the inlet air for the tank is cooled to less than 4.4 °C (40 °F) (EDT 606541). This is shown as Configuration B.

There is also a third configuration (Configuration C) that will be used when the sluicing is underway. This configuration consists of a recirculation loop with a cooler/condenser, followed by an electric heater. There is also a separate exhaust fan to maintain confinement on the tank dome space, but it operates at a nominal flow rate of about 10% of the other two configurations. The primary function of this system is to defog the dome space to provide good visibility for sluicing. Heat removal is only a secondary function. Each configuration can only be run separately and not in conjunction with each other.

Figure 2-1. Sluice System Block Diagram.

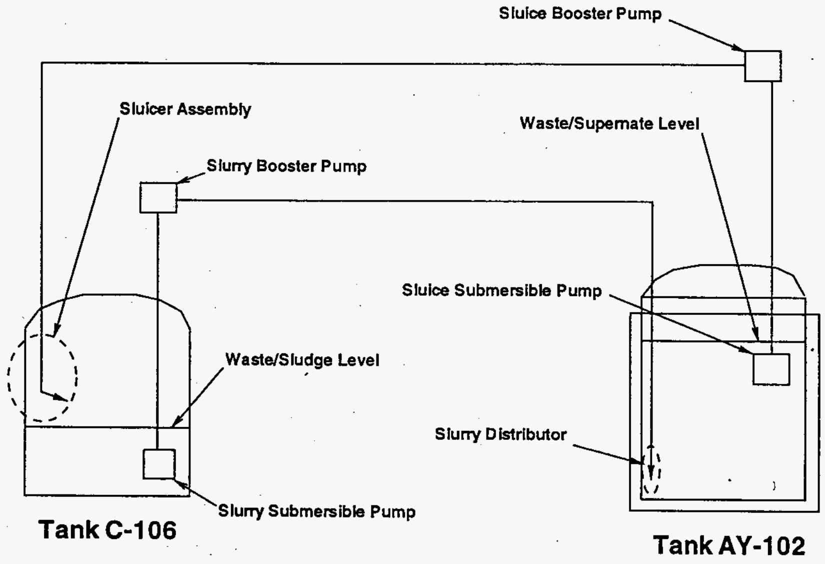
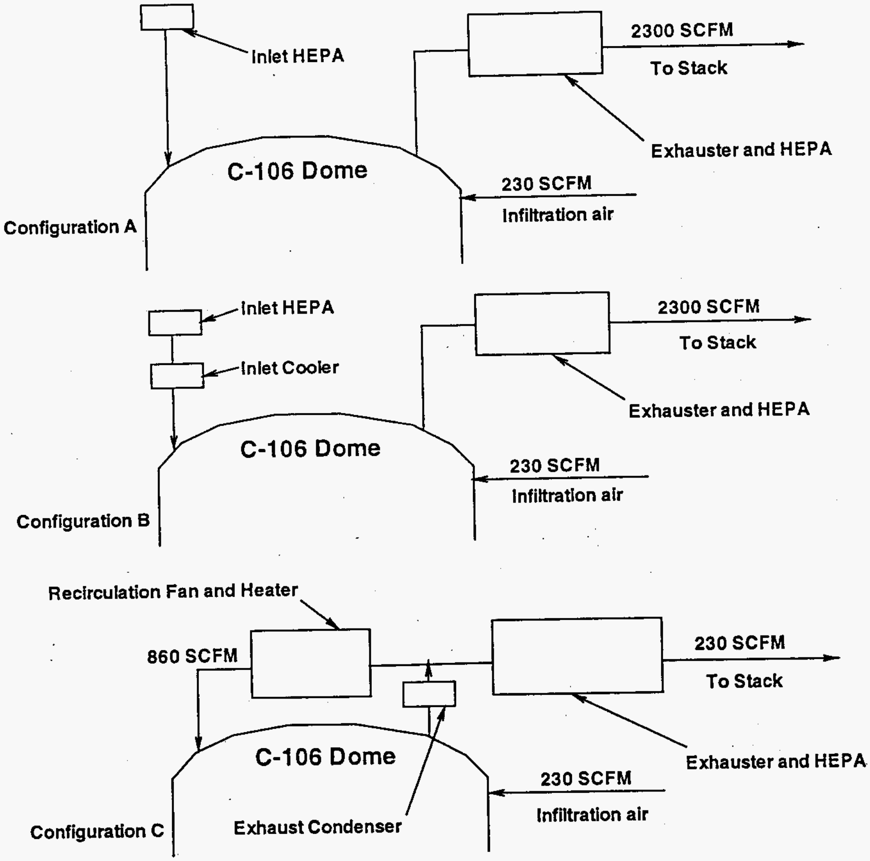


Figure 2-2. Ventilation System Configurations.



3.0 SCOPING EVALUATION

3.1 TECHNICAL ISSUES

The operational controls for the tank 241-C-106 retrieval require that the waste be initially subcooled and that the waste remain subcooled throughout the waste retrieval process. There are three primary factors controlling the maximum waste temperature during sluicing, as discussed in the following sections.

3.1.1 Diminished Heat Removal

As discussed in Section 2.2, the sluicing ventilation system was designed for defogging of the dome space with reduced ventilation flow and hence reduced heat removal from the tank. Therefore, during the operation of this system, the initial subcooling established by operation of the chiller ventilation system will decrease with time. The performance of this ventilation system is discussed in Section 5.1.

3.1.2 Reduced Hydrostatic Head

Removal of the waste through the sluicing operation will decrease the hydrostatic head (total pressure due to both solids and liquid) at the tank bottom, which will decrease the saturation pressure and temperature. Figure 3-1 shows the saturation temperature of water and waste as a function of hydrostatic pressure. The maximum hydrostatic pressure in the tank is determined from the current waste level. The saturation pressure decreases by about 1.1 °C (2 °F) per foot of water or waste decrease. Waste removal then reduces the subcooling, and this effect is felt immediately throughout the waste.

3.1.3 Reduced Conduction Path

A first order approximation for the steady state temperature distribution in the waste can be obtained by treating the waste as a finite slab (Carslaw and Jaeger 1959). The temperature difference between the waste surface temperature and any point in the waste can be approximated by

$$T(x) - T_{surface} = q(L^2-x^2)/2K \qquad (1)$$

where :

$T(x)$ = Waste temperature at vertical elevation x

$T_{surface}$ = Waste surface temperature

q = Heat generation rate

L = Waste depth

x = vertical elevation measured from bottom of waste.

K = Waste thermal conductivity.

with boundary conditions:
$T_{surface}$ at the top of the slab (x=L) and
dT/dx=0 at the bottom of the slab (x=0).

The maximum waste temperature (T_{max}) which occurs at the bottom of the slab is given by the expression (substituting x=0 in equation 1):

$$T_{max} = qL^2/2K + T_{surface} \tag{2}$$

3.2 TRANSIENT SCOPING ANALYSES

The reduction of bottom waste temperature resulting from the decreased conduction length will occur over time as the energy is conducted through the waste. The sluicing rate, which contributes to the change in saturation temperature, is controlled by the conduction transient time.

3.2.1 Continuous Surface Temperature Change (no sluicing)

The transient temperature behavior of a 1.8-m (6-ft) slab with one insulated boundary and a constant temperature ramp of 0.5 °C/day (1 °F/day) on the second boundary is shown in Figure 3-2. This model illustrates the transient time required to propagate a temperature change at the surface to the bottom sludge with the full 1.8 m (6 ft) of waste. The thermal properties of tank 241-C-106 were used for this closed-form solution. Figure 3-3 shows the transient temperatures at 0.3 m (1 ft) intervals. The 0 m (0 ft) elevation (surface temperature) represents a 0.5 °C/day (1 °F/day) temperature change in the waste surface. The temperature begins to change within 1 day at 0.3 m (1 ft) below the surface, but at 1.8 m (6 ft) (tank bottom), the initial response time is an order of magnitude larger. Figure 3-2 shows the transient temperatures as a function of waste depth for 10-day intervals. There is essentially no change in temperature in 10 days at the tank bottom. After 30 days, the surface temperature has decreased by 17 °C (30 °F), while the waste temperature at the tank bottom has decreased by less than 2.8 °C (5 °F).

The sluice rates allowed by the sluicing system for the tank 241-C-106 retrieval will allow the tank to be sluiced in less than 1 week provided no unforeseen problems occur. This simple model shows that the reduced surface temperature does not affect the bottom sludge temperature for many days. If sluicing proceeds too quickly, waste cooling effects (Section 3.1.3) may not compensate for the decreasing saturation temperature caused by the loss of hydrostatic head (Section 3.1.2). Therefore, the maximum initial amount sluiced may be controlled by the initial level of subcooling. Waste can only be removed until the loss of hydrostatic head reduces the subcooling to an acceptable minimum value. This problem is further evaluated with a GOTH computer simulation, which accounts for these effects in an integrated fashion (Section 5.0).

3.2.2 Step Change in Surface Temperature (sluicing)

During the initial sluicing process the dome and liquid pool temperatures will remain nearly constant. Using estimated uniform values of q and K and a waste depth of 1.8 m (6 ft) in Equation 1 (Section 3.1.3) the temperature difference between the surface and 0.3 m (1 ft) from the surface is about 22 °C (40 °F). Thus, sluicing will have the effect of imposing a step change in temperature of 22 °C (40 °F) at the new waste surface. The reduction of waste depth by 0.3 m (1 ft) will result in a reduction of steady state maximum waste temperature of about 22 °C (40 °F) (Equation 2, Section 3.1.3). For waste removal of 0.3 m (1 ft), the decrease in maximum waste temperature of 22 °C (40 °F) due to the reduction of conduction path length more than compensates for the decrease in saturation temperature of 1.1 °C (2 °F) due to the reduction of hydrostatic head. However, the change in temperature at the bottom of the tank is not immediate, in contrast with the change of saturation pressure due to hydrostatic head reduction, but depends upon the transient conduction time.

Figure 3-4 shows the transient response of a 1.5 m (5 ft) slab with a 22 °C (40 °F) temperature decrease at the surface. There is no temperature change at the 1.8 m (6 ft) elevation in the first day. However, after 7 days the temperature has dropped by 3.9 °C (7 °F) and nearly 7.2 °C (13 °F) after 21 days.

The saturation pressure and temperature for water and tank 241-C-106 waste with vapor pressure suppression is shown in Figure 3-1. As discussed in Section 4.5, the initial maximum waste temperature after chiller operation is expected to be 107 °C (224 °F). Thus, a reduction of just over 2.2 °C (4 °F) will reduce the maximum waste temperature below the saturation temperature at dome conditions, completely eliminating any possibility of steam bumps. This simple model suggest that sluicing a modest amount of waste followed by a 1 to 2 week hold period will eliminate the steam bump potential completely. Figure 3-5 shows the effect of a 0.6 m (2 ft) sluice using the simple slab model. The results are the same but the transient cooling of the waste is significantly faster. These results are confirmed using the GOTH model as discussed in Section 5.2.

Figure 3-1. Saturation Pressure and Temperature.

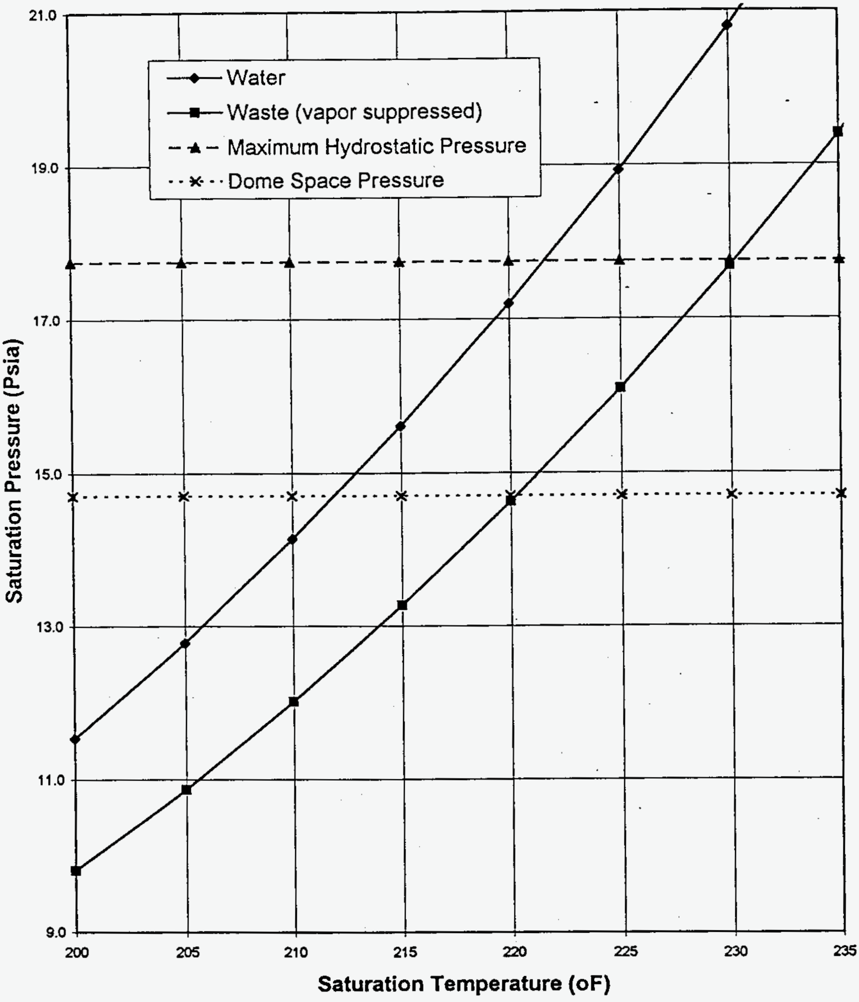


Figure 3-2. Slab Model (6 ft) Transient Temperature Versus Time.

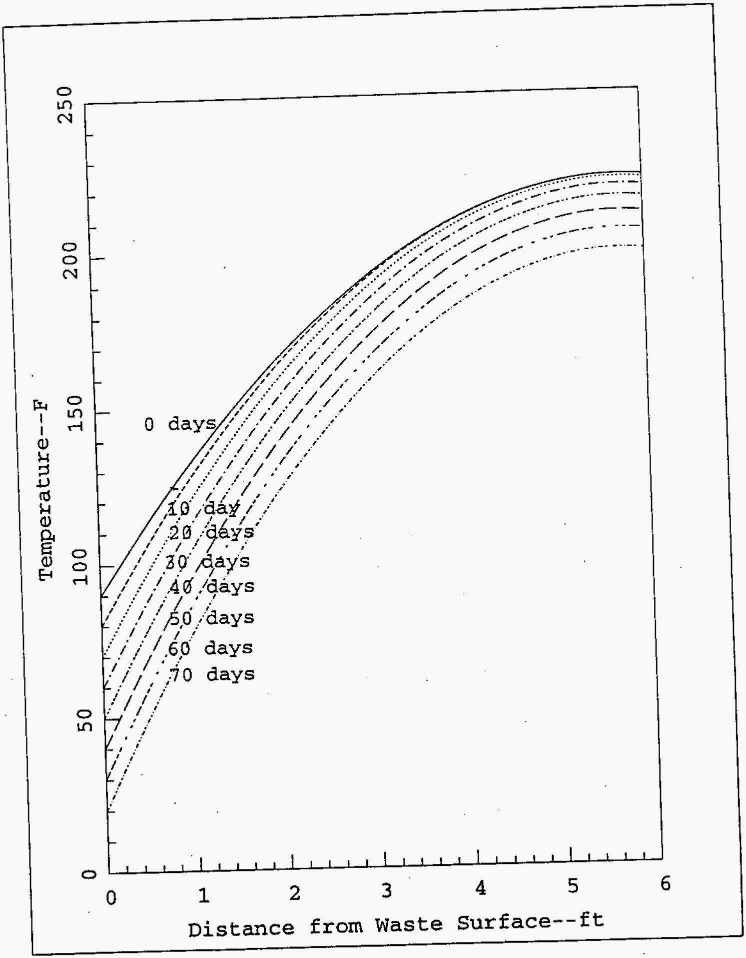


Figure 3-3. Slab Model (6 ft) Transient Temperature Versus Distance.

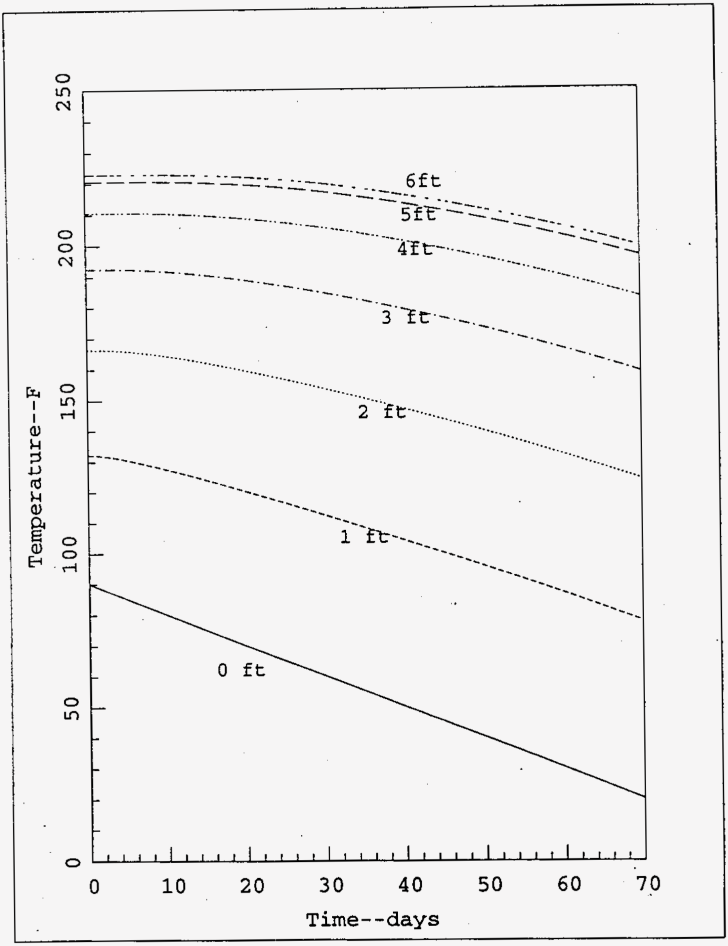


Figure 3-4. Slab Model (5 ft) Transient Temperature Versus Distance.

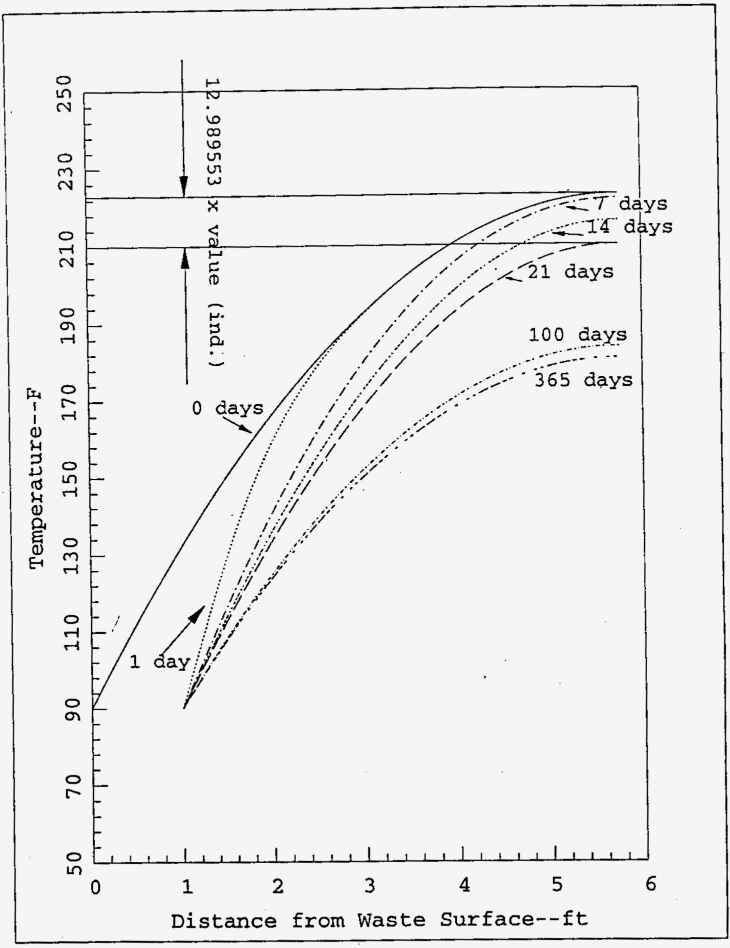
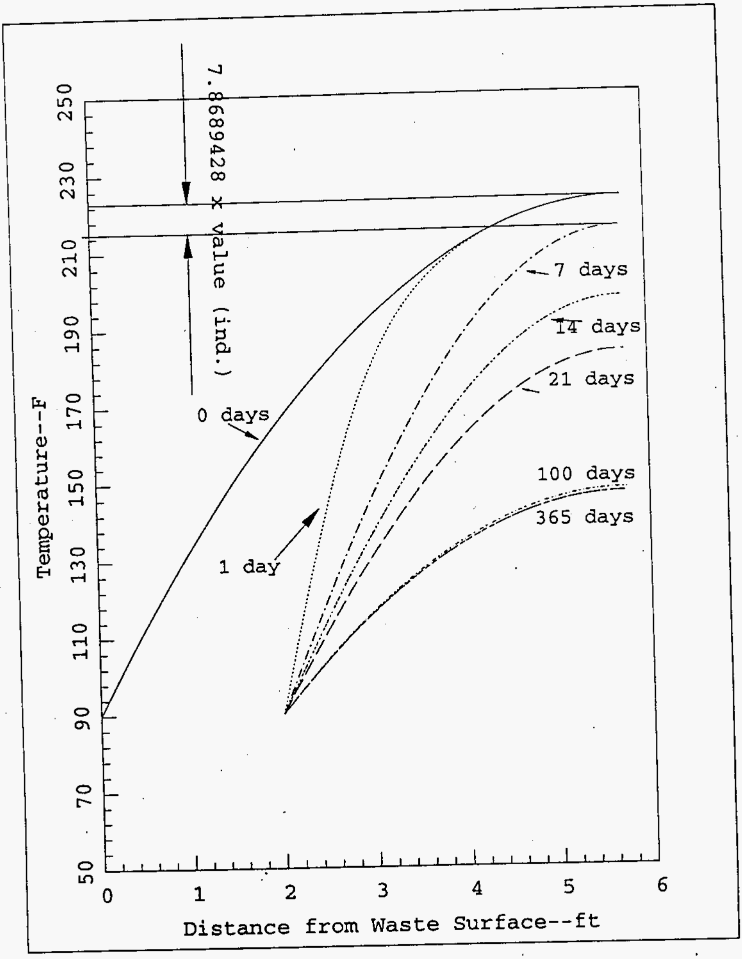


Figure 3-5. Slab Model (4 ft) Transient Temperature Versus Distance.



4.0 COMPUTER MODELS

4.1 GOTH MODEL DESCRIPTION

The GOTH[1] model that was used for these simulations was a one-dimensional model (Figure 4-1) of the tank sludge, liquid pool and dome space. The sludge portion was divided into six discrete lumped-parameter nodes, while only one lumped-parameter node was used for both the liquid pool and the dome space. This is representative of the waste near the center of the tank. Thermal conduction to the soil under the tank was not modeled. The contribution of heat removal from the tank through the soil to the water table is modest, and can conservatively be neglected.

The constitutive model of the waste sludge used for this analysis is based on the models developed in (Sathyanarayana 1993) and (Thurgood and Fryer 1993). One of the attributes of this waste constitutive model is that while there is a yield strength and a particle loading dependent on viscosity, the waste in a subvolume can be made to flow by injecting water into the subvolume. This has the effect of reducing the particle volume fraction in that subvolume. The reduced particle volume fraction then reduces the viscosity and yield strength of the waste and allows it to flow. The sluicing process was modeled in this fashion. The erosion of waste by the kinetic energy of the sluice jet was not modeled.

The sensible and latent heat transfer of the liquid pool, the ventilation airflow, and the sluicing and slurry flows are all based on the simulation capabilities of the GOTH computer code (George et al. 1993). One other important variable in the models is the vapor pressure depression due to the presence of dissolved salts in the liquid phase of the waste. These analyses were conducted with a liquid phase vapor pressure that is 85% of that of pure water, shown as vapor suppressed waste in Figure 3-1. This is consistent with liquid sample data shown in Appendix B (Reynolds 1994).

Several variations of the basic model were developed to model different aspects of the sluicing process. The model that was used to simulate the performance of the recirculation ventilation system, prior to sluicing, is the simplest. In this model, one volume is defined and is divided into six subvolumes of sludge and one subvolume that simulates the dome space with the liquid pool at the bottom. The inlet and outlet of the recirculation ventilation system are introduced into the dome space subvolume. In addition, another air source is specified at an inlet temperature of 25 °C (77 °F), to account for infiltration air and air that may come through the cascade line from tank 241-C-105. This temperature is used as a hottest average inlet tank temperature. The inlet conditions for the recirculation system are taken from WHC 1995.

The model used to simulate the actual sluicing behavior has a number of attributes developed to simulate the sluicing operation (Figure 4-1). These include a series of discrete boundary conditions to simulate the sluicing jet

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[1] GOTH is a trademark of JMI, which is derived from GOTHIC-a registered trademark of EPRI Corp., CA.

in each subvolume, as well as a series of trips to sequentially activate and deactivate the sluicing jets. The sluicing jet into a subvolume is tripped on when the void fraction in the subvolume above exceeds 90%. The sluicing jets are tripped off when the particle fraction in the cell currently being sluiced is reduced below 5%.

The last model is the one used to examine the behavior of the sludge after it has been partially sluiced. It is derived from the previous model, with the exception that the ventilation air is introduced in the subvolume that has been sluiced, and a boundary condition is set to replace the water lost by evaporation over the long term.

4.2 P/THERMAL MODEL DESCRIPTION

The finite element thermal model of the tank 241-C-106 structure and the surrounding soil was constructed using PATRAN[2] (PATRAN 1990), a computer code for creating and analyzing finite element and finite difference models. The thermal analyses for the model were obtained using P/THERMAL[3] (P/THERMAL 1991), a thermal analysis package for solving steady-state and transient problems, whose results can be post-processed (viewed and analyzed) using PATRAN. The thermal radiation view factors utilized in these analyses were calculated with P/VIEWFACTOR[4] (P/VIEWFACTOR 1991), a computer code closely integrated with P/THERMAL. An emissivity of 0.9 is used for all of the surfaces in the tank (Kreith 1959). The forced air ventilation through the tank is modeled with an advective heat transfer element from the tank air volume to the outside air.

The boundary conditions on the soil surfaces are shown in Figure 4-2. An air temperature of 25 °C (77 °F) (Stone et al. 1983) is used for the outside ambient air to represent average summer conditions. The energy loss to the atmosphere through the soil surface is modeled using a forced convective heat transfer coefficient of 3.5 W/m^2-°C (2 Btu/h-ft^2-°F) at the ground surface (Bander 1993), which is based on an average wind speed of 12.4 km/h (7.7 mi/h) across the surface (Stone 1983). An isothermal boundary of 12.8 °C (55 °F) (Bander 1993) is employed at the water table 61 m (200 ft) below the ground surface. The axi-symmetric model assumes an adiabatic boundary condition at the outer cylinder of the soil at a radius of 15 m (50 ft.) The 23-m (75-ft) diameter tanks were built with a distance of 31 m (102 ft) between the centers of the tanks. The 15-m (50-ft) radius provides less soil for heat flow out of the tank (through the soil to the water table or soil surface) than a typical tank would have, therefore higher temperatures would be obtained for a given heat source. This gives some conservatism to the thermal model used in estimating the temperature distribution in the tank.

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[2] PATRAN is a registered trademark of the MacNeal-Schwendler Corporation.

[3] P/THERMAL is a registered trademark of the MacNeal-Schwendler Corporation.

[4] P/VIEWFACTOR is a registered trademark of the MacNeal-Schwendler Corporation.

4.3 TOTAL HEAT LOAD AND HEAT LOAD DISTRIBUTION

Heat load estimates for tank 241-C-106 were derived through thermal analyses of the tank and comparison with tank temperature data. An estimated total heat load of 32.2 kW +/- 5.9 kW (110,000 +/- 20,000 Btu/h) was obtained (Bander 1993). Total heat load estimates have also been obtained from inventory records (Brevick 1995). The heat load estimate for tank 241-C-106 was reevaluated using a two-fluid computer code, which mechanistically accounted for water evaporation (Fryer and Thurgood 1995). The revised total heat load estimate was 38.8 kW (132,400 Btu/h). This heat load estimate was used for all the analyses reported in the following sections.

The tank temperature data and inventory records suggest that the tank heat load is skewed toward the bottom of the tank with 89% of the heat in roughly 66% of the sludge. A comparison of the results of this model with thermocouple data is given in Appendix A (Crea 1996). This distribution is taken as the best-estimate heat load distribution.

Recent grab samples from tank 241-C-106 have been analyzed for ^{90}Sr and ^{137}Cs content (Babad et al. 1996). A comparison is made of the total heat source estimates based on these samples, the sample taken in 1986, and the value used in the thermal modeling. The grab samples of the sludge were taken from depths between 36 and 76 cm (14 and 30 in.) below the surface of the waste. This region is part of the top layer of sludge used in the thermal modeling (Figure 4-2), which was formed from the noncomplexed waste added to the tank between 1977 and 1979. This layer consists of relatively low amounts of heat-generating materials compared to the amounts in the layers below it. The bottom layer in the P/THERMAL model (Figure 4-3) consists of a hardpan segment at the bottom, which contains a lower concentration of radionuclides (Agnew 1994) than the moist segment above it. However, in the thermal model, the heat distribution is considered uniform throughout this bottom layer.

In order to compare the 1996 samples and the 1986 homogenized sample, an estimate of the strontium and cesium for a homogenized sample of the 1996 samples was made. The calculations of homogenized concentrations for the 1996 samples assume that the ratio of the radionuclide concentrations between the bottom two layers and the top layer is the same as that used in the thermal modeling (a factor of 4.2). That is, the concentration of radionuclide material is a factor of 4.2 higher in the bottom two layers than in the top layer. Since the grab samples were obtained from the top layer of the sludge, the radionuclide concentration in the bottom two layers is assumed to be 4.2 times higher than what was measured in the grab samples. The volumes of the sludge layers assumed in calculating homogenized 1996 concentrations are those used in the thermal model (397,000 L [105,000 gal]) in the bottom two layers and 348,000 L [92,000 gal] in the top layer). Maximum and average measured values of concentrations obtained from the grab samples were used in the homogenized 1996 sample calculations (Tables 4-1 and 4-2). The homogenized concentration of ^{90}Sr in the 1986 sample falls between the homogenized values using maximum and average measured concentrations of the 1996 samples. The ^{137}Cs comparison indicates much higher concentrations in the 1996 samples compared to the 1986 sample, possibly due to different analyses conducted.

The calculations of total heat source (Table 4-3) using the maximum measured sample values give an upper bound for the heat source, and the calculations using the average measured sample values give a best estimate for the heat source. The estimates of the heat source from the 1996 samples is consistent with estimates used in the thermal modeling. The variability in the sample values and the uncertainties in the radionuclide distribution in the sludge can account for the differences in the estimates of heat source from the 1996 samples, the 1986 sample, and the thermal modeling.

Table 4-1. Strontium and Cesium Concentrations in Samples (Riser 1 and 7 combined in 1996 sample).

	1996 Sample (maximum /homogenized)	1996 Sample (average /homogenized)	1986/Riser 1 (homogenized) (decayed to 1996)
	Sample from top layer	Sample from top layer	Sample from entire core
Sludge (microCi/g)			
^{90}Sr	862/2336	533/1444	1611
^{137}Cs	890/2412	572/1550	269
Liquid (microCi/mL)			
^{90}Sr	0.932/2.525	0.609/1.65	1.34
^{137}Cs	158/428	127/344	22.6

Table 4-2. Strontium and Cesium Concentrations in Solids of Samples (Riser 1 and 7 separate in 1996 sample).

	1996 Sample (maximum /homogenized)	1996 Sample (average /homogenized)	1986 Sample (homogenized) (decayed to 1996)
	Sample from top layer	Sample from top layer	Sample from entire core
Riser #1 (microCi/g)			
^{90}Sr	693/1878	488/1322	1611
^{137}Cs	644/1745	516/1398	269
Riser #7 (microCi/g)			
^{90}Sr	862/2336	603/1634	N/A
^{137}Cs	890/2412	656/1778	N/A

N/A: Not applicable

Table 4-3. Heat Source using Homogenized Concentrations (kW) (decayed to 1996).

	1996 Samples			1986 Sample	Thermal model
	Riser 1	Riser 7	Riser 1 & 7		
	Maximum of Measured Values				
Sludge	25.1	32.5	32.5	14.5	N/A
Liquid	0.1	0.1	0.1	<0.01	N/A
Total	25.2	32.6	32.6	14.5	29.2
	Average of Measured Values				
Sludge	18.6	23.3	20.5	14.5	N/A
Liquid	0.1	0.1	0.1	<0.01	N/A
Total	18.7	23.4	20.6	14.5	29.2

4.4 SLUICING JET THERMAL CONDITIONS

The sluicing jet enters tank 241-C-106 at a temperature that is very close to the supernate temperature in tank 241-AY-102. Based on analyses using the GOTH model (Sathyanarayana and Fryer 1996), the initial temperature of the jet will be at approximately 23 °C (74 °F). If the sluicing is concluded fairly rapidly, then this will not change appreciably. The same reference shows that, after transfer of the complete decay heat load from tank 241-C-106 to 241-AY-102, the equilibrium supernate temperature will rise to 37 °C (98 °F).

While the sluicing is being performed, there are several additional energy terms that may contribute to the temperature of the supernate in tank 241-AY-102. Table 4-4 contains the important energy terms for the complete process, with values that are based on the liquid temperatures at the start of the sluicing process. As the sluicing process continues, liquid temperatures may increase, but the loss terms will also increase in magnitude. The second column, which contains a duty cycle factor of 0.35 (2 shifts per day, 5 days per week, plus downtime) for those terms that are a direct result of the sluicing, shows that the energy inputs of the sluicing process are considerably moderated by the actual duty cycle.

Table 4-4. Sluicing Process Energy Terms.

Energy Terms	Full value (watts)	Duty cycle (watts)
Decay heat (tank 241-C-106)	38.7	38.7
Decay heat (tank 241-AY-102)	9.7	9.7
Pump energy (slurry line)	58.6	20.5
Line loss (slurry line)	-13.2[a]	-4.6
Pump energy (sluice line)	58.6	20.5
Line loss (sluice line)	-11.7[a]	-4.1
Total loss (tank 241-C-106)	-37.2	-37.2
Total loss tank (241-AY-102)	-9.7	-9.7
Annulus (tank 241-AY-102)	-11.7	-11.7
Kinetic energy (sluice jet)	29.3	10.3
Total		32.3

[a] Reference Appendix C, Evaluation of Heat Loss to the Soil from Sluice and Slurry lines.

A lower bound on the mass of the system that is affected by the surplus energy shown in Table 4-4 is the mass of the waste in the two tanks. A very conservative lower bound on the mass-specific heat product of the waste in the system is 2100 kWh/°C (4,000,000 Btu/°F). The overall initial rate of rise for the system temperature implied by these conservative values is 0.37 °C/day (0.66 °F/day). Based on this analysis, it is appropriate to use the temperature of the supernate in tank 241-AY-102 at the beginning of the process as the temperature of the sluicing jet throughout the entire process.

4.5 INITIAL SUBCOOLING

The operational controls for tank 241-C-106 sluicing (Conner 1996) require the use of a chiller system to subcool the waste prior to sluicing. The performance of the chiller system was evaluated to assess the level of subcooling at the initiation of sluicing. This system has been evaluated using the GOTH simulation for the expected system parameters (Ogden and Thurgood 1996). The results of this study were used for the analyses presented in Section 5.0. However, the evaluation of the actual ventilation system will be required to confirm the assumed level of subcooling.

The chiller system was evaluated with a detailed two-dimensional GOTH model which accounted for evaporation, convection, and conduction heat losses using annual meteorological boundary conditions. The bottom sludge temperatures for various radial positions are shown in Figure 4-3. The analyses were initiated from steady state winter conditions, shown in Figure 4-3 as 0 days. The tank heat-up is due to the normal summer conditions. The maximum temperatures are near 109 °C (228 °F), which is near saturation conditions (Thurgood 1995). The tank chilling was initiated near maximum tank temperature conditions, which occur in September and October. The chiller system cools the waste to near-winter conditions in 3 to 4 months. The minimum temperature is 107 °C (224 °F), or approximately 2.2 to 3.3 °C (4 to 6 °F) subcooling. The analyses of Section 5.0 assume that the initial maximum waste temperature for the sluicing evaluation was 107 °C (224 °F).

Figure 4-1. GOTH Computer Model of Tank 241-C-106.

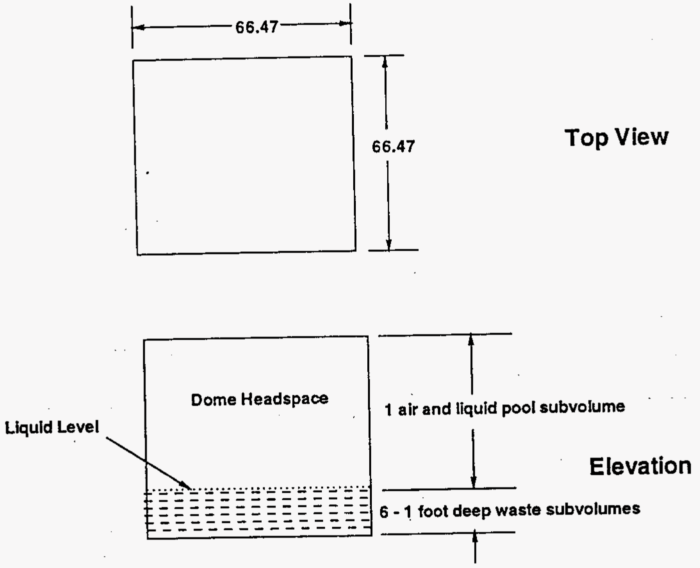


Figure 4-2. Thermal Model of Tank 241-C-106.

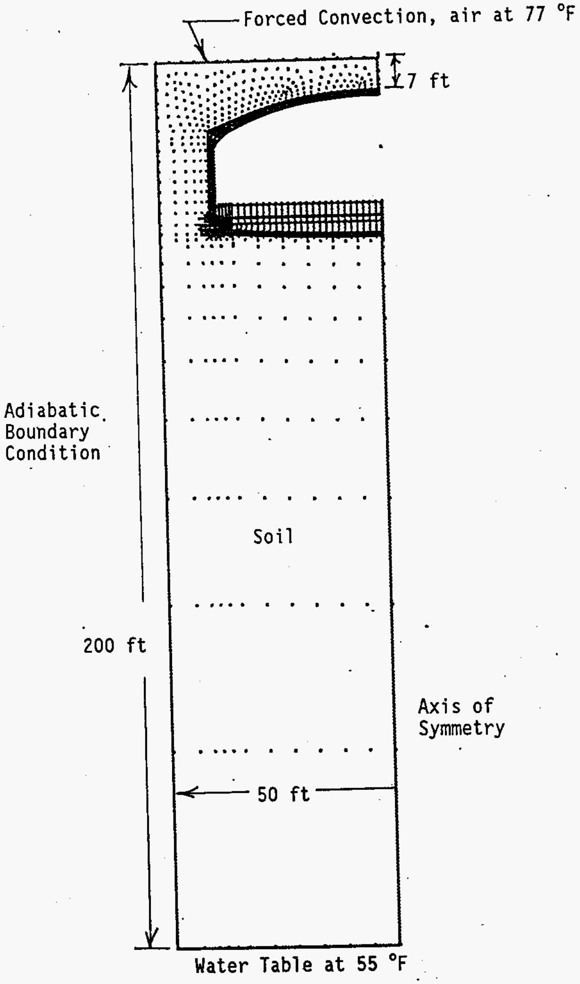


Figure 4-3. Thermal Model Region Around Tank 214-C-106.

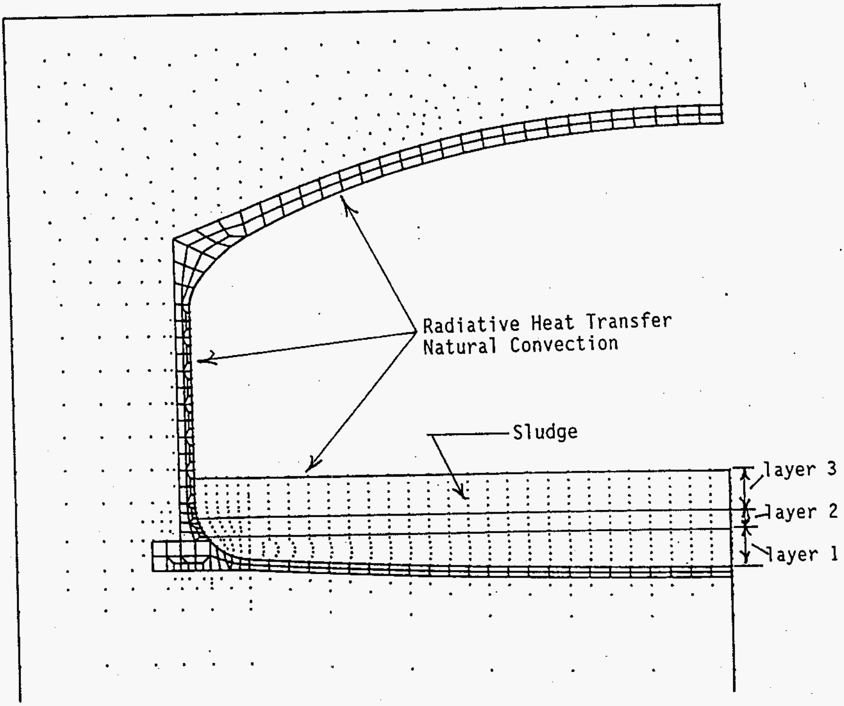
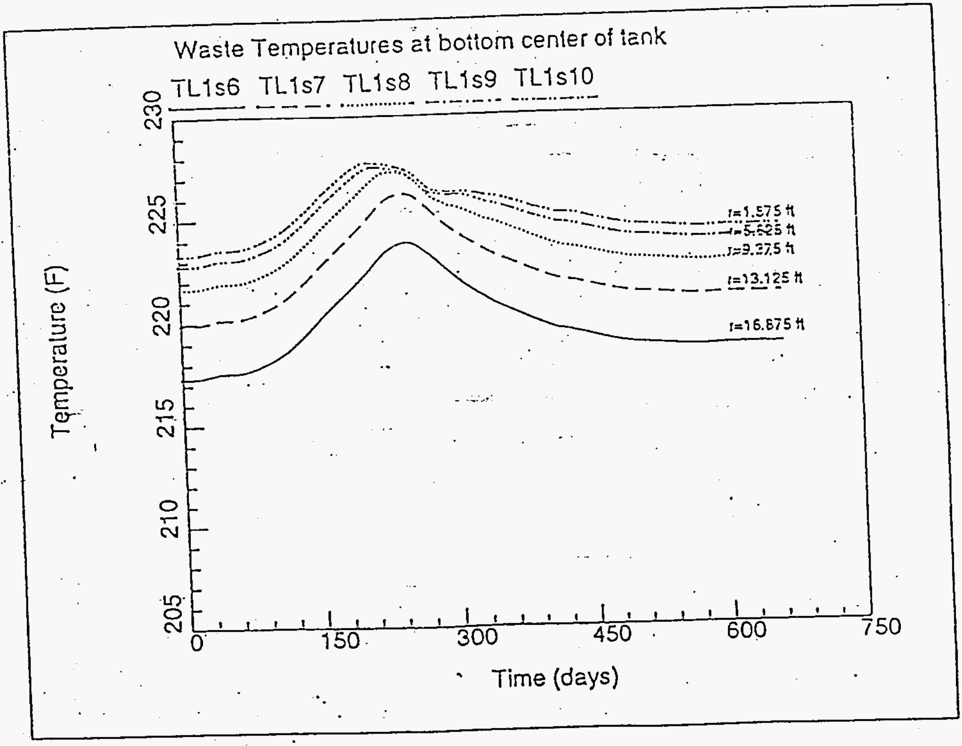


Figure 4-4. Chiller Thermal Performance.



5.0 SLUICING EVALUATION

5.1 VENTILATION SYSTEM ANALYSES

Analyses were performed to evaluate the thermal performance of the sluicing ventilation system discussed in Section 2.2. This system was designed primarily for defogging the dome space during, sluicing and not to maximize heat removal from the tank. Thus, when the chiller system is placed in operation as discussed in Section 2.2, the heat transfer from the tank will decrease.

An evaluation of the thermal performance of the system (Configuration C) was performed with the GOTH computer model (Section 4.1). A transient analysis was initiated with calculated waste temperatures, following operation of the chiller ventilation system to a steady state condition (Configuration B, 107 °C (224 °F) maximum waste temperature). Hot summer ambient conditions were assumed. The sludge, liquid pool, and dome temperatures are shown in Figure 5-1. The initial oscillation of temperature is a function of the model initial temperature. However, this is followed by a steady increase in temperature, which decreases the initial subcooling margin. After 6 months, the temperature has increased to 109 °C (229 °F). The dome temperature increases from 22 °C to 32 °C (72 °F to 90 °F). This is a result of the 29 kg/min of dry air (860 SCFM) recirculation flow, which is returned to the tank at 25 °C (77 °F). Based on this, it is advisable to delay reconfiguration of the ventilation system from Configuration B to Configuration C until shortly before sluicing will begin.

5.2 SLUICING ANALYSES

Analyses were performed to evaluate the thermal effect of sluicing on the waste. The operational controls require that the waste remain below local saturation temperatures during the sluicing operation. Analyses performed with the GOTH model (Section 4.1) are discussed in the following sections.

5.2.1 Sluicing To Saturation

The maximum temperature in the waste, following chiller operation, is expected to be 107 °C (224 °F) (2.8 °C [5 °F] of subcooling). As shown in Figure 3-1, if waste is removed (reducing the hydrostatic head) without adequate time for heat transfer, the saturation temperature can decrease to the local waste temperature (resulting in steam formation). To demonstrate this effect, an analysis of the sluicing operation was performed with the GOTH computer model. The analysis was initiated with a maximum waste temperature of 107 °C (224 °F). The particle loading of the sluice line was assumed to be 0% to give a rapid sluice rate. Figure 5-2 shows the waste hydrostatic pressure and saturation pressure at the tank bottom. The loss of hydrostatic pressure from waste removal reduces pressure to the saturation pressure level at approximately 16 hrs. The waste temperature near the tank bottom is shown in Figure 5-3. The maximum temperature is not decreased with this rapid sluicing rate. Figure 5-4 shows the tank waste liquid level and the steam void fraction at the tank bottom. Significant voiding occurs as the hydrostatic pressure is reduced to the saturation pressure. Therefore, while rapid sluicing is possible with the Project W-320 sluicing system, rapid sluicing without sufficient time for heat transfer will result in significant steam voiding.

5.2.2 Sluice and Hold

The transient scoping analyses discussed in Section 3.2.2 suggest that an initial sluice of 0.3 to 0.9 m (1 to 3 ft), followed by a period of heat transfer and waste cooling, may be the best sluicing strategy. The GOTH model was used to analyze this scenario. A rapid sluice was simulated, removing 0.9 m (3 ft) of waste. The sluicing was then terminated, allowing the tank sluicing ventilation system to remove heat. Figure 5-5 shows the tank liquid level. In the first day 0.9 m (3 ft) of waste is sluiced, followed by a hold period.

The waste temperatures near the tank bottom are shown in Figure 5-6. After 1 to 2 days, the temperature decreases at approximately 1.1 °C/day (2 °F/day). The temperature is reduced to below saturation temperature for the waste at atmospheric conditions in approximately 4 days, and to below the saturation temperature for water at atmospheric conditions (100 °C [212 °F]) in 8 days. This is consistent with the scoping analyses. The dome temperature is shown in Figure 5-7. The dome temperature increases as hot waste is exposed. The increased convective and evaporative heat transfer, combined with the reduced conduction length, enhances the cooling of the waste.

These analyses support a sluicing strategy which includes an initial sluicing of 0.3 to 0.9 m (1 to 3 ft), followed by a hold period of 1 to 2 weeks. The waste becomes significantly subcooled, which eliminates any possibility of steam bumping.

It should be noted that there is little transient delay in cooling the bottom waste. However, the maximum waste temperature will be reduced by over 39 °C (70 °F) and this will occur over an extended period of time. This is shown in both the scoping analyses (Figure 3-5) and the GOTH analyses (Figure 5-6). It may require up to 3 months to reach steady conditions. Any heat load estimate made during this period will be conservatively high.

Figure 5-1. Waste and Dome Temperature for the GOTH Ventilation System Analyses.

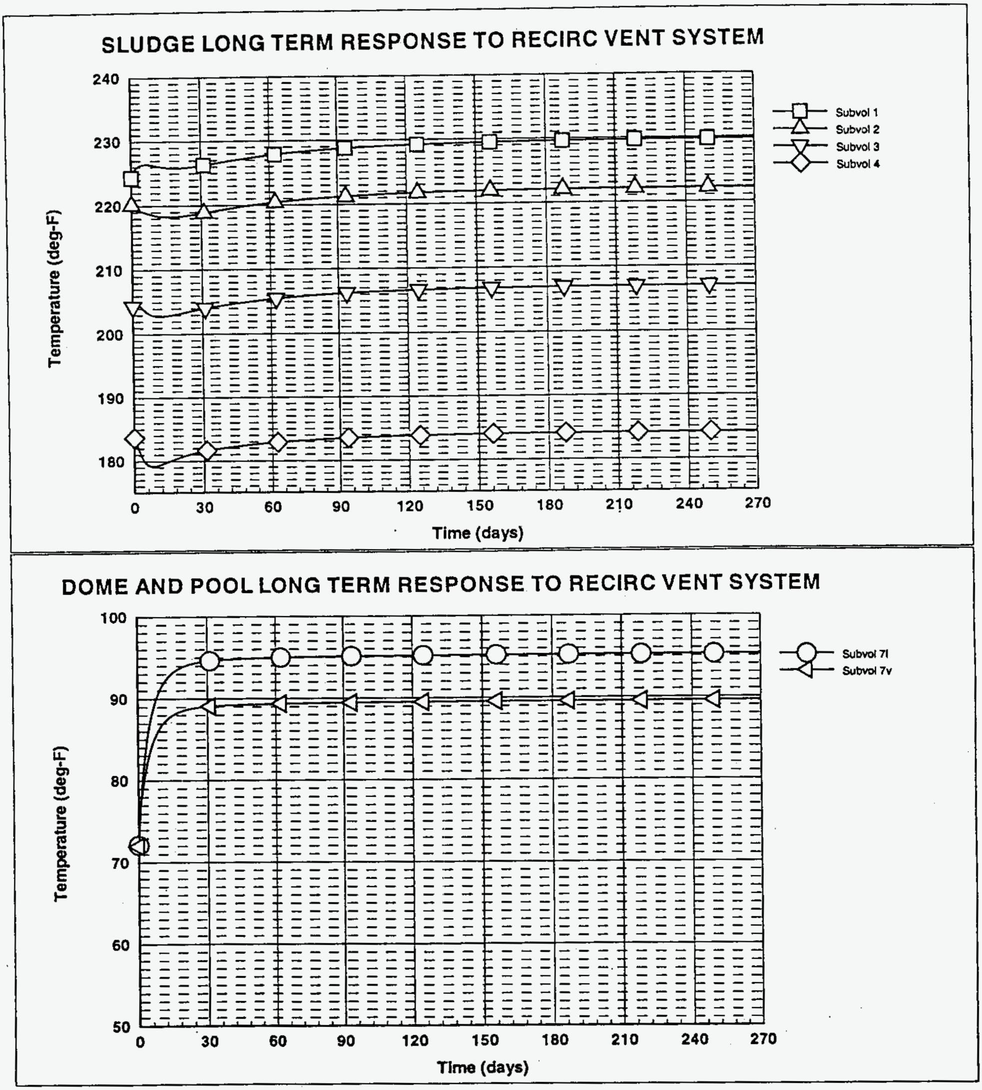


Figure 5-2. Hydrostatic Pressure for Sluicing to Saturation.

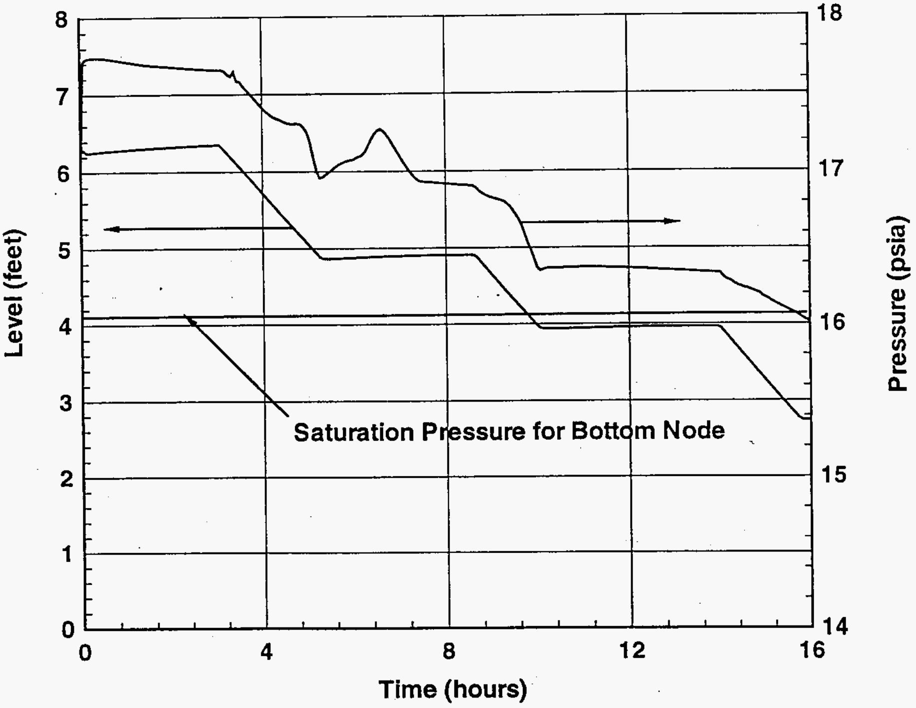


Figure 5-3. Waste Temperature for Sluicing to Saturation.

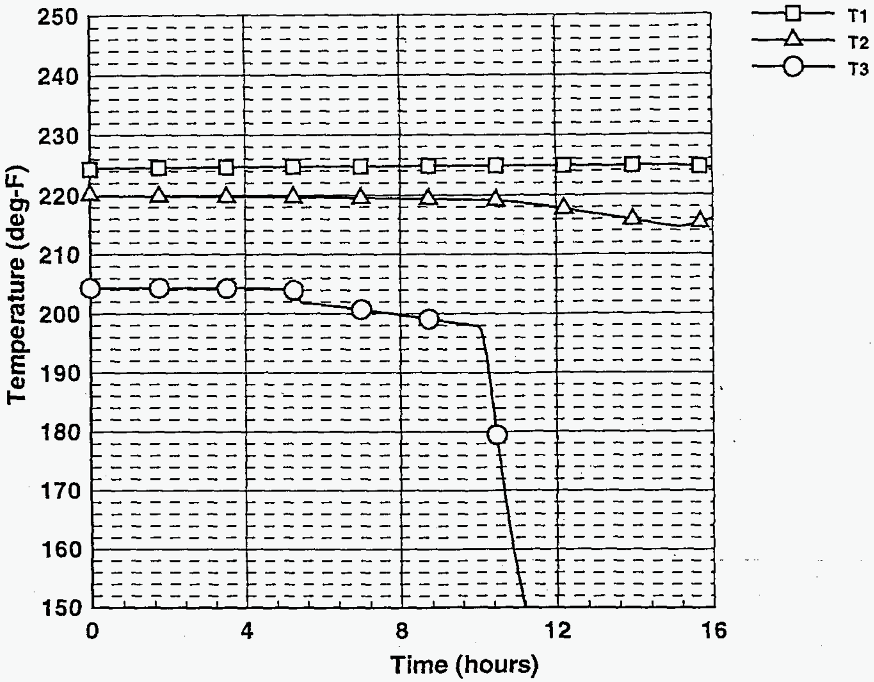


Figure 5-4. Tank Liquid Level and Bottom Steam Void Fraction for Sluicing to Saturation.

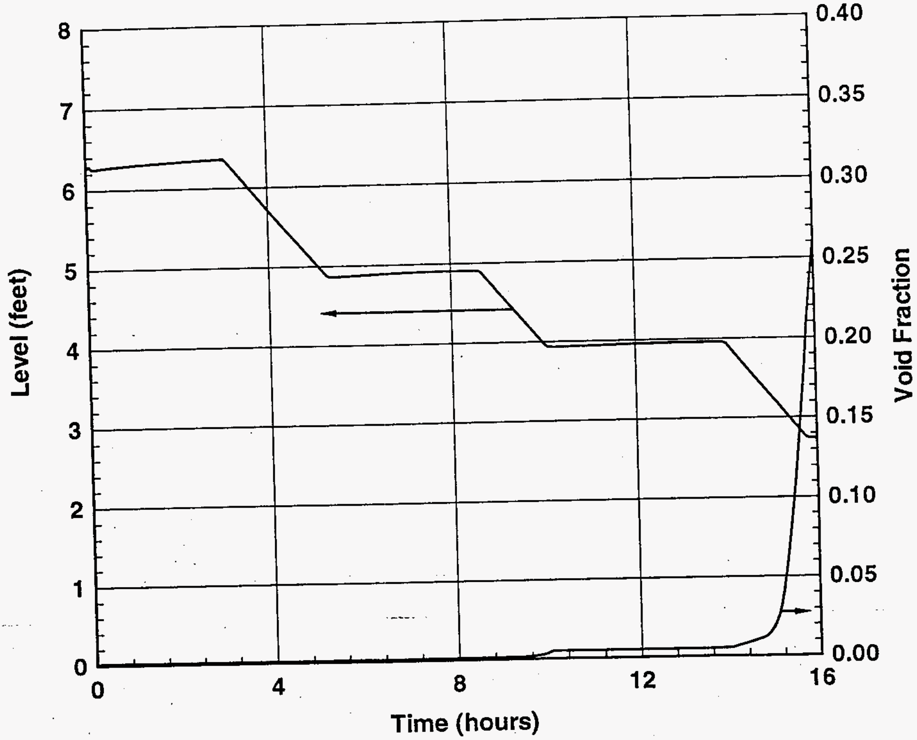


Figure 5-5. Tank Liquid Level for Sluicing and Hold.

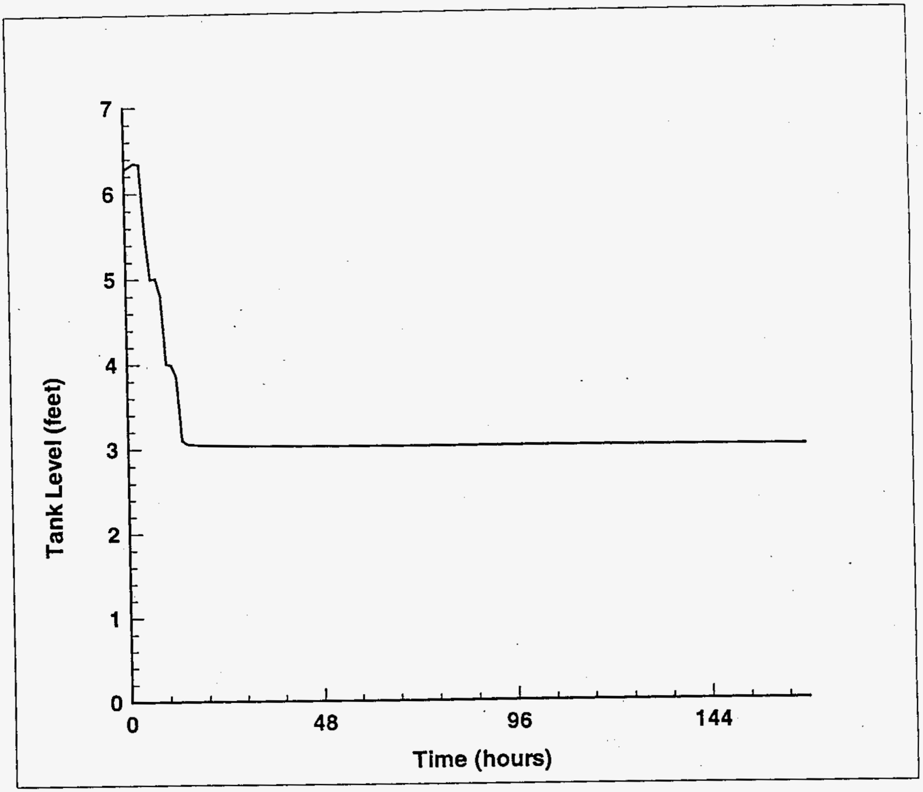


Figure 5-6. Waste Temperatures for Sluicing and Hold.

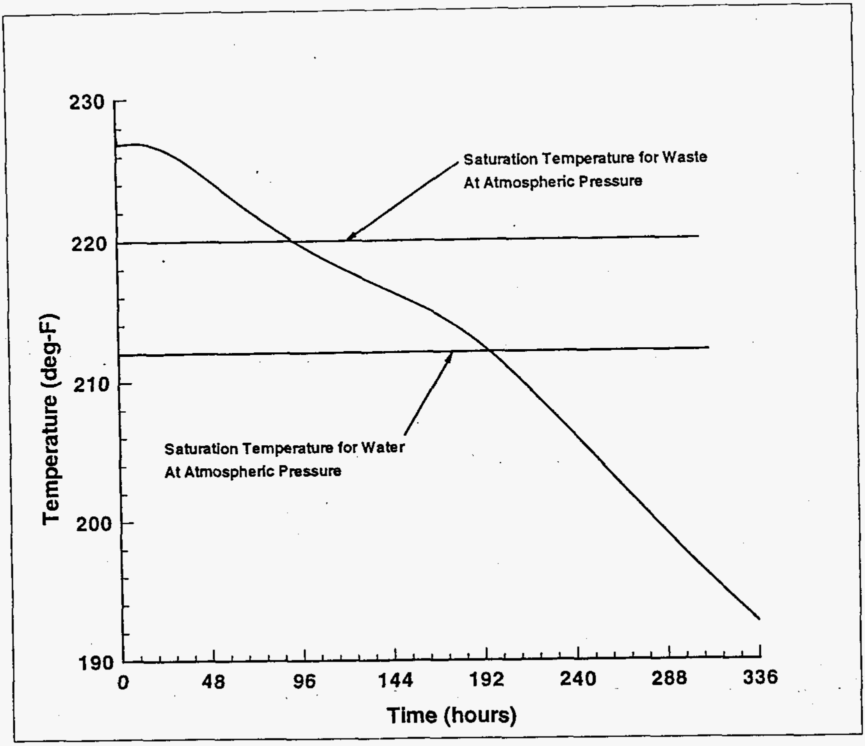
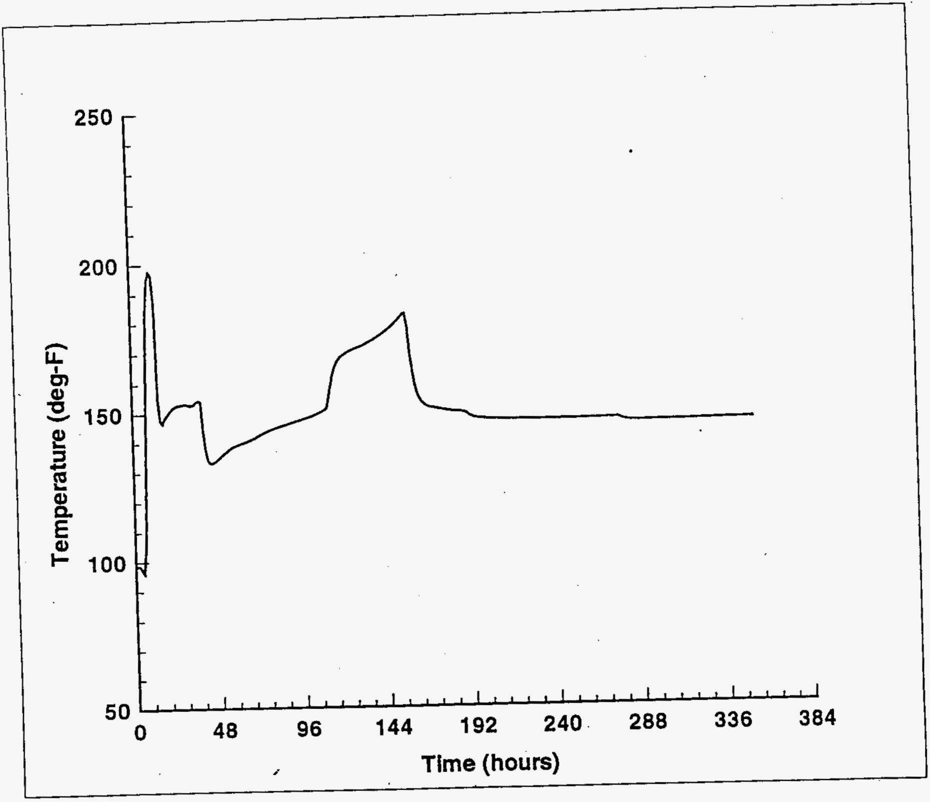


Figure 5-7. Dome Space Temperature for Sluicing and Hold.



6.0 POST SLUICING EVALUATION

6.1 TEMPERATURE LIMITS

The temperature limits for tank 241-C-106 are based on the operating specifications for SSTs (WHC 1996). The Operating Specifications Document (OSD) structural temperature limit is 149 °C (300 °F) in the waste and 177 °C (350 °F) in the concrete. Organic reactions may be possible if organics are present. However, these reactions normally occur near 199 °C (390 °F) (Webb et al. 1995), which is well above the OSD temperature limit.

The 1994 process test and subsequent analyses (Thurgood 1995) demonstrated that tank 241-C-106 operates near saturation temperatures (228 °F), creating the potential for steam release events. This will not be a concern after sluicing, since the remaining moist sludge will be below the saturation temperature. Based upon the above considerations, the OSD limit of 149 °C (300 °F) in the sludge was selected as the temperature limit for this study.

6.2 DRY WASTE THERMAL CONDUCTIVITY

For a dry waste tank, a major determinant of peak waste temperature is the dry waste thermal conductivity. There are no reported values for thermal conductivity of the waste in tank 241-C-106 that are based on an actual waste sample. The values that are used in the thermal models (Bander 1993 and Thurgood 1995) are based on values that give the best fit to the observed temperature data. These values are consistent with parallel conduction models for conduction in a water sludge mixture. These values are for moist waste and will decrease for dry waste.

Measured thermal conductivities for actual tank wastes have been documented (Willingham 1994). This data is shown in Figure 6-1. The average value of 0.47 W/m-°C (0.27 Btu/h-ft-°F) at 149 °C (300 °F) was selected as the best estimated dry conductivity. The conductivity of tank 241-C-106 is expected to be higher than these values since it should be compacted with a much smaller porosity than the powders formed from actual wastes (Willingham 1994).

6.3 MOIST WASTE STEADY-STATE ANALYSES

Thermal analyses were performed with the P/THERMAL model to evaluate the post sluicing thermal behavior. Steady-state analyses were performed which would represent the tank condition following a temperature transient leading to a steady state condition for the new waste configuration (reduced waste level). The GOTH analyses of Section 5.2 suggest that the tank would reach the new temperature condition in about 3 to 6 months following sluicing. These analyses were performed with moist waste thermal conductivity and reduced power resulting from the waste removal.

The ventilation configurations for the post sluicing steady-state analyses are shown in Table 6-1. These are discussed in Section 2.2.

Table 6-1. Ventilation Configurations for the Post Sluicing Steady State Thermal Analyses.

Ventilation system	Ventilation rate kg/min (SCFM)	Inlet temperature °C (°F)
Once-through	78 (2300)	4.4 (40)
Once-through	78 (2300)	25 (77)
Recirculation	37 (1090)	9 (48)
Recirculation	37 (1090)	25 (77)
Passive	1.7 (50)	25 (77)

The maximum waste temperature as a function of waste removed is shown in Figure 6-2. The analyses show that the waste temperatures are well below the OSD temperature limit of 149 °C (300 °F) for all of the active ventilation configurations. Approximately 1.1 m (3.5 ft) of waste must be removed if there is no active ventilation system (passive ventilation only) to remain below the OSD temperature limit. The maximum temperatures are below the atmospheric saturation temperature (100 °C [212 °F]) for between 0.3 m (1 ft) and 0.5 m (1.5 ft) waste removal with active ventilation. The transient waste dry out, discussed in the next section, will result in increasing temperatures. However, the waste dry out will be slow and not exceed the waste temperatures shown in Figure 6-2 for several years before dryout begins.

6.4 TRANSIENT DRY OUT THERMAL ANALYSIS

Previous post sluicing analyses (Appendix A) did not account for the time required for wet waste to dry out and the subsequent decrease in tank heat load from radioactive decay. Analyses were performed to remove this conservatism and provide a best estimate thermal history for the post sluicing period.

6.4.1 Models and Assumptions

The P/Thermal model used for the steady state analyses presented in Section 4.2 was modified to simulate the drying process following the sluicing. The analyses assumes that no water is added to the tank following the sluicing operation. The total initial inventory of water in the waste was assumed to be approximately 50% of the waste volume. The ventilation system was assumed to operate at a minimal level of 7.8 kg/min of dry air (230 SCFM) in the once-though mode (sluicing ventilation system without the recirculation flow). Two cases were considered. The first case assumed that 0.8 m (2.7 ft) of waste was removed during sluicing (this corresponds to 1.2 m [4.0 ft] waste depth at tank center). The remaining heat load was based on the Thurgood best estimate distribution with 33 kW (111,000 Btu/h) remaining. This was distributed evenly (hard pan was not modeled). The second case assumed that 1.3 m (4.1 ft) of waste was removed during sluicing (this corresponds to 0.8 m [2.6 ft] waste depth at tank center) with a remaining heat load of 19 kW (64,000 Btu/h).

Figure 6-3 gives a graphical representation of the important parameters for the dry out analyses. The evaporation rate was decreased linearly to approximate the drying process. The initial rate was based upon the initial pool temperature and the time to dry out was determined by the evaporation rate and the water inventory. As seen in Figure 6-3, the dry out period can exceed 12 years for this minimal ventilation case. The radioactive decay heat source was also included and was based upon an approximately 30 year half life. This power decay makes a significant contribution to the tank temperature history for the long dry out times.

The thermal conductivity during the dry out of a porous media varies non-linearly with the waste moisture fraction (Hillel 1982). The conductivity can actually increase initially due to mass diffusion effects. This behavior is shown in Figure 6-4. A similar behavior is expected for the dry out of tank 241-C-106 waste. The intermediate dry out thermal conductivity may actually exceed the saturated moist value (Moyne et al. 1989) although the actual dry out curve for tank 241-C-106 waste has not been experimentally determined. The variable thermal conductivity for the dry out analyses was modeled assuming a linear decrease from moist conductivity to dry conductivity shown in Figure 6-3. The possible thermal conductivity enhancement was modeled as shown in Figure 6-3 (dashed line segment).

6.4.2 Transient Dry Out Analyses

The results of the thermal transient dry out analyses are presented in Figure 6-5. The 1.3 m (4.1 ft) waste removal case uses the linearly varying thermal conductivity. The temperature decreases initially as the tank responds thermally to the reduction of the conduction length resulting from the waste retrieval. As waste dry out proceeds, the thermal conductivity decrease causes an increase in temperature. After approximately 12 years the waste is dry and the decreasing tank heat load (radioactive decay) results in monotonically decreasing temperatures. The maximum waste temperature does not exceed 121 °C (250 °F).

The 0.8 m (2.7 ft) waste removal case shown in Figure 6-4 also assumed a linear decrease in thermal conductivity. The behavior is similar to the previous case. However, the waste temperature initially increases because the reduction in conduction length does not compensate for the reduced ventilation flow (78 to 7.8 kg/min of dry air [2300 to 230 SCFM]). The maximum waste temperature slightly exceeds 149 °C (300 °F) and then decreases as the power decays. These analyses suggest that with 0.9 m (3 ft) of waste removal and active ventilation on the order of 10 kg/min of dry air (300 SCFM), the maximum waste temperature will not exceed the OSD limit if the waste is allowed to dry out.

The final analyses used the thermal conductivity enhancement discussed in the previous section. It was performed for the 0.8 m (2.7 ft) waste removal case. The temperature initially decreases due to the enhanced thermal conductivity. However, since waste dry out precedes the temperature turn around due to power decay, the maximum waste temperature is not significantly different.

6.5 DRY WASTE STEADY-STATE ANALYSES

A thermal evaluation was previously performed to evaluate the post sluicing thermal behavior of tank 241-C-106 (Crea, Bander, and Ogden 1996). The evaluation was performed to assess the impact of a non-uniform heat distribution and an assumed non-sluiceable hard pan. The issues were identified during the Tier 2 review of Project W-320. These analyses (provided in Appendix A) show that for very conservative assumptions for soft waste volume, heat load distribution, and dry waste thermal conductivity, sufficient heat can be removed to eliminate the need for further water additions. These analyses were very conservative and did not account for the waste dry out time and the subsequent decay of the tank heat load discussed in Section 6.4. Steady state thermal analyses were performed with the P/THERMAL model to evaluate the post sluicing thermal behavior following the waste dry out period. These analyses remove the unnecessary conservatism of the Appendix A analyses. Based on the transient analyses of Section 6.4, the dry out time for these analyses was assumed to be 12.5 years. The analyses were performed for the recirculation and passive ventilation configurations summarized in Table 6.1.

Figure 6-6 shows the calculated peak temperatures as a function of waste removed using the best estimate for thermal conductivity of dry waste (0.47 W/m-°C [0.27 Btu/h-ft-°F]). These are steady state thermal analyses using the P/THERMAL model with the best estimate heat distribution discussed in Section 4.3. Table 6-2 lists the amount of sludge that must be removed to satisfy the 149 °C (300 °F) OSD temperature limit with no water addition for the recirculation and passive ventilation configurations. The amount of sludge to be removed is taken from the intersection of the curves in Figure 6-5, with the 149 °C (300 °F) OSD temperature limit. An inlet temperature of 9 °C (48 °F) can be obtained with the chiller that is being installed for Project W-320. This chiller will be available for cooling in July 1996. The inlet temperature of 25 °C (77 °F) is the average ambient temperature for summer conditions (Stone et al. 1983).

Table 6-2. Sludge Removal Required to Remain Below 149 °C (300 °F) (OSD Temperature Limit).

Ventilation system	Ventilation rate kg/min (SCFM)	Inlet temperature °C (°F)	Sludge removed m (ft)
Recirculation	37 (1090)	9 (48)	0.6 (2)
Recirculation	37 (1090)	25 (77)	0.7 (2.3)
Passive	1.7 (50)	25 (77)	1.2 (4)

The results show that if approximately 1.2 m (4 ft) of sludge is removed the tank can be maintained at the OSD limit with passive ventilation only. In addition, no water needs to be added and the tank can be allowed to dry out. If at least 0.6 m (2 ft) of sludge is removed, then the tank can be maintained below the OSD limits without adding water using an active ventilation system.

Figure 6-1. Elevated Temperature Conductivity.

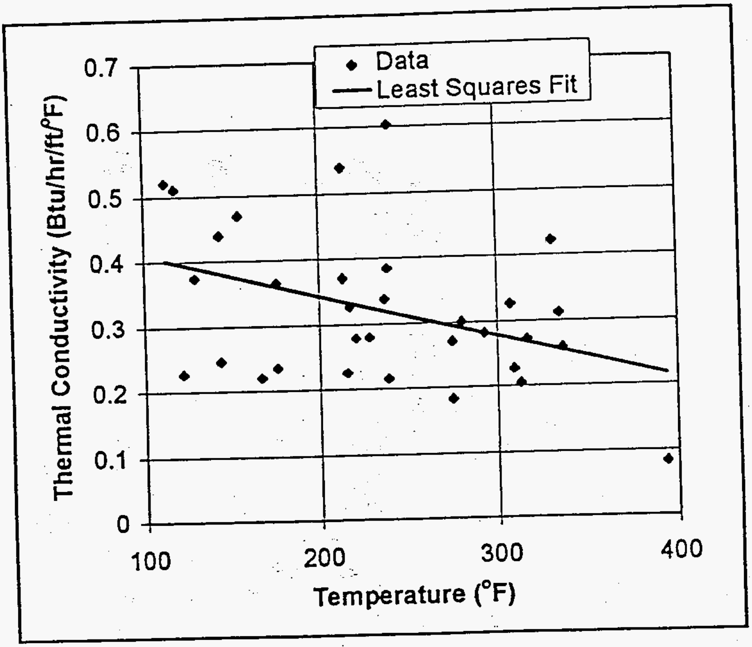


Figure 6-2. Calculated Maximum Temperature for Moist Waste.

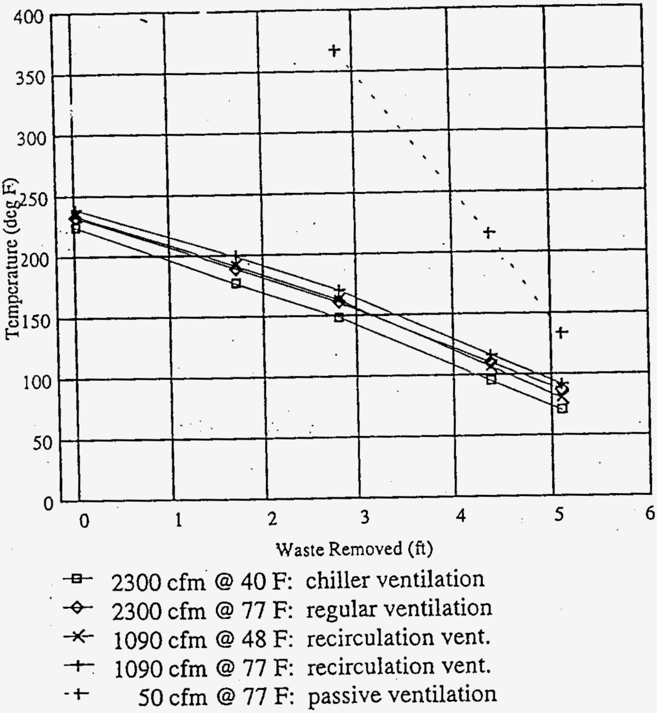


Figure 6-3. Input Parameters for Dry Out Transient Analyses.

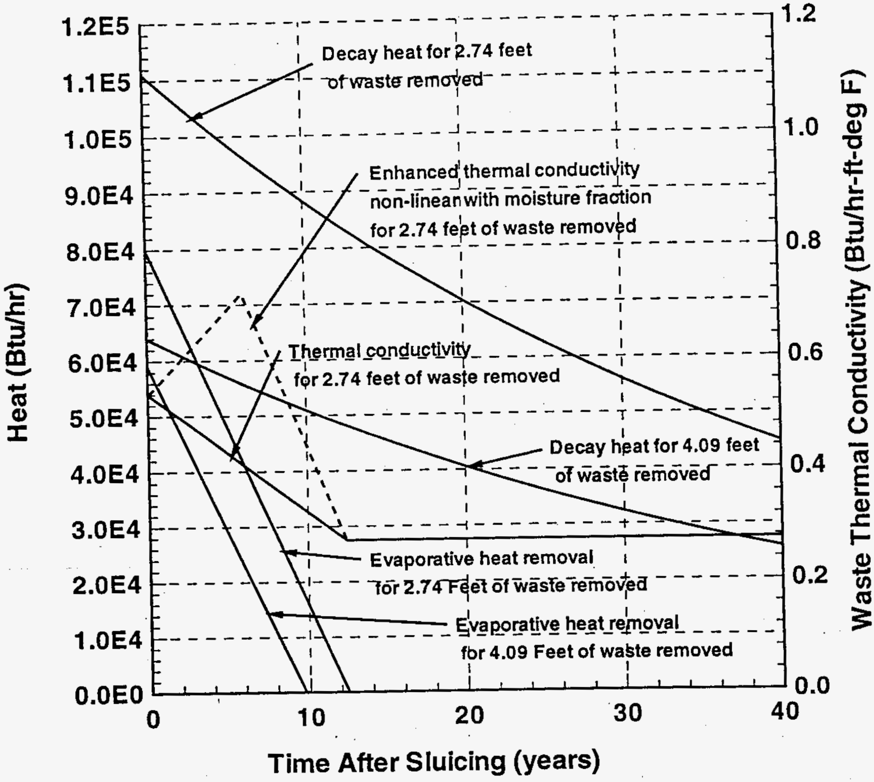


Figure 6-4. Variable Thermal Conductivity for Porous Media Drying.

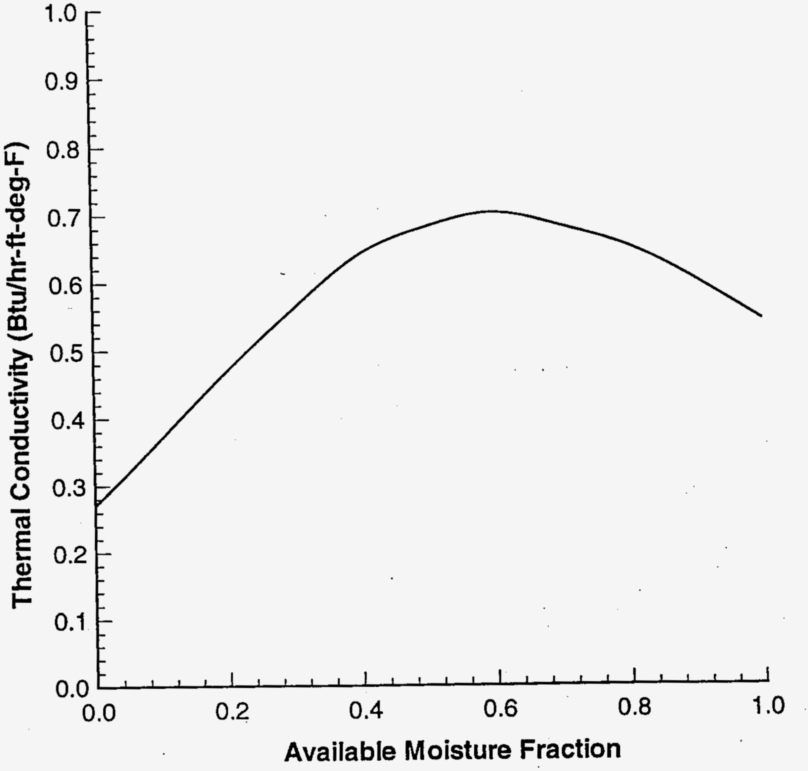


Figure 6-5. Dry Out Transient Analyses Temperature Response.

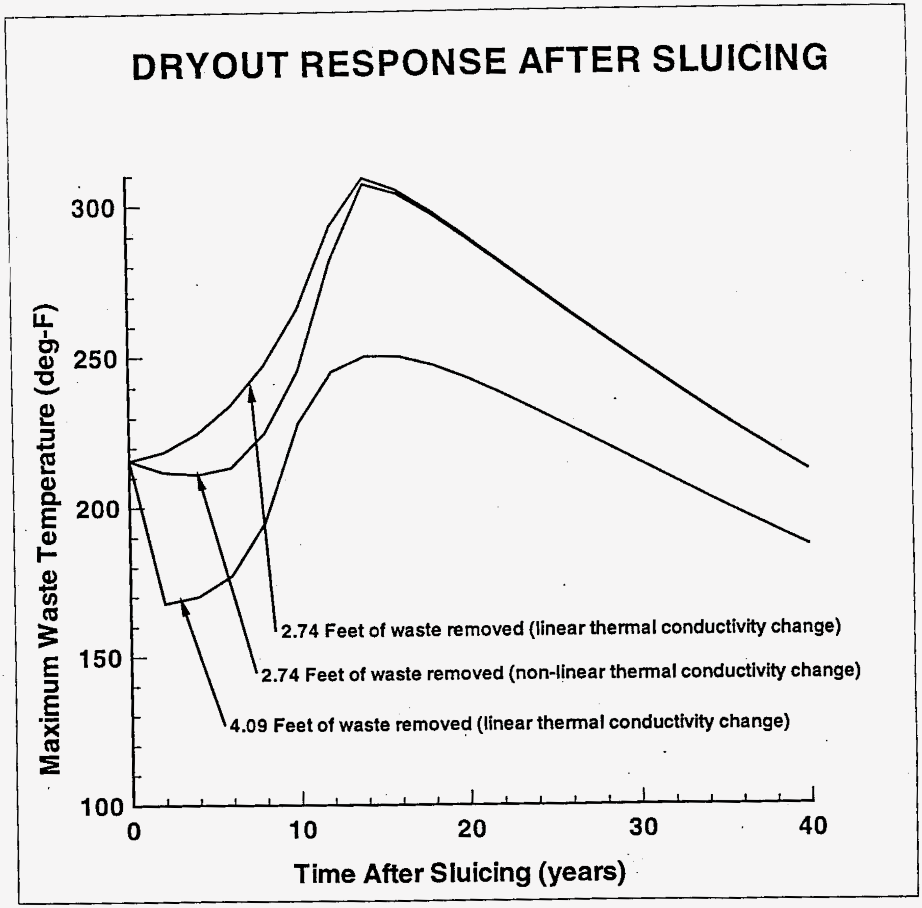
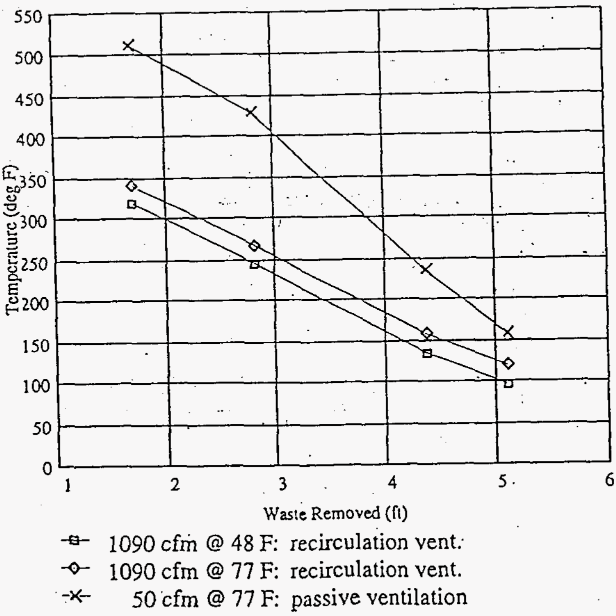


Figure 6-6. Calculated Maximum Temperature for Dry Waste.



7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

- Rapid sluicing can eliminate the waste subcooling resulting in steam generation in the waste. With an initial waste temperature of 107 °C (224 °F), rapid waste removal of 0.9 m (3 ft) will decrease the saturation temperature to the local maximum waste temperature.
- The sluicing ventilation system will result in reduced heat transfer and a loss of waste subcooling over time. The ventilation system should be reconfigured to the sluicing configuration just prior to waste sluicing.
- An incremental retrieval of waste, followed by cooling periods, will eliminate the possibility of a steam bump.
- Water additions for tank 241-C-106 can be eliminated with about 0.6 m (2 ft) of the waste removed if active ventilation is maintained.
- Active ventilation can be eliminated with approximately 1.2 m (4 ft) of waste removal.
- Waste dry out will proceed slowly. The time to reach peak waste temperatures may exceed 10 years.

7.2 RECOMMENDATIONS

Waste retrieval should be performed in incremental steps with a hold period for waste cooling. The size of the incremental steps and the length of the hold periods must consider the uncertainties and simplifying assumptions of the thermal evaluation documented in this report. Important parameters include the saturation curve (degree of vapor suppression), initial waste subcooling and the non-uniformity of the waste removal.

All available tank data, including riser 8 and 14 temperature and tank level, should be monitored during the retrieval process. Waste or liquid pool level should be the primary parameter for controlling the sluicing operation. It is recommended that the sluicing be performed with a constant liquid level, with no waste exposed except at the tank wall. This will maintain a constant tank bottom pressure, contribute to near uniform sluicing, and ensure accurate level measurements.

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APPENDIX A. LETTER REPORT 74A50-96-BAC-006.

Westinghouse Hanford Company **Internal Memo**

From: Process Engineering Analysis 74A50-96-BAC-006
Phone: 376-0205 H0-34
Date: February 27, 1996
Subject: TANK C-106 HEAT DISTRIBUTION AND POST SLUICING TEMPERATURES

To: R. J. Cash S7-14

cc:				
	H. Babad	S7-14	J. P. Harris, III	S2-48
	T. J. Bander	H0-34	D. M. Ogden	H0-34
	J. C. Conner	A2-25	J. P. Sloughter	R2-54
			BAC File/LB	

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INTRODUCTION

Retrieval of tank C-106 waste will be accomplished through Project W-320 in late 1996. The goal of the project is to sluice the tank soft sludge and thereby eliminate the need for water additions or active ventilation cooling. The success of the project depends in part on the heat distribution in the waste. A concern was expressed during the Tier 2 review of Project W-320 that much of the tank heat may be in a non-sluiceable hard pan which could jeopardize the success of the project.

A study was performed to address this concern. Analyses have shown that for very conservative assumptions for soft waste volume, heat load distribution and dry waste thermal conductivity, sufficient heat can be removed to eliminate the need for further water additions. In addition, using best estimate heat load distributions, which are consistent with the measured tank data, the project will achieve the full project goals.

HEAT LOAD DISTRIBUTION

Heat load estimates for tank C-106 were derived through thermal analyses of the tank and comparison with tank temperature data. Reference 7 gives an estimated heat load of 110,000 Btu/h. This heat is distributed over two regions (0 to 4 feet, 4 to 6 feet). The tank data suggest that the tank heat is skewed toward the bottom with 89% of the heat in roughly 66% of the sludge. A comparison of the results of this model with the Riser 8 thermocouple data is shown in Figure 1. There is excellent agreement for the first three thermal couples. Thermocouple 4 is believed to be near the pool/dome space interface and therefore does not represent a waste temperature.

The heat load estimate for tank C-106 was re-evaluated using a two-fluid computer code, which mechanistically accounted for water evaporation (Reference 2). The revised heat load estimate was 132,400 Btu/h. This heat load estimate was used for all the analyses reported in the following sections. Table 1 summarizes the heat load distributions used for this study. These include the best estimate heat load distribution of Reference 7 and conservative distributions that will be discussed later.

Table 1. Heat Load Distributions.

Distribution	Region 1	Region 2
Best Estimate 132,400 Btu/h total	7.9 Btu/hr-ft^3 (0 - 4 ft)	1.9 Btu/hr-ft^3 (4 - 6 ft)
Conservative Case 1 67,000 Btu/h	9.4 Btu/hr/ft^3 (0 - 2.33 ft)	N/A
Conservative Case 2 130,100 Btu/h	18.4 Btu/hr-ft^3 (0 - 2.33 ft)	N/A
Conservative Case 3 82,400 Btu/h	21.3 Btu/h/ft^3 (0 - 1.5 ft)	N/A
Conservative Case 4 132,400 Btu/h	34.2 Btu/h/ft^3 (0 - 1.5 ft)	N/A

Differences in temperature in the waste are an indication of the local heat load distribution within the tank. Figure 2 shows a comparison of the temperature gradients for the Riser 8 thermocouples with the calculated gradients based upon the heat load distribution of Reference 7. The temperature gradients for heat generation at the surface, heat generation at the bottom, and uniform heat generation are also shown for information. The best estimate heat load is in reasonable agreement with the data from Riser 8.

NON-SLUICEABLE HARD PAN

Concerns for the success of Project W-320 are based on the heat load distribution and the volume of the non-sluiceable hard pan that may exist in the bottom of the tank. Figure 3 shows the tank C-106 sludge level history. The metal bearing waste was added to the tank during the early waste additions (prior to 1965). It is this material that may have formed a hard pan. As shown in Figure 3, the maximum thickness of the hard pan region could be no more than 1.5 feet. This is about 15% of the total waste volume. The historical document suggests that most of the tank heat was added after 1965 (Reference 5). Thus, the hard pan should contain very little heat. Migration of radionuclides into the hard pan may have occurred but could not exceed the best estimate uniform heat distribution.

MODEL DESCRIPTIONS

Scoping Model

Scoping analyses were performed with a one-dimensional model. A solution to Poisson's equation for one-dimensional, steady-state heat conduction was used. The model assumed axial heat conduction with no heat loss from the tank bottom. Heat removal from the dome included heat conduction to the soil and convective heat transfer through the ventilation system.

Detailed Thermal Model

Detailed two-dimensional models were used to confirm the results of the scoping analyses. The primary model employs P/THERMAL, a standard thermal analyses computer code. Models were developed for previous analyses of tank C-106 and are documented in Reference 7. The P/THERMAL model is a two-dimensional finite element model. Two configurations of the model were used. Both were derived from the model documented in Reference 7. One of the models is configured to account for about 75% waste removal (the remaining waste varies from a thickness of 2.33 feet in the center to 1.33 feet at the outside of the tank). This is considered a conservative estimate of the sluiceable sludge. The second model is configured to match the best estimate of the sluiceable sludge (the remaining waste varies from a thickness of 1.5 feet in the center to 0.5 feet at the edge of the tank). The waste conductivities were modified to simulate the conductivity of dry sludge. The model is shown in Figure 4.

Dry Waste Thermal Conductivity

For a dry waste tank, a major determinant of peak waste temperature is the dry waste thermal conductivity. There are no reported values for thermal conductivity of the waste in tank C-106 that are based on an actual sample of the waste. The values used in the models of References 2 and 7 are based on values that give the best fit to the observed temperature data. These values are consistent with parallel conduction models for conduction in a water sludge mixture. These values are for wet waste and will decrease significantly for dry waste.

Measured thermal conductivities for actual tank waste are documented in Reference 6. These data are shown in Figure 5. The average value of 0.27 Btu/h-ft-°F at 300 °F was selected as the best estimate dry conductivity. The lowest measured value (0.089 Btu/h-ft-°F) was selected as a conservative estimate of the conductivity. The conductivity of tank C-106 hard pan material is expected to be higher than these values since it is compacted with a much smaller porosity than the powders of Reference 6.

TEMPERATURE LIMITS

The temperature limits for tank C-106 are based on the operating specifications for single-shell tanks (Reference 1). The Operational Safety Document (OSD) structural temperature limit is 300 °F in the waste and 350 °F in the concrete.

Organic reactions may be possible if organics are present. However, these reactions normally occur near 390 °F (Reference 4) which is well above the OSD temperature limit.

The 1994 process test and subsequent analyses (Reference 3) demonstrated that tank C-106 operates near saturation temperatures, creating the potential for steam release events. This will not be a concern after sluicing since the remaining material will be hard (non-sluiceable) and therefore not subject to steam bumps. Steam generated during drying will be released nearly continuously.

Based upon the above considerations, the OSD limit of 300 °F in the sludge was selected as the temperature limit for this study.

RESULTS OF SCOPING ANALYSES

Results from the one-dimensional scoping calculations are shown in Figure 6. The analyses assume waste dryout occurs with ventilation cooling (2300 cfm) only. The analyses were done for the best estimate (BE) and conservative thermal conductivities. The straight lines represent the remaining heat load as a function of remaining waste depth. This is shown for both the best estimate heat load (Table 1) and 2 times the BE heat load. The curved lines are the result of the scoping model for the two thermal conductivities considered. They represent the heat load as a function of remaining waste depth that will result in a maximum waste temperature of 300 °F (OSD limit). The point of intersection of the curves is the maximum waste depth allowed for the assumed thermal conductivity. As an example, for the best estimate heat load and best estimate thermal conductivity, the OSD limit will not be exceeded for waste depths up to about 3.25 feet. For the conservative heat load the OSD limit will not be exceeded for waste depths up to about 2.25 feet. For the conservative thermal conductivity, the values are 2 feet and just under 1.5 feet. The non sluicable hard pan is not expected to exceed 1.5 feet in the center of the tank. Thus, these scoping analyses suggest that, both on a best estimate and conservative basis (for both heat load and thermal conductivity), no water additions will be required after sluicing to keep sludge temperatures below OSD limits.

RESULTS OF P/THERMAL ANALYSES

Analyses were performed for two waste retrieval scenarios. The first assumes that 75% of the waste will be removed by sluicing. This is clearly a conservative assumption since the hard pan material as discussed above should be no more than 15% of the waste volume. The best estimate second scenarios assumes that all soft waste is removed by sluicing leaving only a hard pan material of about 15%. The analyses results are presented below.

CONSERVATIVE WASTE REMOVAL

Removal of 75% of the waste by sluicing leaves a depth of 2.33 ft in the center and 1.33 ft at the edge (see Figure 4). Analyses were performed to determine how much heat load could remain without exceeding the OSD temperature limit. The waste was assumed to be dry and heat removal occurred by soil heat conduction and dome ventilation flow of 2300 cfm (no evaporation).

The results are summarized in Table 2. Three heat load distributions were considered as summarized in Table 1. The conservative heat loads were selected so the maximum waste temperatures did not exceed the OSD limits for the two thermal conductivities considered.

Table 2. Results for 75% Waste Removal.

Heat Load Distribution (HLD)	Heat Load (Btu/hr)	Conservative Conductivity (0.089 Btu/hr-ft-°F)	Best Estimate Conductivity (0.27 Btu/hr-ft-°F)
Best estimate HLD with 2300 cfm ventilation	56,000	264 °F	175 °F
Conservative HLD with conservative conductivity Conservative Case 1	66,600	300 °F	N/A
Conservative HLD with best estimate conductivity Conservative Case 2	130,000	N/A	300 °F

For the best estimate Heat Load Distribution with full ventilation flow, the maximum waste temperature would be 264 °F for the most conservative conductivity and 175 °F for the best estimate thermal conductivity (Note that the scoping model results discussed in the previous section predict that the OSD limit would be exceeded for a waste depth of 2.33 feet. Because the scoping model is one-dimensional, it does not account for the tank bottom dish nor thermal conduction to the soil through the tank bottom and sides. Thus, as expected the model gives conservative results).

The second analysis establishes the maximum allowable heat load with the conservative conductivity. With 75% waste removal, 67,000 Btu/h could remain in the sludge without exceeding the OSD temperature limit. This is 51% of the total tank heat load.

The third analyses shows the maximum allowable heat load for the best estimate thermal conductivity. A heat load of 130,000 Btu/h or 98% of the total tank heat load could remain after sluicing without exceeding the OSD limit.

A representative temperature contour plot is shown in Figure 7. This temperature distribution is representative of 75% waste removal with a Conservative Case 1 heat load distribution and best estimate thermal conductivity.

The results of both the scoping and P/THERMAL analyses show that for the conservative case of 75% waste removal, the dry waste temperatures can be maintained below OSD temperature limits without evaporative cooling with a significant amount of the total heat load remaining in the waste. These heat load distributions however are clearly not consistent with the measured tank temperature data. The steady-state temperature gradient (prior to sluicing) for the two conservative heat load distributions are compared with actual tank data in Figure 8. The measured temperature difference between TC1 and TC2 for the riser 8 thermocouple tree is less than the temperature difference that would exist for either of the conservative heat load distributions.

The P/THERMAL analyses show that water additions following sluicing will not be required even for very conservative assumptions for waste removal, heat load distribution, and dry waste thermal conductivity.

BEST ESTIMATE WASTE REMOVAL

The analyses of the previous section assumed only 75% waste removal. This is a very conservative estimate. The best estimate for the non-sluiceable hard pan is 15% of the waste volume with a thickness at tank center of 1.5 feet. Analyses were performed with the two-dimensional P/THERMAL model to again demonstrate that a large amount of the tank heat could exist in the hard pan without jeopardizing the success of the project even though such heat load distribution are inconsistent with the tank data. The analyses assumed total waste dryout and were performed for full ventilation (2300 cfm) and ventilation flows representative of passive ventilation flow rates with high tank heat loads (50 cfm). The results are summarized in Table 3. The conservative heat loads were selected so the maximum waste temperatures did not exceed the OSD limits for the two thermal conductivities considered.

Table 3. Results for Best Estimate Waste Removal.

Heat LoadDistribution (HLD)	Heat Load (Btu/h)	Conservative Conductivity (0.089 Btu/h-ft-°F)	Best Estimate Conductivity (0.27 Btu/h-ft-°F)
Best Estimate HLD with 2300 cfm ventilation	32,200	151 °F	106 °F
Best estimate HLD with 50 cfm ventilation	32,200	230 °F	188 °F
Conservative HLD with conservative conductivity Conservative Case 3	82,400	300 °F	185 °F
Conservative HLD with best estimate conductivity Conservative Case 4	132,400	N/A	262 °F

For the best estimate Heat Load Distribution with full ventilation flow, the maximum waste temperature would be 151 °F for the most conservative conductivity and 106 °F for the best estimate thermal conductivity. These temperatures are well below the OSD limits. The heat load of 32,000 Btu/h is also below the 40,000 Btu/h limit for high heat tanks. Thus, the project should be successful in eliminating the tank from the high heat tank list and eliminating water additions.

It should be noted that the best estimate heat load assumes a uniform heat load in the bottom 4 feet of the tank. While the data are sufficient to show that large amounts of heat are not present in the hard pan, the data cannot show that the hard pan is not heat bearing. However, the historical record of tank waste additions suggests that the hard pan should contain little heat. Thus, the actual remaining heat load would probably be less than 32,000 Btu/h.

The second analyses were performed with the best estimate heat load and 50 cfm ventilation flow. This value is comparable to natural convection flows or passive breathing. The analyses indicate the removal of the soft sludge will allow for the elimination of active ventilation with no water additions even assuming conservative values for dry waste thermal conductivity.

The third analyses establishes the maximum allowable heat load with the conservative conductivity. This is Conservative Case 3 in Table 1. With removal of all the soft sludge, 82,000 Btu/h or 62% of the total tank heat load could remain in the sludge without exceeding the OSD limit.

The fourth analyses shows the maximum allowable heat load for the best estimate thermal conductivity. This is Conservative Case 4 in Table 1. The entire heat load of the tank could remain without exceeding the OSD temperature limit.

The results of both the scoping and P/THERMAL analyses show that for the best estimate waste removal, dry waste temperatures can be maintained below OSD temperature limits without evaporative cooling with a significant amount of the total heat load remaining in the waste. These heat load distributions however are clearly not consistent with the measured tank temperature data. The steady-state temperature gradient (prior to sluicing) for the two conservative heat load distributions are compared with actual tank data in Figure 9. The measured temperature difference between TC1 and TC2 for the Riser 8 thermocouple tree is significantly less than the temperature difference that would exist for either of the conservative heat load distributions.

The P/THERMAL analyses show that water additions and active ventilation following sluicing will not be required even for very conservative assumptions for heat load distribution and dry waste thermal conductivity.

PROJECT GOALS REVISITED

The Project W-320 goals are based in part upon safety and environmental concerns. Because of the heat load of tank C-106, frequent water additions and active ventilation are required to control the waste temperatures below OSD limits. In the event of a tank leak, the drainable liquid would be leaked to the environment and water additions (either bulk or spray) would still be required, which could allow continued leakage. In addition, the 1994 process test demonstrated that steam can accumulate in the waste, thus providing a potential for steam bump events. It needs to be understood that Project W-320 does not need to retrieve all the soft sludge in tank C-106 to reduce the environmental and safety risk associated with a potential tank leak.

Figure 10 shows the calculated peak waste temperature as a function of waste depth using the best estimate thermal conductivity (0.27 Btu/h-ft°F) of dry waste. The analyses were performed with the P/THERMAL model using the best estimate heat load distribution and full ventilation flow. The analyses show that if the tank leaked and was allowed to dry out with the current water inventory, the temperatures would well exceed the OSD limits. This would create a serious concern for the structural integrity of the tank. Thus, continued bulk water additions or a water spray system would be required to maintain tank cooling. However, if three feet of sludge is removed, the tank temperatures could be maintained below OSD temperature limits with ventilation flow only. Removal of any sludge will allow the remaining waste to be cooled more easily. This is due both to heat removal and a shorter conduction path.

Achieving the full goals of Project W-320 is very desirable, but any waste removal will improve both the environmental and safety risk associated with tank C-106 operations.

D. M. Ogden, Team Leader
Process Engineering Analysis

T. J. Bander, Principal Engineer
Process Engineering Analysis

B. A. Crea, Principal Engineer
Process Engineering Analysis

bab

Attachment

74A50-96-BAC-006

ATTACHMENT

FIGURES 1 - 10

Consisting of 6 pages,
including cover page

Figure 1. Riser 8 Temperature Profile for Normal Conditions

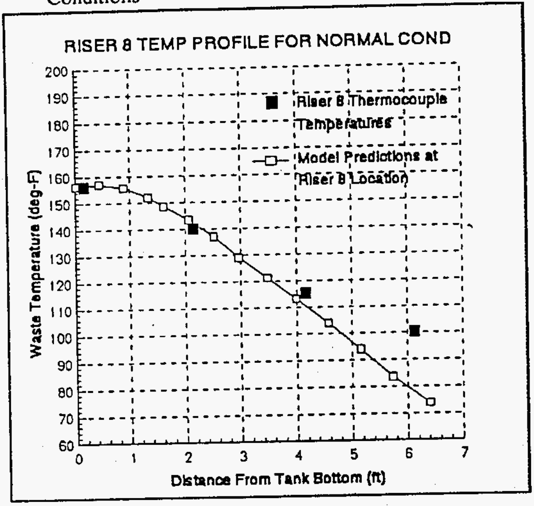


Figure 2. Tank C-106 Temperature Gradients

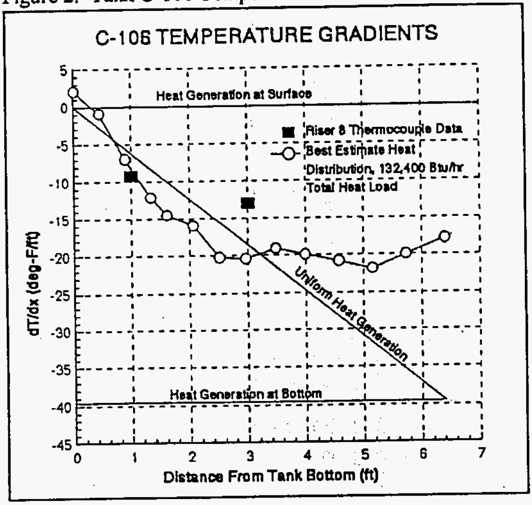


Figure 3. Tank C-106 Fill History

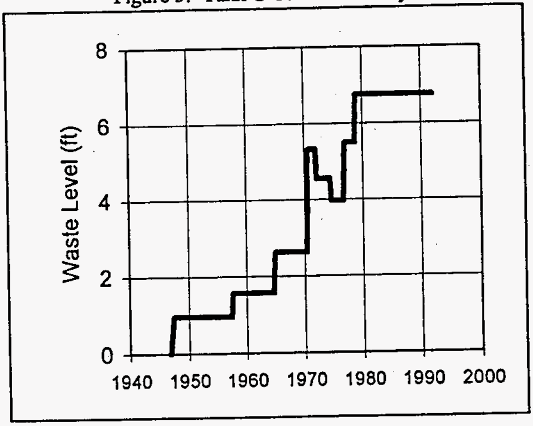


Figure 4. P/THERMAL Finite Element Model.

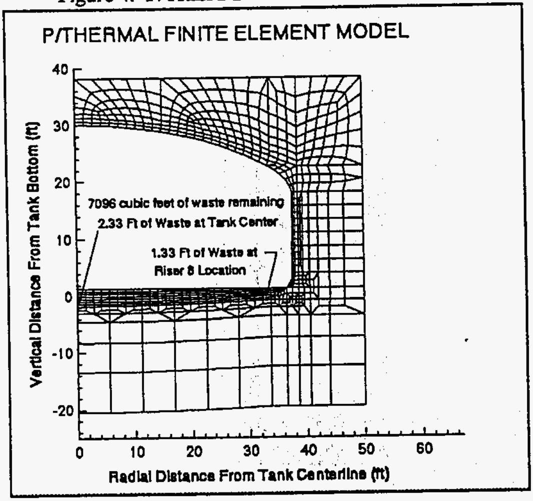


Figure 5. Elevated Temperature Conductivity.

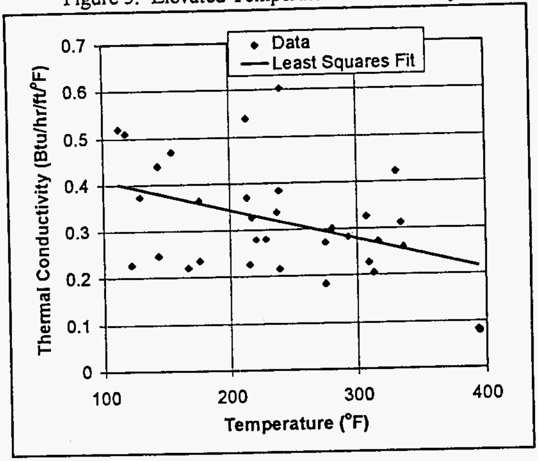


Figure 6. Scoping Model Results.

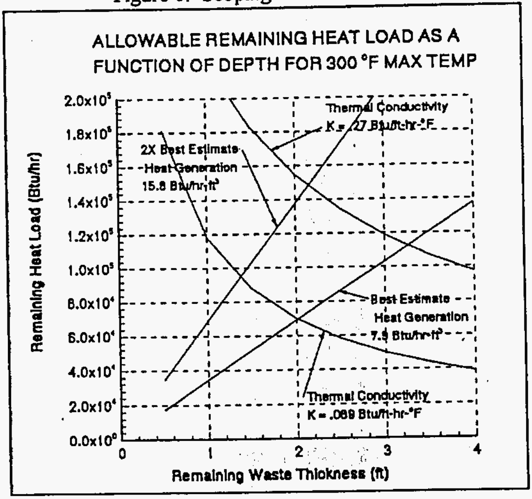


Figure 7. Temperature Distributions After Sluicing.

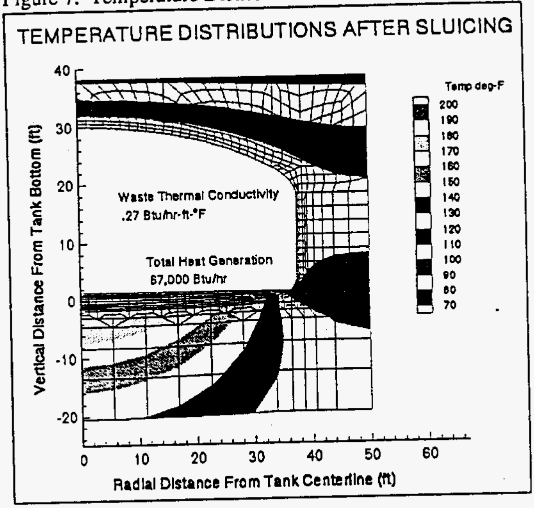


Figure 8. Conservative Waste Removal Compared to Data.

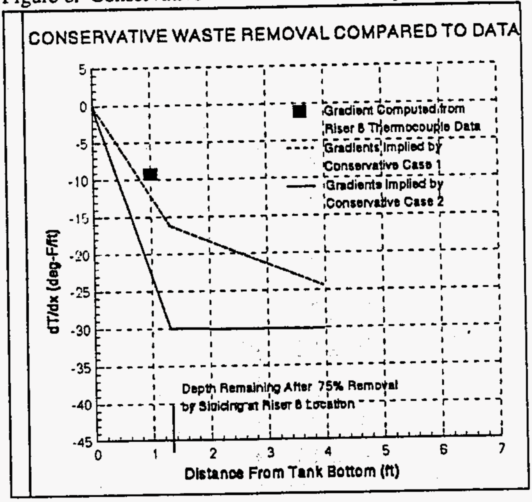
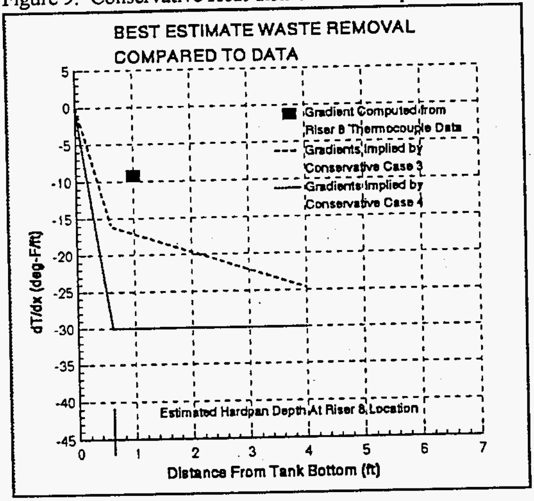
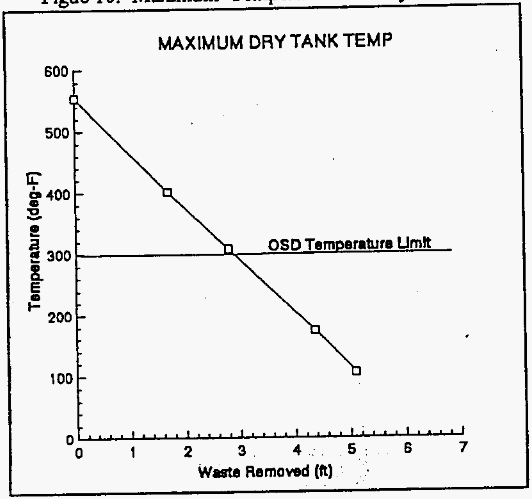


Figure 9. Conservative Heat distribution Compared to Data



Figue 10. Maximum Temperature for Dry Waste.



APPENDIX B. LETTER REPORT 7E310-94-039.

Westinghouse
Hanford Company

Internal
Memo

7E310-94-039

From: Waste Tanks Process Control
Phone: 373-3115 R2-11
Date: August 3, 1994
Subject: Estimated Boiling Point of the Liquid in 241-C-106

To: N. W. Kirch NWK R2-11

cc:

S. D. Estey	R2-11	D. M. Ogden	H0-34
L. L. Eyler	K7-15	R. E. Raymond	R2-54
J. P. Harris III	S6-12	R. C. Roal	H5-27
T. B. McCall	H0-33	J. P. Sederburg	R2-11
W. C. Miller	S4-55	DAR File/LB	

Tank 241-C-106 (C-106) has been monitored for temperature closely since the recent process test. The temperatures on one thermocouple tree are slowly rising. The increase in temperature has lead to interest in what the boiling point of the liquid in tank C-106 will be. This memo provides an estimate of the boiling point based on sample analyses.

The liquid waste in C-106 was sampled in 1990. This was the last time the tank was sampled. The composition of the waste was reported in the appendix to J. P. Sederburg[1]. Table 1 shows a summary of the liquid in C-106.

Table 1
Chemical Analysis of C-106

Cations	mg/l	Anions	mg/l
Al	270.1	OH	0.176
Ba	0	F	164
Ca	0	NO3	67156
Cr	0	NO2	9750
Fe	0	Cl	554
K	0	TOC	27677
La	0	PO4	4039
Na	91094	SO4	4995
		CO3	44860

---

[1] J. P. Sederburg, "Chemical Compatibility of Tank Wastes in Tanks 241-C-106, 241-AY-101, and 241-AY-102", WHC-SD-WM-ES-290, Rev. 1, Westinghouse, May 1994

The approach to estimating the boiling point is to use the ProChem[2] chemical equilibrium computer package. ProChem estimates the activity coefficients of the various chemical species and then calculates the water activity through the Gibb-Duhem equation. The ProChem model requires that the charges be balanced. This was done by using the information in Table 1 and adjusting the *sodium* ion concentration to arrive at charge neutralility. The input to the program is shown in Table 2.

Table 2
Input to the ProChem Model

	mmole/l	mg/l	g/l	g/tank
H2O		807.5	807.51	1.470E+08
AlOH3	0.01	0.8	0.00	1.469E+02
BaSO4	0.00	0.0	0.00	0.000E+00
CrOH3	0.00	0.0	0.00	0.000E+00
BaOH2	0.00	0.0	0.00	0.000E+00
CaOH2	0.00	0.0	0.00	0.000E+00
CaSO4	0.00	0.0	0.00	0.000E+00
FeOH3	0.00	0.0	0.00	0.000E+00
KNO3	0.00	0.0	0.00	0.000E+00
KOH	0.00	0.0	0.00	0.000E+00
LaOH3	0.00	0.0	0.00	0.000E+00
NaNO3	1188.64	93922.3	93.92	1.709E+07
NaNO2	211.93	14622.2	14.62	2.661E+06
NaOH	0.00	0.0	0.00	0.000E+00
NaF	8.63	362.5	0.36	6.597E+04
NaCl	15.63	913.2	0.91	1.662E+05
Na3PO4	42.53	6972.2	6.97	1.269E+06
Na2CO3	747.55	34372.1	34.37	6.256E+06
NaAcetate	468.75	38453.4	38.45	6.999E+06
SiO2	47.82	2873.1	2.87	5.229E+05
AlNO33	10.00	1950.7	1.95	3.550E+05
Na2SO4	52.00	7385.9	7.39	1.344E+06

Note that sodium acetate was used to model the total organic carbon (TOC).

---

[2] Product of OLI Inc, Morris Plains, NJ

The column marked as grams per tank (g/tank) was the input for the program. The program was instructed to find the temperature where there would be one gram mole of vapor at a given pressure. Table 3 summarizes the boiling points.

Table 3
Estimated Boiling Point Based on ProChem

Pressure	Temperature		
Atmos	Kelvin	°C	°F
1	375.19	102.04	215.35
1.1	377.93	104.78	220.28
1.2	380.48	107.33	224.86
1.3	382.85	109.70	229.13
1.4	385.08	111.93	233.14
1.5	387.18	114.03	236.93
1.6	389.17	116.02	240.51
1.7	391.07	117.92	243.92
1.8	392.87	119.72	247.16
1.9	394.59	121.44	250.27
2	396.24	123.09	253.24

ProChem would estimate that this rather dilute solution would have a boiling point rise of about 3 °F at atmospheric pressure.

The pressure in the tank was estimated based on the hydrostatic head. The densities used were 1.4 g/ml for the sludge and 1.16 g/ml for the liquid per J. P. Sederburg. The depth of the sludge was taken as 69 inches with 9 inches of liquid over the top. Once the pressures were estimated, the boiling point at that elevation was estimated by interpolating the values in Table 3. The results are shown in Table 4 and in the figure attached.

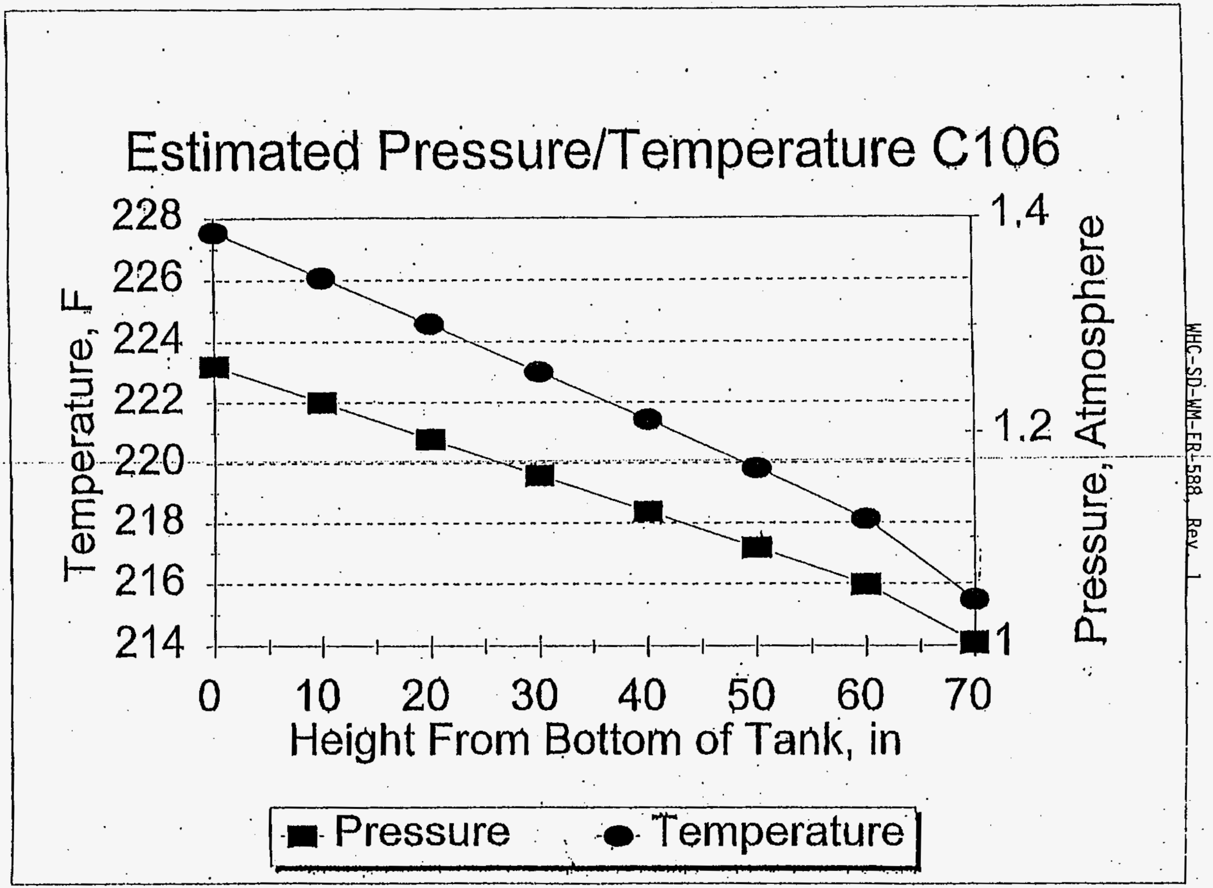

Estimated Pressure/Temperature C106
Temperature, F
228
226
224
222
220
218
216
214
Pressure, Atmosphere
1.4
1.2
1
0
10
20
30
40
50
60
70
Height From Bottom of Tank, in
■ Pressure
● Temperature

Table 4
Boiling Point with Height

Height From Bottom Inches	Pressure psi	Pressure Atmos	Boiling Point °F
0	18.6	1.26	227.6
10	18.1	1.23	226.1
20	17.6	1.19	224.6
30	17.1	1.16	223.0
40	16.5	1.13	221.4
50	16.0	1.09	219.8
60	15.5	1.06	218.1
70	14.7	1.00	215.5

An estimate of the heat of hydration was also requested. This could be best found with a Differential Scanning Calorimeter (DSC) and a Thermogravimetric Analysis (TGA). However, there is no record of these analysis being performed on this waste. ProChem was used to look at the heat of dilution of the liquid. This study looked at the difference in the enthalpy of the solution as the last 10% of the water was added to the solution. Before the addition of the last 10% of the water, the solution enthalpy was -3,685.45 cal/g. After the water addition, the solution enthalpy was -3,685.75 cal/g. This analysis contains some uncertainties. For instance, the dilution in the tank is unknown. The small numbers may well be within the uncertainties of the computer program. However, the indications are that no more than a few tenths of a calorie per gram due to heat of dilution, which is insignificant in relation to the radiolytic heat load.

D A Reynolds

D. A. Reynolds, Fellow Engineer
Waste Tanks Process Control

crm

Attachment

APPENDIX C. CALCULATION OF HEAT LOSS TO THE SOIL FROM SLUICE AND SLURRY LINES.

File to calculate the heat loss to the soil as the waste slurry from C-106 is transfered to AY-102 and then also as the sluice flow is pumped back to C-106

Nomimal waste flow (both ways) $Wg := 350$ gpm

$$Ww := \frac{Wg}{(7.48 \cdot 60)} \quad \text{ft}^3\text{/sec}$$

Set some values (pipe geometry) for the double wall pipe system carrying the waste

$dii := 4.026$ in

$dio := 4.5$ in

$doi := 7.981$ in

$doo := 8.625$ in

Waste flow area $Af := \left(\frac{\pi}{4}\right) \cdot \left(\frac{dii}{12}\right)^2$ ft²

Waste velocity $Vw := \frac{Ww}{Af}$ $Vw = 8.821456$ ft/sec

Waste density $\rho w := 1.25 \cdot 62.38$ lbm/ft³ $\rho w = 77.975$

Waste viscosity $\mu w := 440 \cdot .000672$ lbm/ft-sec $\mu w = 0.29568$

Waste specific heat $cpw := 1.0$ Btu/lbm-°F

Waste thermal conductivity $kw := .36$ Btu/hr-ft-°F

$$Re := \left(\frac{dii}{12}\right) \cdot \left(Vw \cdot \frac{\rho w}{\mu w}\right) \qquad Pr := \frac{cpw \cdot (\mu w \cdot 3600)}{kw} \qquad Re = 780.487989$$

$Pr = 2956.8$

$$Nu := .023 \cdot Re^{.8} \cdot Pr^{.4} \qquad Nu = 115.864287 \qquad Hc := Nu \cdot \frac{kw}{\left(\frac{dii}{12}\right)}$$

$Hc = 124.325316$

The thermal resistance is then $$Rwp := \frac{1}{\left(Hc \cdot \pi \cdot \frac{dii}{12}\right)} \qquad Rwp = 0.007631$$

Now compute the resistance through the pipe wall

$$Kpipe := 25.0 \text{ Btu/hr-ft-°F} \qquad tpipe := \frac{dio - dii}{(2 \cdot 12)} \qquad dim := \frac{dio + dii}{(2 \cdot 12)}$$

$$Rpipe := \frac{tpipe}{(Kpipe \cdot \pi \cdot dim)} \qquad Rpipe = 0.000708$$

Now compute the resistance term for the annular space between the two pipes

Air conductivity

$$Kair := .016 \text{ Btu/hr-ft-°F} \qquad Rair := \frac{\ln\left(\frac{doi}{dio}\right)}{(2 \cdot \pi \cdot Kair)} \qquad Rair = 5.6996$$

Thermal Radiation

$Tmf := 100$ °F $\quad Tmr := Tmf + 460 \quad \sigma := .1714\cdot 10^{-8} \quad \varepsilon := .8$

$$Rrad := \frac{1}{\left(\pi\cdot\frac{dio}{12}\cdot\sigma\cdot\varepsilon\cdot 4\cdot Tmr^{3}\right)} \qquad Rrad = 0.88124$$

Convective transport within the annulus between the pipes $\quad h := .25$

$$Rcon := \frac{1+\frac{dio}{doi}}{\left(h\cdot\pi\cdot\frac{dio}{12}\right)} \qquad Rann := \frac{1}{\left(\frac{1}{Rair}\right)+\left(\frac{1}{Rrad}\right)+\left(\frac{1}{Rcon}\right)}$$

$Rcon = 5.309711 \qquad Rann = 0.667312$

Conductive transport in the soil out to a 2 ft radius

$ds := 48 \qquad Ksoil := .5$

$$Rsoil := \frac{\ln\left(\frac{ds}{doo}\right)}{(2\cdot\pi\cdot Ksoil)} \qquad Rsoil = 0.54639$$

$Rt := Rsoil + Rann + Rpipe + Rwp \qquad Rt = 1.222041$

$L := 1700$ ft $\qquad Ts := 55 \qquad Tw := 85$

$$Qloss := \frac{L\cdot(Tw - Ts)}{Rt} \qquad Qloss = 41733.455463 \text{ Btu/hr}$$

$Qloss\cdot .0003927 = 16.388728$ Horsepower

DISTRIBUTION SHEET

To Distribution	From D. M. Ogden	Page 1 of 1
		Date July 10, 1996
Project Title/Work Order Tank 241-C-106 Sluicing Evaluation		EDT No.
		ECN No. 186732

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
ON-SITE					
DOE-RL					
W. Abdul	S7-53	X			
R. G. Harwood	S7-54	X			
B. L. Nicoll	S7-53	X			
Westinghouse Hanford Company					
H. Babad	S7-14	X			
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W. B. Barton	R2-11	X			
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J. P. Harris III	S2-48	X			
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J. M. Jones	S5-13	X			
N. W. Kirch	R2-11	X			
G. A. Meyer	S2-48	X			
D. M. Ogden	H0-34	X			
S. H. Rifaey	R1-56	X			
W. E. Ross	S5-07	X			
J. P. Sloughter	R2-54	X			