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Ferrocyanide Safety Program: Thermal Analysis of Ferrocyanide Tanks, Group I

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Date Published
June 1994

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

**Westinghouse
Hanford Company**

P.O. Box 1970
Richland, Washington 99352

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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LIST OF TERMS

ITS	In-Tank Solidification
LOW	Liquid Observation Well

METRIC CONVERSIONS

To Change	To	Multiply By
meters	feet	3.281
meters	inches	0.0254
gm/cm ³	lb _m /ft ³	62.43
tonnes	tons	1.1023
liters	gallons	0.2642
°C	°F	9/5 then add 32
W/m-°C	Btu/hr-ft-°F	0.5778

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FERROCYANIDE SAFETY PROGRAM: THERMAL ANALYSIS OF FERROCYANIDE TANKS, GROUP I

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to document the results of a series of analyses conducted to determine the heat loads of the first of two groups of tanks on the Ferrocyanide Watch List. The analyses use the fill/transfer history with a transient solution for the heat load determination. Nominal values of the heat load are determined, as well as the upper and lower bounds of the heat load. Ranges of thermal conductivity of the tank waste are also determined.

1.2 BACKGROUND

During the 1950s, a program was begun to concentrate the radioactive waste products of the uranium and plutonium recovery processes. This program used sodium nickel ferrocyanide to precipitate radioactive cesium from the waste streams. The precipitate was then stored in large underground single-shell tanks at the Hanford Site in south central Washington State.

The precipitated solids also contain nitrates and nitrites. In 1989, a tank safety concern arose because ferrocyanide and nitrates/nitrites can be made to react violently under certain conditions.

Several of the tanks have been "stabilized," a process that included removing as much pumpable liquid as possible from the tanks. This liquid contained heat-producing radionuclides. Because of the many transfers involved, the lack of accurate inventory data for the various waste streams, and the absence of a need for an accurate heat load value, the heat loads of the ferrocyanide tanks have only been estimated. As a result of the intense radiation field within these tanks, the chemical content of the waste has changed. This, coupled with the fact that the characteristics of the input waste were not well known, has resulted in unknown thermal characteristics of the stored sludge. All of the above parameters are needed to evaluate the safety of these tanks.

The method used in this report to determine tank heat loads and the thermal conductivity of the waste uses computer analysis of the tanks and their contents, along with temperature data obtained from thermocouple trees. A computer model of the tanks and their contents is used, and the surrounding soil is included.

The model described in this report uses improved data concerning several additional parameters that have been shown to be necessary. Among them are a detailed analysis of the conductivity of the soil surrounding the tanks, and transient behavior from the filling and temperature histories of the tanks.

2.0 SUMMARY OF RESULTS

Analyses of tanks 241-BY-103, -105, -106, -107, -108, -110, -111, and 241-C-109 were conducted to determine the upper and lower bounds of these tanks' heat loads. Results are shown in Table 2.1. The table also contains the results of previous work (Crowe et al. 1993, Borsheim and Simpson 1991) for comparison.

Table 2-1. Results of Analyses.

TANK NUMBER	NOMINAL	UPPER BOUND	LOWER BOUND	CROWE	BORSHEIM AND SIMPSON
241-BY-103	1.2kW	2.1 kW	0.7 kW	1.6 kW	2.3 kW
241-BY-105	2.2 kW	3.5 kW	1.8 kW	2.5 kW	1.3 kW
241-BY-106	2.5 kW	4.2 kW	1.9 kW	3.0 kW	3.3 kW
241-BY-107	1.8 kW	3.3 kW	1.3 kW	2.6 kW	2.1 kW
241-BY-108	2.0 kW	3.1 kW	1.5 kW	2.7 kW	2.7 kW
241-BY-110	2.1 kW	3.2 kW	1.5 kW	2.0 kW	2.9 kW
241-BY-111	1.3 kW	2.3 kW	0.7 kW	1.6 kW	0.2 kW
241-C-109	1.9 kW	3.4 kW	1.1 kW	2.1 kW	0.6 kW

The waste's thermal conductivity is very dependent on its liquid content. The ranges of the conductivities shown in Table 2-2 are very wide as a result of considerable variance in the liquid content of the waste in the various tanks.

Tables 2-2 and 2-3 are compilations of the maximum and minimum values determined from all the tanks studied except for tank 241-BY-103, which appears to be sodden and would skew the results high, and tank 241-C-109, which was not analyzed for thermal conductivity because of lack of data. The averages shown are averages of values of the compiled tanks and are less than the averages of the extremes. The results are presented in two tables to differentiate between waste sludges and saltcake.

Table 2-2. Thermal Conductivity of Tank Waste.

Case	Nominal Case	Upper Bound	Lower Bound
Upper Value	1.73 W/m-°C	2.94 W/m-°C	1.21 W/m-°C
Lower Value	0.78 W/m-°C	1.30 W/m-°C	0.52 W/m-°C
Average Value	1.17 W/m-°C	2.03 W/m-°C	0.83 W/m-°C

Table 2-3. Thermal Conductivity of Saltcake.

Case	Nominal Case	Upper Bound	Lower Bound
Upper Value	0.87 W/m-°C	1.73 W/m-°C	0.66 W/m-°C
Lower Value	0.35 W/m-°C	0.61 W/m-°C	0.26 W/m-°C
Average Value	0.63 W/m-°C	1.14 W/m-°C	0.46 W/m-°C

3.0 DESCRIPTION OF MODEL

3.1 MODEL CONFIGURATION

The development of the model used is described in detail in McLaren 1993, and is briefly described here. The model was created for use with the HEATING7 code using regions describing the tank, the tank contents, and the surrounding soil. The tank was modeled using data from the tank drawings, with a stepped floor, cylindrical sides, and stepped roof. Because of symmetry, the tank was modeled in cylindrical coordinates, in two dimensions only, vertically from the soil surface to the water table, and radially from the centerline to the outer boundary of the model. Figure 3-1 shows the model of tank 214-BY-105 as developed for the HEATING7 code.

The model used 7 regions inside the tank to describe the airspace, 11 regions to describe the concrete tank bottom, sides and dome, 15 regions outside the tank to describe the soil surrounding the tank, and a varying number of regions inside the tank to describe the waste. The regions describing the waste are in the form of layers. The characteristics of these regions changed during the analysis of the tank because the waste volume within the tank changed over time; specifically, when the tank was saltwell pumped. The material descriptions of these regions were changed by creating a new model after stabilization.

The physical boundaries of the model were: (1) the soil surface with a forced convection heat transfer coefficient for heat rejecting to a constant temperature of 12.2 °C (54 °F); (2) a boundary at 61.0 m (200 ft) below the surface with heat rejecting to a constant temperature of 12.8 °C (55 °F); (3) the centerline of the tank, projected up to the surface and down to the 61.0-m boundary; and (4) a reflective boundary at 17.54 m (57.55 ft) horizontally.

3.2 HEAT TRANSFER MODELING

Heat transfer within the waste itself was by conduction. While there was convection within the waste's liquid regions, this method of heat transfer was accounted for by using a high thermal conductivity (2.60 W/m-°C) within these regions. Heat transfer within the tank airspace was by radiation and convection. Convective heat transfer and radiative heat transfer were from the waste surface to the domed top of the tank. During the time period from when the tank was placed into in-tank solidification (ITS) service to the time of saltwell pumping, the tank was on forced ventilation. This is accounted for by a prescribed heat loss from the top surface of the tank contents. Tank breathing due to atmospheric pressure changes was not taken into account because studies of the volume exchange due to this mechanism (3 to 9 tank volumes per year) indicated that the heat loss was too low to be significant. Heat transfer from the tank to the soil boundaries was by conduction through the soil surrounding the tank.

3.3 SOIL CONDUCTIVITY

3.3.1 Introduction and Summary of Results

The use of a thermal model to estimate heat loads of the single-shell waste storage tanks requires a knowledge of the thermal conductivity of the soil surrounding the tanks. Analyses have shown that the primary path of heat rejection from the tank is through the soil directly above the tank to the atmosphere, with a considerable fraction travelling through the soil around and under the tank upwards to the atmosphere, and only a small fraction going to the water table below the tank. Parameter studies have shown that soil thermal conductivity is the most important parameter in making the heat load estimation.

A very important factor in determining soil conductivity is the amount of moisture in the soil. Hanford Site soils have considerable variability in the lithological description, or soil types, ranging from fine sand to coarse gravel. Each of these soil types shows different moisture retention properties. As a result, the thermal conductivity of the soils surrounding the single-shell waste storage tanks is not well known.

Until recently, the only laboratory analysis of soil conductivities was conducted in 1975 on SX farm soils, with results that are open to question. In 1993, laboratory analyses of thermal conductivities and heat capacities of soils at the proposed site for the Multi-Function Waste Facility storage tanks were conducted, using a specified density and under varying conditions of temperature. Results from these analyses indicate conductivities different from previous results. The results from the more recent analyses of soil conductivities are used in the tank heat load analyses in this report. This section will delineate the soil thermal conductivity values used in this report's analyses and evaluate the data used to determine them.

Two basic soil types have been identified from borehole samples: a "shallow" type of soil from the surface to 37 m (120 ft) below the surface, called the Pleistocene deposits, and a "deep" type of soil, which is more compacted, called the Hanford Formation, which lies below the upper 37-m layer and extends to below the water table. These soil types originate from the various geologic periods of deposition.

Moisture in the soils surrounding the tanks and deep under the tanks has been measured to be approximately 4 wt% in a band from the surface to the 10-m (33-ft) depth. Below 10 m, the soil moisture has been measured to be approximately 2 wt%. The lower bounds of these moistures are taken to be 20% lower than the nominal values. The upper bounds are taken to be 20% higher than the nominal value for soils below 10 m, and to be 8 wt% for soils above 10 m.

The soil regions used in the model are: (1) a layer of shallow-type soil from the surface to 9 m (30 ft) below the surface, at a nominal moisture of 4 wt%; (2) a layer of shallow-type soil from 9 m below the surface to 37 m (120 ft) below the surface at a nominal moisture

content of 2 wt%; and (3) a layer of deep-type soil from 37 m below the surface to the water table at 61 m (200 ft) below the surface. Note that the tank bottom is below the 10-m (33-ft) depth, so the tank is surrounded by soil with two different moisture contents, and is above a second type of soil.

The values of soil conductivity used in these analyses are summarized in Tables 3-1 to 3-3. No limits of accuracy were stated in the analysis report, but these values are considered accurate within 10%. The values show the effects of the conductivity accuracy and soil moisture accuracy.

Table 3-1. Nominal Soil Conductivity Values (Btu/hr-ft-°F).

Soil regions	Moisture (nominal)	Conductivity (55 °F)	Conductivity (110 °F)	Conductivity (170 °F)
Shallow	4 w/o	.537	.547	.57
Shallow	2 w/o	.400	.412	.43
Deep	2 w/o	.59	.61	.63

Table 3-2. Upper Bound Soil Conductivity Values (Btu/hr-ft-°F).

Soil regions	Moisture (nominal)	Conductivity (55 °F)	Conductivity (110 °F)	Conductivity (170 °F)
Shallow	4 w/o	.827	.838	.867
Shallow	2 w/o	.475	.487	.508
Deep	2 w/o	.733	.755	.779

Table 3-3. Lower Bound Soil Conductivity Values (Btu/hr-ft-°F).

Soil regions	Moisture (nominal)	Conductivity (55 °F)	Conductivity (110 °F)	Conductivity (170 °F)
Shallow	4 w/o	.442	.451	.470
Shallow	2 w/o	.331	.342	.358
Deep	2 w/o	.484	.500	.522

3.3.2 Evaluation of Soil Moisture Data

Various studies of soil moistures have been conducted in specific locations within the Hanford Site. The Atlantic Richfield Hanford Company made estimations of soil moistures in the early 1970s (Isaacson et al. 1974), and bore hole studies were made in the C-Farm location in support of groundwater migration studies (Sisson and Lu 1984). The Multi-Waste Treatment Facility project made studies of soil moisture content in the area where their storage tanks were planned, along with soil conductivity measurements (Poppendiek et al. 1993). The overall results of these studies show that the soil moisture content in a shallow band of 10 to 12 m (33 to 39 ft), just beneath the surface of the soil, is about 4 wt%. Moisture in soils below that band is on the order of 2 wt%, and the maximum moisture determined was 8 to 10 wt%. Figure 12 from Isaacson et al. 1974 is shown here as Figure 3-2. This figure shows the distribution of moisture with depth as determined in that report. It should be noted that while there have been many moisture measurements made down to 18 m (60 ft) below the surface, relatively few have been made below that depth.

Figure 3-2. Soil Moisture Profiles in Well 32-49D.

Table 3-2 shows the soil moistures used in the various soil regions in the model.

Table 3-4. Soil Moisture Values Selected for the Analysis.

Soil Regions	Soil Moisture (wt%)		
	Nominal	Lower Bound	Upper Bound
Shallow	4	3.2	8.0
Shallow	2	1.6	2.4
Deep	2	1.6	2.4

3.3.3 Soil Regions of Model

Hanford Site soils consist of two types, the Hanford Formation and the Pleistocene deposits that overlie it. Near the surface, the soils are generally loose, composed of sands and gravels. At deeper depths, the soil composition changes to a more compacted form. At a depth of around 37 m (120 ft) below the surface, the soil composition changes (Drawings H-2-70485 through H-2-70494 [VITRO 1976a,b]). As a result, the values of thermal conductivity under various conditions is different for the shallow soils and the deeper soils. The thermal model of a single-shell waste storage tank used for these analyses is in the shallow soils, but is deep enough that the moisture content of the soil changes around the tank. The placement of these soils around and below the tank is shown in Figure 3-3.

Note: All dimensions in feet.

3.3.4 Thermal Conductivity Values

Until recently, the only information available concerning the thermal conductivity of Hanford Site soils was a study done by D. G. Bouse in 1975. His report presented thermal conductivity values for various soils under varying conditions of moisture and temperature. Because this report did not present the actual conditions of density, only approximate values could be used for the various regions of soil around the tank model. The Multi-Waste Treatment Facility project had laboratory analyses conducted on various soil samples taken from the site where construction of tanks for this facility was planned (Poppendiek et al. 1993). These samples were compacted to a specified dry density of 115 lb/ft³ and the thermal conductivity and specific heat were measured under various conditions of moisture content and temperature. The results of these analyses, shown in Figures 3-4 and 3-5, showed considerably higher conductivity values in comparison to the earlier report.

Figure 3-4. Thermal Conductivity for Shallow Soils and Backfill.

Figure 3-5. Thermal Conductivity for Deep Soils.

A comparison of the conductivity values determined by Poppendiek et al. 1993 and the values determined by Bouse 1975 is shown in Figure 3-6. Bouse's values are shown as points, and Poppendiek's values are plotted.

Figure 3-6. Thermal Conductivity for Shallow Soils at 55 °F.

3.3.5 Thermal Conductivity Curves for Shallow and Deep Soils

Figures 3-7, 3-8, and 3-9 show the range of conductivity values for the three basic soil types used in these analyses. The curves show the upper bound, nominal, and lower bound values of thermal conductivity and the limits of moisture for each type.

Figure 3-7. Conductivity Values for Shallow Soil at 110 °F and 4% Moisture (nominal).

Figure 3-8. Conductivity Values for Shallow Soil at 110 °F and 2% Moisture (nominal).

Figure 3-9. Conductivity Values for Deep Soil at 55 °F and 2% Moisture (nominal),

The previous analysis using this method of estimating thermal properties and heat load used soil conductivity values determined by Bouse. This analysis is described in McLaren 1993, which analyzed tank 241-BY-104. In order to show the effect of the latest soil conductivity on the analyses, the layout of the previous model is shown in Figure 3-10. For comparison, note Figure 3-3, which shows the layout of the present model. Table 3-5 shows the values of soil thermal conductivity used in the various regions of the present model with the older values that would have been used in those same locations. It is readily apparent that the new values are nearly twice as high, which implies that previous heat load estimates were low.

Figure 3-10. Soil Regions of Previous Model.

Note: All dimensions in feet.

Table 3-5. Comparison of Present and Previous Values of Soil Conductivity (Btu/hr-ft-°F).

Soil Type & Moisture		Nominal	Upper Bound	Lower Bound
Shallow 4 %	Present	.55	.84	.45
	Previous	.335	.446	.239
Shallow 2 %	Present	.41	.49	.34
	Previous	.249	.311	.192
Deep 2 %	Present	.59	.73	.48
	Previous	.335	.446	.239

3.4 ASSUMPTIONS

3.4.1 Atmosphere

The atmospheric air temperature was assumed to be constant over the entire time period studied. An average of temperatures over 60+ years was used in the model. This average was 12.2 °C (54 °F). Meteorological data is included as Appendix A.

3.4.2 Geometry

The amount of soil surrounding each tank varies depending on the position of the tank in the farm. Surrounding soil is considered to be in the shape of a square for the tanks wholly within the farm, and in the shape of a rectangle with the tank offset for those tanks on the edges of the farm. The actual geometry was simplified by assuming that the soil around each tank was in the shape of a cylinder and equal in volume to the amount surrounding a tank completely enclosed within the farm. The dimensions of this cylinder were 17.5 m (57.55 ft) in radius and 61.0 m (200 ft) in height.

3.4.3 Ventilation

The heat loss from forced ventilation was varied during the period that forced ventilation was applied. This heat loss was applied by creating a time dependent function that prescribed a specified heat removal over time. No attempt was made to duplicate the temperature profile of the tank contents during this period because these data were rarely available. Also, the purpose of the analysis during this period was to develop soil temperatures around the tanks, not accurate temperatures within the tanks, and high accuracy of the waste temperatures was not necessary. The modeled ventilation heat loss was from the upper surface of the tank contents.

3.5 INPUT DATA AND UNCERTAINTIES

The data used as input for determining the heat load and thermal characteristics of the waste in the single-shell tanks are the temperature readings at various levels within the waste and/or within the tank airspaces. Discussions with C. C. Scaief indicate that these readings may have an error of as much as ± 5 °C (± 9 °F) under the worst conditions, but usually have an error of only ± 1.7 °C (± 3 °F). This error is primarily from temperature measurement errors at the reference junction, and as a result, temperature errors for a given thermocouple string are almost always in one direction, either plus or minus, but not both. This means the shapes of the data curves are accurate and the thermal conductivity errors are not caused by extreme variations in slope of the temperature-vs.-height curve.

Other data used for the analysis are the tanks' fill/transfer and temperature histories (Anderson 1990). The fill/transfer histories are generally known, but temperature histories are known only from about 1975 on. As a result of this gap in temperature histories, considerable error can exist between the actual and the calculated heat load at various times between 1957 and 1983. The intent in developing this history is to heat the soil surrounding the tanks to the proper temperature at the time of stabilization; therefore, this error does not have much effect on the solutions at the end of the period studied (1984 to 1993). Parametric analyses have shown that sizeable errors can exist between the computed and actual temperatures within the tanks with very little (<0.5 °C, <1 °F) change in the soil temperatures. This insensitivity allows good analyses using estimated data.

3.6 HEAT LOAD DETERMINATION METHOD

An iterative process is used to determine the tanks' heat loads. The analysis is conducted in two phases. The first phase models a tank from the time of initial filling to the time it was saltwell pumped, and the second phase models the tank from the time of saltwell pumping to the present. Two phases are required because the HEATING7 code does not allow changes in the region dimensions during a given computer run, even with restarts. The purpose of Phase I is to preheat the soil to the proper temperatures and temperature distribution just prior to saltwell pumping. Phase II starts at this point with the current tank configuration and develops the present heat load of the tank.

In Phase I, a model of the tank prior to stabilization is created. The input data are the tank's fill/transfer history and temperatures. The process starts by developing the fill/transfer history data into a plot to determine the average contents and region heights. Then the salient points of the temperature history are identified. When this process has been completed, a heat load-vs.-time curve is developed. These temperature histories will require that the heat load-vs.-time curves be stepped at various times. This curve is input into the model and a transient problem is computed and analyzed. The intent is to match the temperatures at the salient points previously determined. This will require altering the initial heat load of the tank, the heat load-vs.-time curves, and the ventilation loads to accomplish the match. The purpose of this phase is to get a fairly accurate preheat of the soil surrounding the tank at the time just before saltwell pumping. When this has been accomplished, the second phase of the analysis begins.

Phase II begins by altering the model to describe the contents of the tank after the free liquid has been removed. A soil temperature map at the time of saltwell pumping is determined from Phase I. This map is input into the model as a series of normalized temperature-vs.-position curves. The temperature-vs.-height data of the waste at the beginning of this second phase is input as an initial condition and the iterative process begins again, this time from the time of saltwell pumping to the present. An estimation of the tank heat load and heat generation distribution is made based on the shape and values of the final temperature-vs.-height curve. An estimate of the thermal conductivity of the waste is also made from the shape of the final temperature-vs.-height curve. These estimates are input into the model and

a computer prediction of the waste temperatures is generated. The results of the prediction are compared against the final temperature data. The estimates of the tank heat load, heat generation distribution, and waste thermal conductivities are adjusted and the process repeated until the computer predictions match the data. A close match between the predicted temperatures and the data is necessary at the end of the problem in order to develop as good a prediction of heat load and waste thermal conductivity as possible; however, an exact match is not required.

3.7 ERROR BOUNDS

The error bounds of the analysis are determined by running two Phase II analyses with the temperature data skewed to the limits of the accuracy described in Section 3.5 and the soil conductivities skewed to their accuracy limits as described in Section 3.3.

The lower bound is determined by skewing the temperature data used as the waste initial conditions 3 °F high and the final temperature data, which are the conditions to be estimated by the computer prediction, 3 °F low. The lowest soil conductivity values within their accuracy are used.

In addition, the soil temperatures determined by the Phase I analysis are also modified. This is done by taking the completed Phase I analysis and altering the soil conductivities to their lowest values and rerunning the analysis, keeping all other parameters constant. The resulting temperatures of the soil surrounding the tank are normalized in order to preserve the shape of the curves and used as initial conditions for the Phase II model. The normalization factors come from the nominal case, and are skewed 3 °F high. Therefore, the model will start with higher initial waste and soil temperatures than the nominal case. This modification of the data results in the largest temperature difference between the starting and ending points for the analysis, and requires the lowest heat load in order to match the final data.

The upper bound is determined the same way, except the waste's initial conditions are skewed 3 °F low and its final conditions are skewed 3 °F high. The temperatures of the soil surrounding the tank are determined in the same way as before, only the soil conductivity values are skewed to their highest value to get the temperature distribution, and the normalization factors are skewed 3 °F low. This data modification will result in the lowest temperature difference between the initial and final conditions, which will require the highest heat load in order to match the final data.

4.0 RESULTS

The following paragraphs describe the results of the analyses. If a more complete description of the procedure and results is required, refer to Appendix B, which is a detailed description of the analysis of tank 241-BY-105.

4.1 TANK 241-BY-103

Tank 241-BY-103 is a 753,000-gal tank with 2.1 m (7 ft) of soil cover over the top center of the tank. The fill and transfer history of the tank (Figure 4-1) indicates that there was little solid waste in the tank prior to in-tank solidification (ITS) service. Available temperature data begins in 1974 and continues through 1993 with a gap between 1984 to 1989 (Figure 4-2). The temperature data used to initialize the tank contents for Phase II of the analysis were the October 7, 1977 data. Because the temperature data during this time period were not consistent, engineering judgement had to be exercised in order to produce a usable temperature profile. The assumptions used to create this profile from the data do not introduce much inaccuracy into the analysis because of the time span of this analysis: 16 years. The level used for the tank contents was 3.9 m (12.75 ft). The data used for matching at the end of the analysis were the December 6, 1993 data. These data indicate that the waste level is about 4.9 m (16 ft), while the published waste height is 3.9 m (Hanlon 1993). In the interest of conformity, the published waste height was used. The temperature of the waste surface was taken to be the temperature of the airspace, and a line was drawn from that point to the data point at 3.1 m (10.3 ft). This became the data curve that was matched by the computer predictions. This difference in level will not affect the estimate of the tank heat load, but could affect the thermal conductivity of the waste in this region. Should the level indicated by the temperature data (3.9 m) be correct, then the waste thermal conductivity in this region will be higher than estimated here. The analysis determined that the tank contents seemed to be divided into two layers with the division 3.1 m above the bottom center of the tank. There appeared to be a distinct difference of conductivity above and below this level (Figure 4-3). The results of the analysis are shown in Table 4-1.

Figure 4-1. Tank 241-BY-103 Fill/Transfer History.

Figure 4-2. Tank 241-BY-103 Maximum Temperature History.

Figure 4-3. Tank 241-BY-103 Computer Prediction vs. Nominal Case Data.

Table 4-1. Results of Tank 241-BY-103 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 3.1 m	k above 3.1 m
Upper bound*	2.1 / 7,000	Homogeneous	2.9 / 1.7	0.7 / .40
Nominal	1.2 / 4,000	Homogeneous	2.2 / 1.3	0.4 / .25
Lower bound*	0.7 / 2,400	Homogeneous	2.1 / 1.2	0.3 / .15

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.2 TANK 241-BY-105

Tank 241-BY-105 is a 753,000-gal tank with 2.4 m (8 ft) of soil over the top center of the tank. Its fill/transfer history shows that it had nearly all of its solid waste removed prior to ITS service (Figure 4-4). During the ITS service period, the tank also had various other wastes added, yet the temperature-vs.-height data for the tank taken during the period between 1978 and 1993 indicate that the heat generation appears to be towards the bottom of the tank (Figure 4-5). Available temperature data begins in 1974 and continues through 1993 (Figure 4-6). The temperature data from January 29, 1978 were used as the initial conditions for the tank waste for the Phase II analysis, and the data from December 26, 1993 were used for matching at the end of the analysis (Figure 4-5). Note how the slope of the 1978 curve is much flatter than the 1993 curve. This is a result of the forced ventilation cooling the surface of the waste, and the effects of the thermally hot ITS service additions. The waste height was estimated at 4.4 m (14.5 ft). In order to match the computer

predictions with the December 26, 1993 data, a change in thermal conductivity above 3.1 m was required. The distribution of the heat source in this tank was taken to be concentrated in the lower third of the waste. Note that this only means that the heat source appears to be a non-homogeneous distribution located predominantly towards the bottom. The results of this analysis are shown in Table 4-2.

Figure 4-4. Tank 241-BY-105 Fill/Transfer History.

Figure 4-5. Tank 241-By-105 Initial and Final Temperatures for Phase II Analysis

Figure 4-6. Tank 241-BY-105 Maximum Temperature History.

Table 4-2. Results of Tank 241-BY-105 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 3.1m	k above 31.m
Upper bound*	3.5 / 12,000	In lower 1/3	1.90 / 1.10	1.38 / 0.80
Nominal	2.2 / 7,500	In lower 1/3	1.12 / 0.65	0.78 / 0.45
Lower bound*	1.8 / 6,000	In lower 1/3	0.87 / 0.50	0.66 / 0.38

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.3 TANK 241-BY-106

Tank 241-BY-106 is a 753,000-gal tank with 2.1 m (7 ft) of soil cover over the top center of the tank. The fill/transfer history of the tank shows that about 1.2 m (4 ft) of waste was in the tank when ITS service was begun (Figure 4-7). This is borne out by the heat distribution observed, with the heat generation located in the lower part of the tank. The temperature history begins in 1974 and continues through 1993 (Figure 4-8). The temperature-vs.-height data for the first months of 1978 show a nearly linear trace from the bottom of the tank to the waste surface. After 1982, however, the temperature measurements covered only the lower 2.5 m (8.3 ft) with a single measurement in the tank air space (Figure 4-9). Consequently, the data for 1993 do not cover the entire depth of the tank. Therefore, in

order to develop a curve to be matched for the Phase II analysis, a data point for the waste surface was estimated by making it the same as the tank airspace temperature. Experience with previous analyses have shown this to be valid. The shape of the lower five data points shows no sign of a temperature reduction with increasing depth; therefore, a deep layer of heat generation was estimated. With no data above 2.5 m to the surface, an estimated curve was created by drawing a line from the estimated waste surface temperature to the temperature data point at 2.5 m above the tank bottom. Layers of different conductivity could be present in this unmeasured region, which could possibly be indicated by the presence of an interstitial liquid level. The estimated thermal conductivity in this region could be in error, but by how much is unknown. Again, note the effect of the hot ITS wastes and forced ventilation on the 1978 temperature curve. The results of this analysis are shown in Table 4-3.

Figure 4-7. Tank 241-BY-106 Fill/Transfer History.

Figure 4-8. Tank 241-BY-106 Maximum Temperature History.

Figure 4-9. Tank 241-BY-106 Initial and Final Temperatures for Phase-II Analysis.

Table 4-3. Results of Tank 241-BY-106 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 2.7m	k above 2.7m
Upper bound*	4.2 / 14,500	In lower 1/3	2.94 / 1.70	1.73 / 1.00
Nominal	2.5 / 8,500	In lower 1/3	1.73 / 1.00	0.76 / 0.44
Lower bound*	1.9 / 6,500	In lower 1/3	1.21 / 0.70	0.59 / 0.34

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.4 TANK 241-BY-107

Tank 241-BY-107 is a 753,000-gal tank with 2.7 m (9 ft) of soil cover over the top center of the tank. Its fill/transfer history shows that a layer of waste about 0.6 m (2 ft) thick remained in the tank prior to ITS service (Figure 4-10). The final waste level is open to question. All available waste level data indicate that the waste is about 2.6 m (8.7 ft) thick, but the temperature data indicate that it is only 1.5 m (5 ft) thick (Figure 4-11). The 2.6-m waste level was used in the analysis. The data indicated that the heat load was located in the lower half of the waste, and that there was a distinct change in conductivity between the lower half and the upper half of the waste. The March 28, 1977 temperature data were used as initial conditions of the waste for the Phase II analysis, and the December 26, 1993 data were used as final conditions to be matched by the analysis. The results of the analysis are shown in Table 4-4.

Figure 4-10. Tank 241-BY-107 Fill/Transfer History.

Figure 4-11. Tank 241-BY-107 Initial and Final Temperatures for Phase II Analysis.

Table 4-4. Results of Tank 241-BY-107 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 1.5 m	k above 1.5 m
Upper bound*	3.2 / 11,000	In lower 70%	2.60 / 1.50	0.87 / 0.50
Nominal	1.8 / 6,000	In lower 70%	1.04 / 0.60	0.52 / 0.30
Lower bound*	1.3 / 4,500	In lower 70%	1.00 / 0.45	0.43 / 0.25

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.5 TANK 241-BY-108

Tank 241-By-108 is a 753,000-gal tank with 2.4 m (7.8 ft) of soil cover over the top center of the tank. Its fill/transfer history shows that about 2.29 m (7.5 ft) of solid waste was in the tank just prior to ITS service, but during ITS the solids level changed to a low of about 0.61 m (2 ft) (Figure 4-12). The analysis determined that the heat generation in the tank occurred predominantly towards the bottom of the tank. The January 29, 1978 temperature data were used as the waste initial conditions for the start of the Phase II analysis, and the December 26, 1993 temperature data were used for the final conditions to be matched at the end of the analysis (Figure 4-13). The 1978 temperature curve appears to indicate that the position locations of the thermocouples could be in error, and shows the effect of the hot ITS wastes and forced ventilation. If this initial temperature data is in error, such errors would be smoothed out over the long time period of this phase of the analysis (16 years), and would have little effect on the analysis predictions. The analysis indicated that there were three regions of varying thermal conductivity, although the variance was not large. The results of the analysis are shown in Table 4-5.

Figure 4-12. Tank 241-BY-108 Fill/Transfer History.

Figure 4-13. Tank 241-BY-108 Initial and Final Temperatures for Phase II Analysis.

Table 4-5. Results of Tank 241-BY-108 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 0.70 m	k between 0.70 m & 1.38 m	k above 1.38 m
Upper Bound*	3.08/10,500	All in lower 35%	1.21/0.70	1.04 / 0.60	0.87/0.50
Nominal	1.99/ 6,800	All in lower 35%	0.78/0.45	0.61 / 0.35	0.52/0.30
Lower Bound*	1.52/ 5,200	All in lower 35%	0.61/0.35	0.52 / 0.30	0.40/0.23

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.6 TANK 241-BY-110

Tank 241-BY-110 is a 753,000-gal tank located at the lower end of its group. It has 2.74 m (9 ft) of soil over the top center of the tank. Its fill/transfer history shows that about 1.5 m (5 ft) of solid waste was in the tank prior to ITS service (Figure 4-14). This tank has quite a bit of solid waste in it; the waste surface is recorded as being 3.86 m (12.7 ft) above the bottom of the tank. The temperature data between 1975 and 1981 is scattered. The plot of assumed and recorded maximum temperature history is shown in Figure 4-15. Both the 1984 and 1993 temperature data show the characteristic curve of a homogeneous heat distribution in the tank in the volume below 2.07 m (6.8 ft). The December 14, 1984 temperature data were used as the waste initial conditions for the start of the Phase II analysis, and the December 26, 1993 temperature data were used for the final conditions to be matched by the computer predictions (Figure 4-16). Once again, note the effects of forced ventilation on the shape of the earlier temperature curve. The effect is not as marked as in the previous tanks, because of the later time of the data (1984 vs. 1978). This tank also showed a varying thermal conductivity over the height of the waste, in this case more varied than seen in other tanks. The results of this analysis are shown in Table 4-6.

Figure 4-14. Tank 241-BY-110 Fill/Transfer History.

Figure 4-15. Tank 241-BY-110 Maximum Temperature History.

Figure 4-16. Tank 241-BY-110 Initial and Final Temperatures for Phase II Analysis.

Table 4-6. Results of Tank 241-BY-110 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 0.70 m	k between 0.70 m & 2.68 m	k above 2.68 m
Upper Bound*	3.22/11,000	All in lower 1/2	1.30/0.75	0.87 / 0.50	0.61/0.35
Nominal	2.05/ 7,000	All in lower 1/2	0.95/0.55	0.69 / 0.40	0.35/0.20
Lower Bound*	1.47/ 5,000	All in lower 1/2	0.87/0.50	0.61 / 0.35	0.26/0.15

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.7 TANK 241-BY-111

Tank 241-BY-111 is a 753,000-gal tank in the middle of its group. It has 2.44 m (8 ft) of soil over the top center of the tank. Its fill/transfer history shows that there was less than 0.61 m (2 ft) of solid waste in the tank just prior to ITS service (Figure 4-17). The results of the analysis indicate that the heat distribution is mostly in the bottom of the tank. This tank was difficult to analyze because so few temperature data were available. Temperature data exists from 1974 through 1979, but it is not known from what riser this data was obtained. This data is very scattered, and only general approximations could be drawn from it. Temperature readings were obtained from 1989 to the present by a thermocouple probe

inserted into the liquid observation well (LOW) in the Riser 1 position, and in 1993 to the present from a new thermocouple tree placed in Riser 14 (Figure 4-18). Riser 1 is located 2.44 m (8 ft) from the center of the tank, and Riser 14 is located 9.02 m (29.6 ft) from the centerline of the tank. The temperatures obtained from the thermocouple tree are lower than those obtained from the LOW, which is to be expected. The July 7, 1979 temperature data were used as the waste initial conditions for the start of the Phase II analysis, and the December 20, 1993 temperature data were used for the final conditions to be matched by the computer predictions (Figure 4-19). There appeared to be a change in thermal conductivity of the waste above and below a level of about 2.7 m (9 ft). The results of the analysis are shown in Table 4-7.

Figure 4-17. Tank 241-BY-111 Fill/Transfer History.

Figure 4-18. Tank 241-BY-111 Maximum Temperature History.

Figure 4-19. Tank 241-BY-111 Initial and Final Temperatures for Phase II Analysis.

Table 4-7. Results of Tank 241-BY-111 Analysis.

Case	Heat Load kW / Btu/hr	Distribution	k below 2.7 m	k above 2.7 m
Upper bound*	2.34 / 8,000	In lower 30%	2.25 / 1.30	1.38 / 0.80
Nominal	1.32 / 4,500	In lower 30%	1.38 / 0.80	0.87 / 0.50
Lower bound*	0.73 / 2,500	In lower 30%	0.78 / 0.45	0.43 / 0.25

Note: Conductivities (k) are listed in W/m-°C / Btu/hr-ft-°F.

*Refer to Section 3.7

4.8 TANK 241-C-109

Tank 241-C-109 is a 500,000-gal tank. The depth of the soil over the top center of the tank was calculated to be 1.98 m (6.5 ft). This tank has very little waste in it, and only one thermocouple in the waste. The thermocouple tree is located in Riser 8, which is 10.16 m (33 ft) from the centerline of the tank. Note that the radius of the tank is 11.43 m (37.5 ft). With only one temperature measurement in the waste, there was no chance of conducting anything but the most rudimentary analysis of the tank. Only the heat load could be estimated; there was no way to estimate the heat distribution or the thermal conductivity of the waste. However, liquid is expected to be in the tank, so the thermal conductivity should be towards the upper values estimated by these analyses.

This tank was placed in ITS service in the last half of 1957, and the solid waste level remained fairly constant from then on (Figure 4-20). Consequently, it is expected that the solid waste is nearly all evaporator bottoms. Reliable temperatures begin in 1989 and continue through 1993 (Figure 4-21). The temperature data from February 2, 1990 were used as the initial conditions in the waste, and the temperature data from December 20, 1993, Riser 1, were used to match the analysis results (Figure 4-22). The results of the analysis are shown in Table 4-8.

Figure 4-20. Tank 241-C-109 Fill/Transfer History.

Figure 4-21. Tank 241-C-109 Maximum Temperature History.

Figure 4-22. Tank 241-C-109 Initial and Final Temperatures for Phase II Analysis.

Table 4-8. Results of Tank 241-C-109 Analysis.

Case	Heat Load kW / Btu/hr
Upper bound*	3.37 / 11,500
Nominal	1.86 / 6,350
Lower bound*	1.06 / 3,600

*Refer to Section 3.7

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APPENDIX A

METEOROLOGICAL DATA

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Average Dry Bulb Temperature 1912-1975 (°F, 4 ft).

Hour	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual average
00	26.8	34.0	40.1	45.4	57.5	61.5	70.2	64.5	56.9	45.0	37.5	36.0	48.0
01	26.7	33.8	38.8	44.3	55.2	59.6	67.9	61.6	55.7	44.4	37.2	35.7	46.7
02	26.2	33.7	38.0	43.0	53.5	57.5	65.0	59.9	53.9	43.7	37.0	35.9	45.6
03	25.3	33.5	37.0	40.6	51.4	56.0	63.1	58.0	52.5	43.5	37.2	35.5	44.7
04	25.5	33.0	36.3	39.1	49.5	55.0	60.9	56.1	52.1	43.0	37.1	35.0	43.6
05	25.0	32.3	35.5	37.6	48.5	56.3	65.0	57.6	51.9	42.0	37.1	35.0	43.2
06	25.0	31.9	34.6	38.0	48.9	60.0	70.5	63.0	53.9	41.4	36.7	34.7	44.4
07	24.3	31.6	35.7	43.3	53.1	64.2	76.4	69.3	58.5	44.1	36.9	34.8	47.2
08	25.7	34.0	40.0	49.8	58.0	68.0	76.4	74.2	63.6	49.2	38.5	35.9	51.1
09	29.7	37.5	46.0	55.2	67.0	70.7	80.0	78.0	67.1	53.3	40.4	37.7	54.9
10	32.6	40.9	50.0	59.0	70.3	74.0	83.2	81.3	71.0	56.2	42.5	39.5	58.1
11	35.1	43.5	53.0	61.5	70.3	76.4	86.2	84.1	74.0	58.8	43.4	40.9	60.6
12	36.5	45.9	54.7	63.7	72.7	78.4	88.9	86.6	76.3	60.8	44.0	42.5	62.6
13	37.2	47.1	55.9	65.6	74.2	79.8	91.1	88.6	78.1	62.0	44.4	43.0	64.0
14	37.4	47.7	56.9	66.8	75.9	80.7	92.6	89.8	79.1	63.0	44.5	42.7	64.8
15	36.6	47.7	57.0	66.9	76.9	80.8	93.5	90.2	79.4	62.5	43.6	42.0	64.8
16	34.4	46.9	56.8	66.5	77.6	80.9	93.8	89.5	79.0	61.0	42.1	40.5	64.1
17	32.2	44.6	55.2	65.0	77.4	79.4	93.3	87.6	76.4	57.7	40.7	39.5	62.4
18	30.3	41.4	52.6	63.0	76.7	77.7	91.5	83.5	70.5	53.7	39.9	38.3	60.0
19	29.4	39.4	49.0	59.0	75.0	74.7	88.3	77.8	66.3	51.7	39.5	37.3	57.3
20	28.8	38.1	46.3	55.0	71.2	71.0	83.3	74.4	63.7	49.8	38.8	36.8	54.8
21	28.2	36.9	44.1	52.2	67.0	67.4	78.6	71.6	61.9	48.5	38.3	36.3	52.6
22	28.0	36.1	42.5	49.8	63.0	64.9	75.2	69.5	59.5	47.3	38.2	35.8	50.8
23	27.3	35.3	40.8	47.8	60.4	63.3	73.0	66.7	57.9	46.0	38.0	35.3	49.3
Average monthly temp.	29.7	38.6	45.7	53.3	64.3	69.0	78.8	74.3	65.0	51.2	39.7	37.8	54.0

Monthly Average of Psychrometric Data Based on Period of Record 1950-70.

Averages														
		Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
	Dry bulb	30.3	37.5	44.0	52.5	61.8	69.9	77.5	75.3	67.0	53.2	40.1	33.4	53.5
	Wet bulb	27.9	33.6	37.3	42.8	49.1	54.5	57.9	57.3	52.6	45.4	36.4	31.2	43.8
	Rel hum	76.0	69.7	55.0	46.4	41.8	39.4	31.5	34.9	39.9	57.6	72.6	80.8	53.8
	Dewpoint	23.2	27.4	27.3	30.4	36.0	41.2	42.3	42.8	39.5	36.9	31.1	27.5	33.8
Monthly Average Extremes														
Dry bulb	Highest	43.0	44.0	48.7	56.2	68.7	75.5	82.8	82.5	72.0	59.1	45.8	38.8	56.3
	Year	1953	1958	1968	1956	1958	1969	1960	1967	1967	1952	1954	1953	1953
	Lowest	12.9	25.8	39.6	48.3	57.2	64.2	73.2	70.6	61.6	50.3	32.3	26.5	51.0
	Year	1950	1956	1955	1955	1962	1953	1963	1964	1970	1968	1955	1964	1955+
Wet bulb	Highest	39.3	40.7	40.8	45.1	54.6	58.6	61.2	61.1	56.5	47.7	42.3	35.8	46.5
	Year	1953	1958	1963	1962	1958	1958	1958	1961	1963	1962	1954	1966	1958
	Lowest	12.4	23.4	32.9	39.3	45.4	51.4	55.6	54.9	48.3	42.4	29.6	25.0	41.8
	Year	1950	1956	1955	1955	1959	1954	1954	1964	1970	1970	1955	1964	1955
Rel hum	Highest	89	87	66	64	*52	54	40	44	55	74	80	90	58
	Year	1960	1963	1950	1963	1962+	1950	1955	1968	1969	1962	1956	1950	1950+
	Lowest	60	54	44	37	31	34	22	24	34	42	64	69	49
	Year	1963	1967	1965	1966	1966	1960	1959	1967	1952	1952	1963+	1968	1967
Dewpoint	Highest	34.4	36.7	34.0	37.1	43.8	47.5	46.6	46.9	45.4	43.5	38.3	34.3	37.7
	Year	1953	1958	1961	1963	1957	1958	1958	1961	1963	1962	1954	1950	1958
	Lowest	6.5	17.3	20.8	26.2	30.4	37.5	34.4	38.4	33.8	32.1	24.0	21.0	31.5
	Year	1950	1956	1965+	1955	1964	1954	1959	1955	1970	1970	1959	1951	1955

+ Also in earlier years

* Although not included in these tables, an average of 63% was recorded in 1948.

APPENDIX B

**A DETAILED DESCRIPTION OF THE THERMAL
ANALYSIS OF TANK 241-BY-105**

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APPENDIX B

HEAT LOAD DETERMINATION OF TANK 241-BY-105

B1.0 INTRODUCTION

This appendix describes the development of a thermal model for tank 241-BY-105 and the use of the model to determine the current tank heat load. The analysis method described in McLaren 1993 was used with the specific tank data and other modifications that are described in this document.

The major objective of the analysis was to bound the heat load of the tank by providing realistic values of the upper and lower heat load estimates at the end of 1993. A second objective was to bound the thermal conductivity of the waste in this tank.

B2.0 SUMMARY OF RESULTS

The heat load of tank 241-BY-105 estimated from the thermal analysis method used in this appendix is shown in Table B-1.

Table B-1. Summary of Results

Case	Heat Load	Distribution	Waste Conductivity	
Upper Bound	3.5 kW	All heat in lower 0.70 m	1.38 W/m-°C above 0.70 m	1.90 W/m-°C below 0.70 m
Nominal	2.2 kW	All heat in lower 0.70 m	0.78 W/m-°C above 0.70 m	1.12 W/m-°C below 0.70 m
Lower Bound	1.8 kW	All heat in lower 0.70 m	0.66 W/m-°C above 0.70 m	0.87 W/m-°C below 0.70 m
Spread	+60% -20%	none	+78% -16%	+69% -23%

B3.0 SUMMARY OF KEY INPUT DATA

B3.1 FILL HISTORY

The fill/transfer history of the tank indicates that prior to being placed in in-tank solidification (ITS) service, one half to one third of the tank contents were solids. However the solids component of the tank contents were almost completely removed just prior to the

tank being placed in ITS service. ITS service consisted of heating dilute liquid wastes to saturation and evaporating them until saturation of the solution was achieved, then pumping the liquid to a storage tank (bottoms tank) and allowing the liquid to cool, precipitating excess solute. These are commonly called "evaporator bottoms." The solute was allowed to settle and the process was repeated. When a certain liquid level was reached, the supernate was pumped out. Consequently, during ITS service, the bottoms tanks were periodically filled with thermally hot solutions. ITS service started in 1967 and continued intermittently until 1974 when the remaining supernate was pumped out. The tank was saltwell pumped in 1977, which removed some of the free liquid in the tank. The tank has not been jet pumped; consequently, free liquid exists within the waste. The level of solids in the tank on June 13, 1993 was measured to be 4.5 m (14.75 ft), while the level calculated from the corrected inventory is 4.85 m (15.9 ft). The discrepancy between these two values will not affect the heat load estimates. The fill/transfer history of tank 241-BY-105 is shown in Figure B-1. In this figure, the total and solids levels in the tank prior to 1981 are calculated from the reported tank inventories (Anderson 1990). From 1981 on, the tank levels are from waste height measurement data. The types of solids deposited in the tank are noted within the level brackets. For a more detailed discussion of the fill/transfer history of this tank, see Appendix C.

Figure B-1. Tank 241-BY-105 Fill/Transfer History.

B3.2 THERMAL HISTORY

Temperature data has been found back to September of 1974. Figure B-2 shows the maximum temperature of the waste from September 1974 to December 1993, together with the estimated maximum temperature in the tank prior to data being taken. The tank contents were estimated to be about 38 °C (100 °F) during the period from 1952 to 1967, when ITS service started. It is understood that the temperature would vary depending upon the waste inventory over time, but this temperature appears to be a reasonable value over this time period.

During the period of ITS service, the tank was being filled with liquid at or near boiling temperature; as a result, the estimated temperature was 82 °C (180 °F). The actual temperatures within the tank are not known; obviously, cycles of hotter and cooler periods occurred within the tank as it was filled and allowed to cool. The use of 82 °C during this time period is an engineering judgement. The detailed fill history indicates that this tank was not a direct recipient of the ITS liquids; consequently, the estimate of 82 °C is probably high. While this overestimate would predict surrounding soil temperatures to be higher than those that actually existed, it is considered that the error introduced is masked by the other inaccuracies of the analysis, such as inexact conductivities of the soil surrounding the tank. After ITS service was completed, the tank cooled rapidly, due primarily to forced ventilation. Sometime prior to 1980 the forced ventilation was stopped.

Figure B-2. Tank 241-BY-105 Maximum Temperature History.

B3.3 SOIL CONDUCTIVITY

The soil in the upper 36.5 m (120 ft) in the tank farm area of the Hanford Site is non-uniform, with strata of varying types of soil intermittently dispersed throughout the area. The thermal conductivity of the soil is influenced greatly by its moisture content. The moisture content of the soil is on the order of 4 wt% in the first 10 to 12 m (33 to 40 ft) down from the surface, then it drops rapidly to about 2 wt% from 12 meters below the surface down to the water table (Isaacson et al. 1974). Recent laboratory measurements of soil thermal conductivities under various conditions were used (Poppendiek et al. 1993). A noding diagram of this model is shown as Figure B-3.

Selection of the thermal conductivities used in this analysis is explained in detail in the body of the basic report. The thermal conductivities for the three soil regions used by the model are shown in Tables B-2, B-3, and B-4.

Figure B-3. Layout Soil Types Surrounding Tank 241-BY-105.

Table B-2. Nominal Soil Conductivity Values (W/m-°C).

Soil Regions	Moisture (nominal)	Conductivity (13 °C)	Conductivity (43 °C)	Conductivity (77 °C)
Shallow	4 w/o	0.929	0.947	1.00
Shallow	2 w/o	0.692	0.713	0.74
Deep	2 w/o	1.02	1.06	1.09

Table B-3. Upper Bound Soil Conductivity Values (W/m-°C).

Soil regions	Moisture (nominal)	Conductivity (13 °C)	Conductivity (43 °C)	Conductivity (77 °C)
Shallow	4 w/o	1.43	1.45	1.50
Shallow	2 w/o	0.822	0.843	0.865
Deep	2 w/o	1.27	1.31	1.35

Table B-4. Lower Bound Soil Conductivity Values (W/m-°C).

Soil regions	Moisture (nominal)	Conductivity (13 °C)	Conductivity (43 °C)	Conductivity (77 °C)
Shallow	4 w/o	0.762	0.781	0.813
Shallow	2 w/o	1.33	0.592	0.620
Deep	2 w/o	0.838	0.865	0.903

B4.0 ANALYSIS METHOD AND RESULTS

The analysis of this tank followed the procedure described in McLaren 1993. This procedure is briefly described below.

The analysis is conducted in two phases. The first phase, called Phase I, covers the time period from the initial fill (first quarter of 1952) to the completion of saltwell pumping (first quarter of 1977) and is used to determine the temperature of the tank and surrounding soil at that time. The tank contents are assumed to be homogenous with a waste level that is an average of the total waste level during this period. Phase II covers the remaining time to the present and is used to determine the present heat load of the tank. The reason for

performing the analysis in two phases is to account for the differences in the level of tank contents during the time the tank was in fill/transfer service, and the time afterwards. The dividing time is considered to be the time the tank was saltwell pumped. The use of two phases is necessary because the HEATING7 code cannot change region dimensions during a run, even with restarts. The same model is used for both phases, with only the dimensions and number of regions describing the waste and tank airspace changing between phases. The noding diagram of the tank and surrounding soil is shown as Figure B-4, with the tank interior noding diagrams being shown as Figures B-5 and B-7.

Figure B-4. Noding Diagram of Tank and Surrounding Soil.

B4.1 PHASE I

In this phase, iterations on the heat load of the tank, together with ventilation heat losses, are performed to reproduce the estimated temperature history of the tank up to the time of saltwell pumping. To do this, a model of the tank under the conditions prior to saltwell pumping was created and a transient problem was run recreating an assumed temperature history of the tank prior to saltwell pumping. As no temperature data were available for analysis for most of this time period, an estimation of the temperature history was made. The only parameter that was matched was the maximum predicted temperature of the tank contents with the estimated maximum temperatures; no attempt was made to reproduce the detailed conditions in the tank during this period.

Figure B-5 shows the noding diagram of the tank and its contents as configured for Phase I. Figure B-6 shows the comparison between the predicted maximum temperatures and the assumed maximum temperatures during the Phase I period.

Figure B-5. Noding Diagram for Phase I Analysis.

Note: All dimensions in feet.

Figure B-6. Comparison of Predicted vs. Assumed Maximum Temperatures for Phase I Analysis.

B4.2 PHASE II

Phase II models the tank conditions from saltwell pumping to the present. This phase starts by remodeling the waste tank contents into the configuration that exists at the present time. This consists of altering the waste level to agree with measured data and reconfiguring the regions in the tank describing the waste. This is necessary because the thermal conductivity of the waste during Phase I is considered uniform, being mostly liquid or thoroughly sodden sludge, where the Phase II waste is sludge with varying amounts of liquid in it depending upon depth. These changed regions are necessary to permit description of the waste's varying material properties. The noding diagram of the resulting model is shown as Figure B-7. The soil temperature profiles are determined from the Phase I results and input into the model as an initial condition.

The temperature profile of the waste within the tank at a time just after saltwell pumping is taken from the temperature data and also input as an initial condition. The analysis is run as a transient problem from shortly after saltwell pumping to a time close to the end of the temperature data, iterating on heat load, heat source distribution, and waste thermal conductivities to develop a predicted vertical temperature profile in the waste that matches the data taken at the end of the Phase II period. In order to evaluate the upper and lower

bounds of the heat load and thermal conductivities of the waste contents, the initial temperatures, final temperatures, and soil conductivities are skewed to the limits of their error bands and the analysis is conducted from these points.

The starting waste temperatures for this analysis were the January 29, 1978 data. The first four months of 1978 are shown in Figure B-8. The data are very consistent, with nearly identical shapes. The shapes of the curves suggest that the waste is fairly homogeneous with the heat source placed low in the tank. The position of the waste surface is calculated from the fill history, and is supported by the shape of the vertical temperature profiles.

Figure B-7. Noding Diagram of the Tank and Contents for Phase II Analysis.

Note: All dimensions in feet.

Figure B-8. Tank 241-BY-105 1978 Temperature vs. Height Data.

A comparison of the starting and final temperatures for the Phase II analysis is shown in Figure B-9. It is evident that the effects of the forced ventilation cooling modified the vertical temperature profile at the beginning of the Phase II period. The waste surface level has been taken from measurement data recorded with the temperature data for the first half of 1992. It is lower than the surface level shown in Figure B-8. Measurements and photographs of the waste storage tanks have shown that as the free liquids are pumped out, there is some consolidation of the waste, with attendant level changes. The shape of the 1978 curve shows that there was waste at 4.88 m (16 ft), while the 1992 level data and the 1993 temperatures indicate a waste surface level at 4.50 m (14.75 ft). This is at variance with the published level of 4.81 m (15.9 ft). The cause of the discrepancy is not known; however, the discrepancy does not induce significant errors in the heat load estimations.

Figure B-9. Tank 241-By-105 Beginning and Final Phase II Temperatures.

Nominal Case Results

The analyses used nominal values for soil conductivity and the temperature profile from the January 28, 1978 data for the Phase II analysis as initial conditions, and matched the December 26, 1993 data. For the nominal case, the data were used as described. The results indicated that a heat load of 2.2 kW (7,500 Btu/hr) with waste conductivities of 0.78 W/m-°C (0.45 Btu/hr-ft-°F) in regions 43, 44, and 45 (refer to Figure B-7) which are from 0.70 m (2.3 ft) above the bottom of the tank to the waste surface and 1.12 W/m-°C (0.65 Btu/hr-ft-°F) in regions 40, 41, and 42, which are below 0.70 m above the bottom of the tank, with the heat generation concentrated in the lower 0.70 m of the tank (regions 40, 41, and 42), would match the unaltered December 26, 1993 data. A comparison of the predicted vertical temperature profile using these parameters with the December 26, 1993 data is shown in Figure B-10.

Lower Bound Case Results

For the lower bound case, 3 °F were added to the January 29, 1978 data, the lower bound soil conductivity values were used, and 3 °F were subtracted from the December 26, 1993 data. This skews the temperature data to the limits of the measuring error as explained in Section 3.5 of the main report. These skews require the lowest heat load in the tank in order to match the data. The results indicated that a heat load of 1.8 kW (6,000 Btu/hr) and a waste conductivity of 0.66 W/m-°C (0.38 Btu/hr-ft-°F) in regions 43, 44, and 45, extending

from 0.70 m (2.3 ft) above the tank to the waste surface and a conductivity of 0.87 W/m-°C (0.50 Btu/hr-ft-°F) in regions 40, 41, and 42, the waste below 0.70 m above the bottom of the tank, with the heat generation concentrated in the lower 0.70 m of the tank (regions 40, 41, and 42) would match the skewed December 26, 1993 data. A comparison of the predicted vertical temperature profile using these parameters with the December 26, 1993 data, skewed 3 °F low, is shown in Figure B-11.

Upper Bound Case Results

For the upper bound case, 3 °F were subtracted from the January 29, 1978 temperature data, the upper bound soil conductivities were used, and 3 °F were added to the December 26, 1993 temperatures. These skews require the highest heat load in order to match the final waste temperature data. The results indicated that a heat load of 3.5 kW (12,000 Btu/hr) with waste conductivities of 1.38 W/m-°C (0.80 Btu/hr-ft-°F) in regions 43, 44, and 45, above 0.70 m from the bottom and 1.90 W/m-°C (1.10 Btu/hr-ft-°F) in regions 40, 41, and 42, below 0.70 m from the bottom, with the heat generation concentrated in the lower 0.70 m of the tank (regions 40, 41, and 42) would match the December 26, 1993 data, skewed 3 °F high. A comparison of the predicted vertical temperature profiles using these parameters with the December 26, 1993 data, skewed 3 °F high, is shown in Figure B-12.

Summary of Results

These results are summarized in Tables B-5 and B-6 below.

Table B-5. Heat Loads.

Nominal	2.2 kW	7,500 Btu/hr
Upper Bound	3.5 kW	12,000 Btu/hr
Lower Bound	1.8 kW	6,000 Btu/hr

Table B-6. Thermal Conductivity Thermal Conductivity in W/m-°C.

Case	Region No.					
	40	41	42	43	44	45
Upper bound	1.90	1.90	1.90	1.38	1.38	1.38
Nominal	1.12	1.12	1.12	0.78	0.78	0.78
Lower bound	0.87	0.87	0.87	0.66	0.66	0.66

Figure B-10. Tank 241-BY-105 Nominal Temperature Prediction vs. Data.

Figure B-11. Tank 241-BY-105 Lower Bound Temperature Prediction vs. Data.

Figure B-12. Tank 241-BY-105 Upper Bound Temperature Prediction vs. Data.

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APPENDIX C

TANK 241-BY-105 WASTE HISTORY

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APPENDIX C

TANK 241-BY-105 WASTE HISTORY

C1.0 INTRODUCTION

Tank 241-BY-105 is a (nominal) 753,000-gal tank constructed in 1948-1949 and first filled with bismuth phosphate metal waste from B Plant in 1951. It was the fifth tank in the metal waste cascade BX-104-105-106-BY-104-105, -106. It appears the tank never overflowed metal waste to the BY-106 tank as planned; the metal waste was sluiced from BY-105 for uranium recovery in 1954 (the tank was declared empty in October 1954).

The tank was next used for collecting ferrocyanide sludge settled in the BY farm scavenged uranium recovery waste collection tanks (BY-106, -107, -108, -110). The waste fill/transfer history (Anderson 1990) and ferrocyanide scavenging model (Borsheim and Simpson 1991), indicate that BY-105 contained approximately 227.1 kgals of solids in June 1957 at the end of its ferrocyanide scavenging service. The tank received approximately 283 kgal of aluminum decladding waste in 1961 from tanks 241-C-108 and -107. The solids level was reduced to approximately 162.3 kgal in mid-1966 by a large transfer to the BY-103 tank. Note that in November 1966 some concentrate from in-tank-solidification unit one (ITS-1, then the BY-101 tank) was pumped to BY-105 and Portland cement was added at a ratio of 1.1 lb of cement per gallon of concentrate. The addition was recorded as 63 tons; thus, the concentrate transfer is estimated as approximately 115 kgals. This attempt to solidify the ITS-1 concentrate was unsuccessful.

The liquids/solids inventory measurements in BY-105 are suspect in the time frame 1967 to 1970 while the tank was receiving waste from ITS-1 (then the BY-102 tank). The solids level is believed to have decreased to approximately 96.3 kgals in 1969. The tank was placed in ITS-2 bottoms loop service in August 1970. The bottoms loops tanks received thermally hot concentrate from the ITS-2 tank (BY-112). As the concentrate cooled in the actively ventilated bottoms tank, some salt, (primarily sodium nitrate) crystallized out and settled in the tank. The remaining supernate was pumped out to downstream (lower temperature) bottoms loop tanks where the cooling, crystallization, and settling was repeated. Eventually the remaining supernate was blended with dilute waste and recycled back to the ITS-2 unit via its feed tank (BY-109). In bottoms service, the BY-105 solids inventory rapidly increased and was reported as 600+ kgals in late 1971. This apparently was an erroneous reading due to floating saltcake. (The solids level was adjusted to 503 gal = 190.5 inches = 4.8 m [15.9 ft] in April 1962.) The ITS systems were shut down in 1974 and the BY-105 tank was removed from service. A saltwell was installed in the tank in January 1975 and the tank was P-10 pumped in 1975-1976. The tank has not been jet pumped and thus still contains most of its interstitial liquid.

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