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7. Abstract This report documents a thermal model of tank 241-SY-101 and the surrounding soil column that was used to predict tank temperatures resulting from heating of the annulus ventilation air. Transient results from the model were input to a structural model of the tank for evaluation of the annulus heat-up event. <div style="text-align: center;">APPROVED FOR PUBLIC RELEASE <i>10/11/94/D. Solis</i></div>		
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**THERMAL ANALYSIS OF TANK 241-SY-101 TO
SUPPORT STRUCTURAL ASSESSMENT**

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THERMAL ANALYSIS OF TANK 241-SY-101 TO SUPPORT STRUCTURAL ASSESSMENT

1.0 PURPOSE

The purpose of this report is to document a thermal model of tank 241-SY-101 and a series of transient calculations that simulate heating of the tank annulus ventilation air as a means for controlling tank temperature. Results of the calculations were electronically mapped onto a structural finite-element model for structural evaluation.

2.0 CONCLUSIONS

A comparison of predicted tank waste temperatures with historical measurements extending from the time the tank was completely filled in November 1980 to January 1994 indicate that the axi-symmetric model of the waste tank and surrounding soil column can adequately predict actual tank temperatures.

Predictions with this calibrated model indicate that heating of the tank annulus ventilation air can raise the current average tank waste temperature of 118 °F (January 1994) to 140 °F in less than 6 months.

3.0 MODEL DEVELOPMENT

A previous thermal analysis of tank 241-SY-101 has shown that a rather simple axi-symmetric model of the tank and surrounding soil can duplicate the tank thermal history (Beaver 1994). In addition, predictions with this previous model have indicated that proposed changes to the tank ventilation system can reverse the current tank cooling trend. Among the proposals evaluated in the document was heating of the annulus ventilation air, which was subsequently deemed the most feasible method for heating the tank contents. Initiation of the annulus heating event was expected to induce additional thermal stresses in the concrete and steel liner of the tank. Therefore further development of the concept required that limitations on the annulus air conditions, if any, be established in order to ensure structural integrity of the tank. The previous thermal model of the tank was not considered adequate to provide the structural temperature profiles needed for the stress analysis because of simplifications made to the tank geometry (eg. secondary tank concrete and steel liner was not explicitly modeled). Therefore, this previous thermal model was revised to include a detailed description of the tank geometry. The revised model was developed using the

PATRAN solids modeling program (PATRAN 1990). The resulting model with the appropriate material properties and boundary conditions was input into the P/THERMAL computer code (Valdiviez 1991) for solution.

3.1 Model Geometry

Figure 1 presents the revised model geometry containing tank 241-SY-101 and a cylindrical column of soil extending 70 ft radially outward from the tank centerline and 200 ft down from the surface to the water table. Dimensions for the steel walls of the tank and surrounding concrete structure were taken from drawings for the 241-SY tank farm (H-2-37704 to H-2-37707 and H-2-37772). Further details of the tank model are shown on Figure 2. The tank waste was treated as four separate layers each with differing thermal heat generation and material properties.

3.2 Material Properties

Estimates for the thermophysical properties of the tank waste and surrounding soil were retained from the previous thermal model (Beaver 1994). Concrete and steel properties were obtained from Gillen 1979 and the Nuclear Systems Materials Handbook. Tank ventilation calculations used standard air properties as a function of temperature. Specific material properties used in the analysis are included in Table 1. Note that the effective thermal conductivity for the so called "non-convective layer" of the waste assumes intermittent operation of the present mixer pump.

3.3 Boundary Conditions

Boundary conditions for this revised thermal model are the same as those derived for the previous simplified thermal model (Beaver 1994) except for the annulus ventilation flowrate and inlet temperature. All of the boundary conditions used in the model are described below.

Inlet air to the tank dome ventilation system uses averaged Hanford air temperatures with seasonal variation, as defined in (PNL-1983). These values are applied to the soil surface as well. This seasonal temperature variation is shown on Figure 3. Heat transfer between the ambient air and the soil surface is simulated with an effective heat transfer coefficient of 1.50 Btu/h/ft²/°F. The lower boundary of the model extends to the water table where a fixed temperature of 55 °F is applied. An adiabatic condition is applied to the soil at the 70 ft cylindrical radius. A radioactive heat source (Reynolds 1992) with an exponential decay rate and a time constant of 43.28 yrs. (30 year half-life for ¹³⁷Cs) is used to model the heat source within the waste. As specified in the reference document, slightly different volumetric heating rates are applied to each waste layer in the model.

Heat loss from the surface of the waste includes convection, radiation, and evaporation. Natural convection heat transfer from the waste surface and the dome is modeled using the following empirical correlation:

$$N_u = \frac{hL}{k} = 0.90 Ra^{\frac{1}{3}}$$

Where Ra is the Rayleigh Number with the characteristic length L taken to be 9.375 ft.

Radiation heat transfer between the waste surface and the tank dome is calculated based on geometric view factors determined by the P/THERMAL code and with a surface emissivity of 0.85. A heat-loss-term dependent on the rate of evaporation from the waste surface is also incorporated in the model. This term uses historical ambient temperatures and measured dome ventilation system flow rates to determine the rate of evaporation as a function of surface temperature. Estimates for the evaporation rate are based on the analogy between heat and mass transfer assuming the saturated salt solution of the actual tank waste exhibits a 50% reduction in vapor pressure over that of pure water (Slaathaug 1993). The resulting evaporative heat loss as a function of surface temperature and ventilation flowrate is given in Table 2. A further reduction to the evaporative heat loss term was added to the model to account for those portions of the surface crust that have dried out. A final evaporative loss term which uses 60% of the Table 2 values was used based on results of the previous thermal analysis.

Heat flux between the primary and secondary tank side walls is modeled as a combination of natural convection and thermal radiation. The convective heat transfer calculations use the following expression for natural convection along a vertical flat plate.

$$h = 6.27E-5(Gr Pr)^{1/4} \text{ Btu/hr/ft}^2/\text{°F}$$

The length scale used for the Grashof Number is 34 feet. The local air temperature is used in calculating the Grashof and Prandtl Numbers. Radiation heat transfer between the primary and secondary tank walls is calculated based on geometric view factors determined by the P/THERMAL code and an emissivity of 0.80 at the wall surfaces.

Heat loss from the bottom of the tank is modeled as conduction through the insulating concrete pad and convection to the air distribution slots. These slots, which are imbedded in the concrete pad, distribute the annulus ventilation flow from the center of the tank out to the base of the surrounding annulus. An effective convective heat transfer coefficient of 0.01 Btu/h/ft²/°F is applied to the tank bottom. This value represents an area weighted average for the heat transfer coefficients in the radial distribution slots at the normal annulus ventilation flowrate.

The feasibility of modifying the SY-101 ventilation system to support heating of the annulus air was evaluated by Tuck, 1993. The conclusion of this report is that the upper limit on annulus air temperature would be 200 °F and 800 cfm would be the practical upper limit on annulus air flow rate. These values were used as the upper bounds for this analysis. A constant dome ventilation flowrate of 463 cfm was also assumed. This value represents the current measured value as of January 1994.

3.4 Model Calibration

Previous thermal analysis of SY-101 had indicated that tank temperatures are not in equilibrium with the surrounding soil and hence initial conditions still influence current tank temperatures. Therefore the temperature field for September 2 1992 for the tank, the waste and the surrounding soil column from previous calculations was mapped onto the current model to provide a set of initial conditions. A transient was then run from September 2 1992 to January 1 1994 and the final results compared with temperature measurements from the Multi-Functional Instrument Tree (MIT) in Riser 17B for that day. The comparison is shown on Figure 4 and indicates good agreement between measurement and prediction. The predicted temperature field for the entire tank and surrounding soil is shown on Figure 5. All subsequent tank heating transients were initiated from the temperatures predicted for January 1 1994.

4.0 Annulus Heating Results

The ground rules established for these calculations was to heat the tank waste as rapidly as possible to an upper limit of 140 °F while maintaining annulus air flow and air temperature within the specified boundary conditions (800 cfm and 200 °F). The structural analysis would then use the calculated temperatures to determine limits, if any, to operation of the annulus ventilation system. Based on these ground rules two limiting operating conditions for the annulus ventilation system were simulated. The first condition assumes an annulus air inlet temperature of 140 °F at a flowrate of 800 cfm. The second condition assumes a 200 °F annulus inlet air temperature until the tank waste reaches 140 °F and then resets it to 140 °F. Annulus air flow for this condition is maintained fixed at 800 cfm. Temperature results from these two operating conditions are described below.

4.1 140 °F Inlet Temperature

An inlet temperature to the tank annulus ventilation ducting of 140 °F was expected to eventually bring the tank waste to approximately that same temperature. The thermal gradients resulting from the change in annulus inlet conditions was expected to be less than those for a 200 °F inlet temperature. Therefore, this event was considered a fall-back condition if the structural analysis of the 200 °F inlet case indicated a problem. The initial conditions assumed a step change in air flowrate from 200 cfm to 800 cfm and a step change in inlet temperature to the tank from ambient to 140 °F. Transient results at all 1476 thermal nodes in the model were electronically mapped onto the ABACUS structural model of the tank using the PATRAN software. In

addition, temperatures histories at selected locations in the structure were plotted and are shown in Figures 6 through 8.

The average waste temperature for this event was calculated at the MIT location in the tank and is shown on Figure 6. These predictions indicate that a 140 °F annulus inlet temperature will heat the tank waste to 140 °F in approximately 21 months. Temperatures in the concrete at the base of the tank near the center are shown on Figure 7. Shown are the predicted temperatures at the upper surface of the insulating concrete, the bottom of the insulating concrete and at the bottom of the secondary concrete where it interfaces with the soil. The temperature gradient across the concrete is seen to increase by approximately 2 °F. Structural temperatures at the lower knuckle of the tank are shown on Figure 8. These temperatures indicate the gradient across the secondary tank concrete at the base (joint between the slab and the side wall) and on the side wall approximately 3 feet above the base. The through-wall temperature gradient in this region is seen to increase by approximately 2 °F also.

4.2 200 °F Inlet Temperature

An inlet temperature of 200 °F to the tank annulus ventilation ducting is the rated temperature for the current ventilation system components and appears to be the practical upper limit for operation (Tuck 1993). Initial conditions for this operating event assumed that the inlet air temperature and flowrate were increased by a step-change to 200 °F and 800 cfm respectively. This represents the maximum heatup rate achievable with this method. Since waste temperatures were to be limited to approximately 140 °F the annulus air inlet temperature was stepped to this temperature when the average waste temperature reached 140 °F. Air flow rate was maintained constant at 800 cfm. Again, the transient results for this case were electronically mapped onto the ABACUS structural model of the tank using the PATRAN software. Temperatures histories at selected locations in the structure were plotted and are shown below.

Average waste temperatures for the event are shown on Figure 9 and indicate heatup of the tank waste to 140 °F in approximately 5 months. The resulting temperature through the concrete slab near the center of the tank are shown on Figure 10. For this case the maximum concrete gradient increased from approximately 3 °F to 6 °F in roughly 20 days. Structural temperatures at the lower knuckle are shown on Figure 11. Maximum concrete temperatures are shown to reach 160 °F before cooling back off as the annulus inlet air temperature is decreased to 140 °F. The maximum through-the-wall gradient is approximately 11 °F. Temperatures in the secondary tank near the haunch region are shown on Figure 12. The temperature gradient in this region increases by approximately 6 °F before decreasing again as the annulus air inlet temperature is lowered.

The conclusion that the tank structure is capable of accommodating these operating conditions is included in the structural report (Watts 1994).

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Nuclear Systems Materials Handbook, 1979, TID 26666, Oak Ridge National Laboratory, Oak Ridge Tennessee.

Table 1. Material Properties.

Thermophysical properties	Constant value
Soil	
Thermal conductivity	0.330 Btu/(h ft °F)
Density	98.0 lb _m /ft ³
Specific heat	0.44 Btu/(lb _m °F)
Insulating Concrete	
Thermal conductivity	0.150 Btu/(h ft °F)
Density	80.0 lb _m /ft ³
Specific heat	0.20 Btu/(lb _m °F)
Concrete	
Thermal conductivity	0.95 Btu/(h ft °F)
Density	141.0 lb _m /ft ³
Specific heat	0.2105 Btu/(lb _m °F)
Structural Steel	
Thermal conductivity	29.8 Btu/(h ft °F) (a function of temperature)
Density	489.0 lb _m /ft ³
Specific heat	0.116 Btu/(lb _m °F)
Tank Waste - Crust	
Thermal conductivity	0.43 Btu/(h ft °F)
Density	82.24 lb _m /ft ³
Specific heat	0.53 Btu/(lb _m °F)
Tank Waste - Convective Layer	
Thermal conductivity	2.0 Btu/(h ft °F)
Density	97.97 lb _m /ft ³
Specific heat	0.62 Btu/(lb _m °F)

Tank Waste - Non Convective layer	
Thermal conductivity	1.3 Btu/(h ft °F)
Density	106.08 lb _m /ft ³
Specific heat	0.53 Btu/(lb _m °F)
Tank Waste - Bottom Layer	
Thermal conductivity	0.47 Btu/(h ft °F)
Density	106.08 lb _m /ft ³
Specific heat	0.53 Btu/(lb _m °F)

Table 2. Surface Heat Flux Based on an Average Latent Heat for Water.

Surface Temperature °F	Air flow rate cfm			
	100	300	500	800
70	0.11879	0.31531	0.48023	0.66875
80	0.29791	0.78143	1.2223	1.77334
90	0.54450	1.47473	2.27419	3.29738
100	0.87837	2.38776	3.69081	5.38395
110	1.31859	3.60691	5.60026	8.18568
120	1.90557	5.22677	8.23526	11.91984
130	2.68034	7.36899	11.483	16.8602
140	3.70404	10.20395	15.92983	23.44883
150	5.05995	13.97384	21.81947	32.18925
160	6.87654	19.03138	29.74267	43.934

NOTE: Heat flux is given in terms of Btu/h ft² and that the assumed average latent heat for water is 1,000 Btu/lb_m.

MODEL GEOMETRY

TANK 241-SY-101

Figure 1. Model Geometry.

TANK MODEL

Figure 2. Tank Geometry.

Figure 3. Average Ambient Air Temperature.

Figure 4. Waste Temperature Comparison.

Figure 5. Initial Temperature Profile.

Figure 6. Average Waste Temperature for 140 °F Inlet Air.

Figure 7. Concrete Temperature at Bottom for 140 °F Inlet Air.

Figure 8. Concrete Temperature at Tank Knuckle for 140 °F Inlet Air.

Figure 9. Average Waste Temperature for 200 °F Inlet Air.

Figure 10. Concrete Temperature at Tank Bottom for 200 °F Inlet Air.

Figure 11. Concrete Temperature at Tank Knuckle for 200 °F Inlet Air.

Figure 12. Concrete Temperature in Tank Dome for 200 °F Inlet Air.