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Page 1 of 1
1. EDT 605519

2. To: (Receiving Organization) Distribution		3. From: (Originating Organization) TWRS Thermal Hydraulics		4. Related EDT No.: N/A	
5. Proj./Prog./Dept./Div.: MWTF		6. Cog. Engr.: E. R. Cramer		7. Purchase Order No.: N/A	
8. Originator Remarks: For Review and release.				9. Equip./Component No.: N/A	
				10. System/Bldg./Facility: N/A	
11. Receiver Remarks:				12. Major Assm. Dwg. No.: N/A	
				13. Permit/Permit Application No.: N/A	
				14. Required Response Date: September 30, 1994	

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-W236A-ER-010		0	Multi-Function Waste Tank Facility Thermal Hydraulic Analysis for Title II Design	SQ	1,2	2	

16. KEY					
Approval Designator (F)		Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)		1. Approval	4. Review	1. Approved	4. Reviewed no/comment
		2. Release	5. Post-Review	2. Approved w/comment	5. Reviewed w/comment
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(G)	(H)	17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)				(G)	(H)
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Document Number: WHC-SD-W236A-ER-010, REV. 0

Document Title: Multi-Function Waste Tank Facility Thermal Hydraulic Analysis for Title II Design

Release Date: 11/10/94

**This document was reviewed following the
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MULTI-FUNCTION WASTE TANK FACILITY
THERMAL HYDRAULIC ANALYSIS
FOR TITLE II DESIGN

October 1994

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Issued by
WESTINGHOUSE HANFORD COMPANY
for the

U.S. DEPARTMENT OF ENERGY
RICHLAND FIELD OFFICE
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**MULTI-FUNCTION WASTE TANK FACILITY
THERMAL HYDRAULIC ANALYSIS
FOR TITLE II DESIGN**

1.0 INTRODUCTION

The purpose of this work was to provide the thermal hydraulic analysis for the Multi-Function Waste Tank Facility (MWTF) Title II design. Temperature distributions throughout the tank structure were calculated for subsequent use in the structural analysis and in the safety evaluation. Calculated temperatures of critical areas were compared to design allowables. Expected operating parameters were calculated for use in the ventilation system design and in the environmental impact documentation.

The design requirements were obtained from the MWTF Functional Design Criteria (FDC) (Groth, 1994). The most restrictive temperature limit given in the FDC is the 200 °F limit for the haunch and dome steel and concrete. The temperature limit for the rest of the primary and secondary tanks and concrete base mat and supporting pad is 250 °F. Also, the waste should not be allowed to boil. The tank geometry was taken from ICF Kaiser Engineers Hanford drawing ES-W236A-Z1, Revision 1, included here in Appendix B. Heat removal rates by evaporation from the waste surface were obtained from experimental data (Crea, 1994).

2.0 CONCLUSIONS

1. The MWTF tank cooling system will meet the design temperature limits for the design heat load of 700,000 Btu/h, even if cooling flow is lost to the annulus region.
2. Temperatures change very slowly during transients due to the high heat capacity of the tank structure and the waste. Accordingly, transients will not be a significant operational problem from the viewpoint of meeting the specified temperature limits.

3.0 DESCRIPTION OF COMPUTER MODEL

3.1 MODEL GEOMETRY AND INPUT DATA

A two-dimensional axisymmetric model of the tank and surrounding soil column was used to model an MWTF tank. The input to the computer model for all of the analyzed cases is listed in Cramer, 1994. The tank dimensions were taken from ICF Kaiser Engineer Hanford drawing ES-W236A-Z1, Revision 1. Schematics of the thermal model are shown in Figures 1 and 2.

The thermal model was developed by the use of the PATRAN modeling program (PATRAN 1990) and solved with associated programs P/THERMAL and P/VIEWFACTOR. These programs are all proprietary products of PDA Engineering that have been validated (Valdiviez, 1991). PATRAN was used for pre- and post-processing. It is a geometry model builder with the capability to define associated

boundary conditions in a discretized fashion that can be used by an analysis code. P/Thermal was used as the finite element thermal solver that transforms the finite element based problem description from PATRAN into an equivalent network description. It has the capability to add other heat transfer boundary conditions such as thermal radiation and convection/advection terms to the model description. P/VIEWFACTOR is an adjunct program to P/THERMAL that defines radiation view factors based solely on geometric considerations. The view factors are defined based on the discretized geometry developed by PATRAN.

The concrete pad on which the primary tank sits, the concrete surrounding the secondary liner, and the steel walls of the primary tank and secondary liner were all included in the model. The air flow in the annulus region between the primary tank and secondary liner and the air flow in the space between the waste surface and the tank dome were included in the model.

Also included in the model is a cylindrical column of soil extending 70 ft radially outward from the tank centerline and 200 ft down from the soil surface to the water table. A 70 ft radius for the model was chosen because the MWTF tanks are planned to be 120 ft apart, center to center. Accordingly, 70 ft is approximately the distance to the adiabatic boundary between tanks. This radius is conservative for minimizing the heat loss calculated from the tanks because the sides of the tank facing away from the other tanks will not actually have an adiabatic boundary. For the tank filling transient the model radius was increased to 130 ft. This is conservative in this case because the temperature gradient across the tank structure is more critical to the structural analysis than the absolute temperature during the filling transient. The larger model radius increases the available heat flow path away from the tank which increases the temperature gradient in the tank structure.

Heat transfer by radiation and convection across the air space between the primary and secondary tanks and from the waste surface to the primary tank dome and walls was included in the model. The radiation and convection models in the tank dome change as the level of waste in the tank changes.

The model of the waste in the tank was divided into 37 layers which can be sequentially added or removed to simulate tank filling or draining. The properties of each layer can be specified separately if required, e.g., to model particle settling conditions as described in Section 4.3.

The heat transfer to the channels under the tank was simulated with an effective overall heat transfer coefficient; individual channels were not modeled. Consequently, the circumferential variations in temperature in the concrete pad caused by the placement of the cooling channels were not calculated. This simplification will not introduce significant error since the amount of heat loss through the bottom of the tank is small.

The variables having the largest effect on the transient results and also having the largest uncertainties are the density and heat capacity of the waste. The value used for the density of the mixed waste was 82.2 lb/ft³ and the value used for the heat capacity of the mixed waste was 1.0 Btu/lb-F (Willingham, 1994). The thermal conductivity of the waste was arbitrarily set high enough to cause the maximum temperature difference between any two points

in the waste to be less than 5 °F. This high thermal conductivity simulates the effect of the mixing pump.

For the loss-of-electric-power case the solid particles that are suspended in the waste during normal operation are all assumed to settle to the bottom. Separate values of the density and heat capacity were required for the settled solids and for the supernatant. The density and heat capacity of the settled solids were assumed to be 96.1 lb/ft³ and 0.07 Btu/lb-F, respectively (Willingham, 1994). The density and heat capacity of the supernatant were assumed to be 75 lb/ft³ and 0.58 Btu/lb-F, respectively, which are conservative lower bound values for the supernatant. The heat capacity of the mixed waste was reduced to a conservative value of 0.396 Btu/lb-F so that the heat capacity of all of the mixed waste would equal the sum of the heat capacities of the supernatant and the settled solids.

Material properties of the tank structure, the waste, and the surrounding soil are given in Appendix A.

3.2 MODEL BOUNDARY CONDITIONS

The heat removal rate from the waste surface by evaporation was obtained from test data as described in Crea 1994. The tests were performed in a 6.25:1 scale test facility that is prototypic of an MWTf tank. The test data that were collected with the simulated waste at a vapor pressure of 55% of that of pure water (45% vapor pressure suppression) were used, except for the cases used as input to the structural analysis and as noted for six of the steady-state cases. Preliminary test results from these data were used in this analysis and are shown in Appendix C. The waste surface heat fluxes shown in Appendix C were input in tabular form as a function of the waste surface temperature.

The bottom surface of the tank is cooled by channels cut in the concrete supporting pad. The flow through these channels is turbulent and the heat transfer coefficients in these channels were calculated from the following turbulent channel flow correlation (McAdams, 1954):

$$Nu = 0.023 (Re)^{.8} (Pr)^{.33}$$

where: Nu, Re, and Pr are the dimensionless Nusselt number, Reynolds number, and Prandtl number, respectively. The Nusselt and Reynolds numbers are based on the hydraulic diameter.

Individual channels in the concrete pad were not modeled. Instead, the channel heat transfer coefficients were adjusted to account for the fraction of the tank bottom surface that is in contact with the flow channels. The adjusted heat transfer coefficients were then used in the model as effective coefficients for the tank bottom surface. Part of the tank bottom has 16 parallel channels, part of it has 32 parallel channels, and part of it has 64 parallel channels. A drawing of the tank bottom supporting pad is shown in Appendix B. Different heat transfer coefficients were used for the three parts of the tank bottom surface as follows:

Number of parallel channels	Channel heat transfer coefficient	Effective heat transfer coefficient
16	3.06 Btu/h-ft ² -F	0.99 Btu/h-ft ² -F
32	1.76	0.27
64	1.01	0.19

The average velocity of the flow through the annulus between the primary and secondary tanks is 0.030 ft/s but the local velocity near the walls due to free convection is calculated to be up to 6 ft/s. Therefore, the flow pattern and the heat transfer are controlled by free convection. Accordingly, the heat transfer coefficient was calculated from an equation recommended for free convection flow over a vertical plate (McAdams, 1954). This equation is:

$$Nu = .13(Ra)^{.33}$$

where: Nu is the Nusselt number and Ra is the Rayleigh number. A characteristic length of 30 ft was used in the Nusselt and Rayleigh numbers, but it cancels out anyway.

The heat transfer coefficient for the tank dome and the waste surface was arbitrarily set at a constant 1.0 Btu/h-ft²-F. The heat transfer coefficient at the ground surface was also arbitrarily set at 1.0 Btu/h-ft²-F. The results show that this heat transfer coefficient has a negligible effect on the solution since the ground surface temperature is within 4 °F of the ambient air temperature for all simulated conditions.

The emissivity of the tank walls facing the annulus region was set at 0.8 (GE, 1973). The emissivity of the tank dome and waste surface was set at 0.9, slightly higher than in the annulus region since the corrosive effect of the waste is expected to increase the emissivity of these surfaces (Larrick, 1994).

The ambient air temperature was set at the site maximum monthly average of 77 °F (Cloud, 1994a, included in Appendix E) and the temperature of the water table 200 ft below the soil surface was arbitrarily set at 55 °F. The radial boundary of the cylindrical column of soil was adiabatic.

Figure 1. Model Geometry.

Figure 2. MWTf Tank Model Geometry.

4.0 DISCUSSION OF RESULTS

Three cases were analyzed for input to the structural analysis: a steady-state case, a tank filling transient, and a tank draining transient. Nine other steady-state cases were analyzed for environmental impact and ventilation design information and four other transients were analyzed for safety evaluation and operational information. The latter four transients bound the results of all anticipated transient events.

4.1 STEADY-STATE CASES

For the steady-state case that was used in the structural analysis, the heat removal rate due to evaporation from the waste surface was reduced until the results showed a maximum temperature of 200 °F in the haunch region. This method provided the design basis temperatures for input to the structural analysis but it was not intended to provide the expected tank operating temperatures. Tank operating temperatures for the design basis conditions are lower than those used in the structural analysis. The temperature results were mapped onto the structural model of the tank and were transmitted electronically to ICF Kaiser Engineers Hanford for use in the structural analysis. Figure 3 shows these temperatures for the tank and part of the surrounding soil. Figure 4 is a close-up view of the same temperatures in the haunch region. These results were also used as the initial condition for the tank drain analysis.

In order to obtain the desired maximum temperature of 200 °F for the structural analysis case, the heat removal rate due to evaporation was reduced by 36% from the evaporation test results shown in Appendix C. These test results were obtained with simulated waste at a vapor pressure of 55% of that of pure water. Air flow rates through the tank annulus region and through the tank dome were kept at the design values of 1100 scfm and 500 scfm, respectively (Cloud, 1994b, included in Appendix E). The heat load to the waste was the Extreme Case value of 700,000 Btu/hr as specified in the FDC (Groth, 1994). Other boundary conditions were also kept at the design values.

In addition to the above structural analysis case, nine other steady-state cases were also analyzed and the input and results for these nine cases are summarized in Table 1. Case 1 is the design basis case for the tank cooling systems. The heat load for this case is the Extreme Case heat load of 700,000 Btu/hr, as specified in the FDC (Groth, 1994). The heat removal rate due to evaporation was obtained from test data (Crea, 1994) with the simulated waste at a vapor pressure of 55% of that of pure water. This case was used as the initial condition for all of the transient cases, except the tank filling and draining transients.

The maximum temperature in the haunch region for the design basis case was calculated to be 187 °F or 13 °F less than the 200 °F limit specified in the FDC. The maximum tank wall temperature was calculated to be 189 °F or 61 °F less than the 250 °F limit specified in the FDC. As in all of the steady-state cases, the waste temperature at the surface of the waste is virtually the same as the maximum haunch temperature. All of the calculated temperatures for the design basis case are shown in Figures 5, 6, and 7.

Case 2 used the nominal case heat load of 110,00 Btu/hr as specified in the FDC. This heat load is more typical of what the MWTF tanks will have most of the time. All other input parameters for Case 2 are the same design basis parameters as for Case 1. The waste temperature is calculated to be 109 °F for this case, compared to 187 °F for Case 1.

Case 3 is the same as Case 2 except that the air flow rate through the tank was reduced to 300 scfm. The evaporation from the waste is nearly in proportion to the air flow rate (Crea, 1994), so the evaporative heat removal is less and the resulting temperatures are all a little higher.

The vapor pressure of the waste was increased to that of pure water (zero vapor pressure suppression) for Cases 4 through 9. This is the upper limit for the waste vapor pressure that is expected in the MWTF tanks and results in a much higher evaporative heat removal rate. Cases 4 and 5 were analyzed with an air inlet temperature of 53 °F which is the average annual temperature at Hanford (Stone, 1983). Cases 6 and 7 show the effect of using the maximum monthly average temperature for Hanford of 77 °F.

Cases 8 and 9 use a tank heat load of 40,000 Btu/hr and the calculated waste temperatures are only 69 °F and 64 °F, respectively, with an air inlet temperature of 53 °F. The evaporation heat removal rates are based on test data ranging from 100 °F to 200 °F (Crea, 1994). Consequently the evaporation rates for these two cases are based on an extrapolation of the test data and may not be as accurate as the other cases.

For all of the steady-state calculations, the tank is in thermal equilibrium with the surrounding soil but, in actual fact, the tank will never be in thermal equilibrium. Diurnal effects, seasonal effects, and the long-term effect of heating the soil around the tank will all have an effect on the results given in Table 1, especially for Cases 8 and 9 with low heat loads.

Figure 3. Steady-State Temperatures for use in Structural Analysis, °F.

Figure 4. Steady-State Temperatures for use in Structural Analysis - Haunch Region Detail, °F.

Figure 5. Steady-State Temperatures for Design Basis Case - Entire Model, °F.

Figure 6. Steady-State Temperatures for Design Basis Case, °F.

Figure 7. Steady-State Temperatures for Design Basis Case - Haunch Region
Detail, °F.

Table 1. MWTf Steady-State Analysis Results
(Excluding Structural Analysis Case).

<u>Input Parameters</u>	Design Basis <u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
Tank Heat Load (Btu/hr)	700,000	110,000	110,000
Waste Vapor Pressure Suppression	45%	45%	45%
Annulus Flow Rate (scfm)	1100	1100	1100
Vapor Space Flow Rate (scfm)	500	500	300
Tank Inlet Air Temp (°F)	77	77	77
Annulus Inlet Air Temp (°F)	77	77	77
Inlet Air Humidity Ratio (lb _{H2O} /lb _{air})	0.003	0.003	0.003
<u>Calculated Parameters</u>			
Waste Temp (°F)	187	109	118
Vapor Space Air Temp (°F)	178	106	116
Annulus Outlet Temp (°F)	186	108	117
Evaporation Rate (lb/hr)	472	46	36
Evaporation Heat Removal (Btu/hr)	482,000	47,000	37,000
Annulus Heat Removal (Btu/hr)	130,000	37,000	48,000
Vapor Space Air Heat Removal (Btu/hr)	55,000	16,000	13,000
Heat loss to Soil (Btu/hr)	33,000	10,000	12,000
Vapor Space Humidity Ratio (lb _{H2O} /lb _{air})	0.212	0.023	0.030
Waste Vapor Pressure (in. Hg)	9.80	1.39	1.79

Table 1. MWTf Steady-State Analysis Results (continued).

<u>Input Parameters</u>	<u>Case 4</u>	<u>Case 5</u>	<u>Case 6</u>
Tank Heat Load (Btu/hr)	110,000	110,000	110,000
Waste Vapor Pressure Suppression	0%	0%	0%
Annulus Flow Rate (scfm)	1100	1100	1100
Vapor Space Flow Rate (scfm)	300	500	300
Tank Inlet Air Temp (°F)	53	53	77
Annulus Inlet Air Temp (°F)	53	53	77
Inlet Air Humidity Ratio (lb _{H2O} /lb _{air})	0.003	0.003	0.003
<u>Calculated Parameters</u>			
Waste Temp (°F)	93	88	104
Vapor Space Air Temp (°F)	91	85	102
Annulus Outlet Temp (°F)	93	87	103
Evaporation Rate (lb/hr)	37	42	61
Evaporation Heat Removal (Btu/hr)	38,000	43,000	62,000
Annulus Heat Removal (Btu/hr)	48,000	41,000	31,000
Vapor Space Air Heat Removal (Btu/hr)	12,000	17,000	8,000
Heat loss to Soil (Btu/hr)	12,000	9,000	9,000
Vapor Space Humidity Ratio (lb _{H2O} /lb _{air})	0.030	0.022	0.048
Waste Vapor Pressure (in. Hg)	1.56	1.33	2.18

Table 1. MWTF Steady-State Analysis Results (continued).

<u>Input Parameters</u>	<u>Case 7</u>	<u>Case 8</u>	<u>Case 9</u>
Tank Heat Load (Btu/hr)	110,000	40,000	40,000
Waste Vapor Pressure Suppression	0%	0%	0%
Annulus Flow Rate (scfm)	1100	1100	1100
Vapor Space Flow Rate (scfm)	500	300	500
Tank Inlet Air Temp (°F)	77	53	53
Annulus Inlet Air Temp (°F)	77	53	53
Inlet Air Humidity Ratio (lb _{H2O} /lb _{air})	0.003	0.003	0.003
<u>Calculated Parameters</u>			
Waste Temp (°F)	98	69	64
Vapor Space Air Temp (°F)	96	68	63
Annulus Outlet Temp (°F)	97	69	64
Evaporation Rate (lb/hr)	68	12	19
Evaporation Heat Removal (Btu/hr)	69,000	12,000	19,000
Annulus Heat Removal (Btu/hr)	24,000	19,000	13,000
Vapor Space Air Heat Removal (Btu/hr)	10,000	5,000	5,000
Heat loss to Soil (Btu/hr)	7,000	4,000	3,000
Vapor Space Humidity Ratio (lb _{H2O} /lb _{air})	0.033	0.012	0.011
Waste Vapor Pressure (in. Hg)	1.82	0.71	0.60

4.2 FILLING AND DRAINING TRANSIENTS

The tank filling and draining transients were analyzed to provide input to the structural analysis. The initial tank filling transient causes the highest temperature gradients of any transient event. The input heat removal rate due to evaporation was the same as that used in the steady-state case that was used in the structural analysis. This heat removal rate is 36% less than the expected heat removal rate, as discussed in Section 4.1, but it provided the design basis temperatures for input to the structural analysis.

The temperature results were mapped onto the structural model of the tank and were transmitted electronically to ICF Kaiser Engineers Hanford for use in the structural analysis. Temperature results were calculated for 3,000 hours (125 days) of each transient. Complete records of the temperatures throughout the model were transmitted to KEH for the following times during each transient:

- Once per hour from 0 to 140 hours
- Once every 10 hours from 150 to 400 hours
- Once every 200 hours from 600 to 3,000 hours

A total heat load of 700,000 Btu/hr was used in the analyses (Groth 1994). Of this amount, 250,000 Btu/hr was assumed to be due to radioactive decay heating for a full tank. Accordingly, the decay heat load of 250,000 Btu/hr was reduced during the drain and fill transients such that it was in proportion to the amount of waste in the tank. The remaining 450,000 Btu/hr was assigned to pump heating and contingency and was conservatively assumed to be added to the waste as long as the pumps are operating, regardless of the level in the tank.

Air flow rates of 1100 scfm through the annulus and 500 scfm through the tank dome were used in the analysis (Cloud, 1994b). The air inlet temperature was assumed to be a constant 77 °F (Cloud, 1994a) and the air inlet humidity ratio was assumed to be 0.003.

4.2.1 Tank Filling Transient

The tank filling transient was started from the initial steady-state condition that is expected at the time of the first tank fill. This was calculated by assuming that the ambient air temperature was the site maximum monthly average of 77 °F and that the temperature of the water table 200 ft below the ground surface was at 55 °F. More soil surrounding the tank was added to the model for the filling transient and the soil thermal conductivity was increased to 0.8 Btu/hr-ft-F. This conductivity is representative of the cold moist soil that is expected to surround the tank at the time of the initial tank fill (Shannon and Wilson, 1993). The larger radius model and the larger thermal conductivity of the soil increased the temperature gradient in the tank structure which will produce the highest stress.

The waste was assumed to enter the tank at 200 °F and at a rate of 160 gpm (Groth, 1994). This results in a liquid level change of 0.29 ft/hr or 6.97 ft/day. The mixer pumps were conservatively assumed to come on at full power when the level of the waste reached 5 ft. It was assumed that the tank was filled to the maximum waste volume of 1,160,000 gallons. All cooling

systems were assumed to be in operation during the entire transient and the evaporation rate was assumed to not change with changing tank waste level.

The results show that the waste quickly cools to 190 °F and remains at that temperature as the tank is filling. After the tank is full, it eventually reaches an equilibrium temperature of 200 °F. The maximum temperature change rate in the secondary tank during tank filling is 2.0 °F/hr in the wall region and 0.7 °F/hr in the haunch region.

4.2.2 Tank Drain Transient

The initial condition for the tank drain analysis was the steady-state case that was used for the structural analysis (see Section 4.1). This is conservative because it assumes that the tank is drained from the highest temperature steady-state case. The drain analysis assumed that waste is pumped out at 160 gpm from the equilibrium condition, which empties the tank in 120 hours. The mixing pumps were assumed to be turned off when the level in the tank reached 5 ft. All cooling systems were assumed to be operating during the entire transient.

Pumping out the waste continued until the waste level in the tank reached 12 inches at the tank center. After the rest of the waste was pumped out, the conductivity of the remaining 12 inches of waste was conservatively changed to 0.5 Btu/h-ft-F which is representative of the conductivity of settled solids.

4.3 LOSS OF ALL ELECTRIC POWER TRANSIENT

This case assumed that all electric power is lost to the mixing pumps and to the cooling systems. The initial condition for the transient was the design basis (Case 1) steady-state result discussed in Section 4.1. The transient was analyzed for 300 hours which should be sufficient time to restore electric power.

The heat load was set at 250,000 Btu/h which is the radioactive decay part of the Extreme Case heat load (Groth, 1994). When the tank is filled to the maximum level of 1,160,000 gallons, this is equivalent to 1.6123 Btu/hr-ft³. It was assumed that all of this heat load resides with the solid particles and that these particles would settle to the bottom 32% of the tank in one week (168 hours). This is conservative compared to the settling time of 360 hours that was calculated using waste property data from tank 101-SY (Chang and Beaver, 1993). It is also conservative to assume that all of the heat load resides with solid particles because some of the existing waste tanks have an appreciable amount of the decay heat in the supernatant (Willingham, 1994). The particle settling was simulated by having the heat load change linearly over a period of 168 hours from the initial condition of a uniform distribution in the entire tank to being concentrated in the bottom 32% of the tank.

The density of the waste in the top 68% of the tank was changed from 82.2 lb/ft³ to 75 lb/ft³ and the heat capacity was changed from 0.396 Btu/lb-F to 0.58 Btu/lb-F. The density of the waste in the bottom 32% of the tank was changed from 82.2 lb/ft³ to 96.1 lb/ft³ and the heat capacity was changed from

0.396 Btu/lb-F to 0.07 Btu/lb-F. These parameters were changed linearly during the first 168 hours of the transient.

The conductivity of the top 68% of the waste was set at 110 Btu/h-ft-F during the entire transient. The results show that this is high enough to simulate the effect of convective currents in the liquid waste, i.e., the temperature gradients in the top 68% of the waste are less than 5 °F. The conductivity of the bottom 32% of the waste was changed linearly from 110 Btu/h-ft-F to 0.6 Btu/h-ft-F between 100 hours and 200 hours into the transient. A conductivity of 0.6 Btu/h-Ft-F is representative of the conductivity of settled solids (Willingham, 1994).

The tank temperatures are shown in Figures 8 through 11 for various times during the transient and the critical tank temperatures are shown in Figure 12. Notice that the tank haunch temperature increases to 192 °F in 300 hours which is still within the 200 °F limit. The maximum temperature of the primary tank wall increases to 218 °F in 300 hours which is also within the 250 °F tank wall limit. The maximum temperature of the waste increases slowly until about 200 hours, when the thermal conductivity of the settled solids is assumed to reach the minimum of 0.6 Btu/h-ft-F. The temperature of the settled solid waste then increases quickly because of the conservative assumptions made about settling time and the effective thermal conductivity. Although the settled solid waste was calculated to reach 250 °F in approximately 10 days, this is much longer than a reasonable time required to restore electric power. The time to reach 250 °F would be much longer if the particle settling time of 360 hours that was calculated from tank 101-SY data were used or if some of the heat load were assumed to be in the supernatant.

4.4 LOSS OF COOLING FLOW TRANSIENTS

Two loss-of-flow events were analyzed. These are the loss of tank dome flow and the loss of annulus flow. In each case, a complete loss of the cooling capability of that particular system was postulated due to an unspecified equipment failure.

Due to the large heat capacity of the waste, the temperatures increase very slowly when one of the cooling systems is lost. The most critical temperature is the primary tank wall temperature in the haunch region and this is plotted in Figure 13. For both cases, the maximum temperature of the waste and the maximum temperature of the tank walls remain just a few degrees higher than the haunch temperature because the mixing pump is conservatively presumed to continue operating at full power during the transients.

These calculations assumed a tank heat load of 700,000 Btu/hr, a tank dome air flow rate of 500 scfm at steady-state, and an annulus air flow rate of 1100 scfm at steady-state. The initial condition for the transient was the design basis (Case 1) steady-state result discussed in Section 4.1.

When the tank dome air flow stops the evaporative cooling of the waste also ceases. Accordingly, the loss of flow in the tank dome is a more severe transient than the loss of annulus flow. As shown in Figure 13, the maximum temperature in the haunch region reaches 200 °F about 300 hours (12.5 days)

after the loss of air flow in the tank dome and it reaches 207 °F about 500 hours (3 weeks) after the loss of air flow in the tank dome.

After the loss of annulus flow, the maximum temperature in the haunch region reaches 190 °F after about 500 hours (three weeks). A steady-state analysis of the tank without annulus flow shows that the maximum haunch temperature would eventually come to equilibrium at 194 °F and the maximum primary tank wall temperature would eventually reach 197 °F. Therefore all of the temperature limits would still be met even if the annulus flow were out of service indefinitely and the mixing pump were to operate continuously.

4.5 POSTULATED EARTHQUAKE EVENT

The expected response to a severe earthquake with a loss of all electric power is the same as the response to the loss of electric power event discussed in Section 4.3. This section addresses the response to the so-called "Smartquake" which is selective enough to disable all of the cooling systems while leaving the mixing pump running. It is further assumed that the tank operators do not stop the mixing pump so the heat input to the tank remains at the Extreme Case value of 700,000 Btu/hr. The initial condition for the transient was the design basis (Case 1) steady-state result discussed in Section 4.1. The waste remains fully mixed because the mixing pump is running.

The most critical temperature is the primary tank wall temperature in the haunch region which is plotted in Figure 14. This temperature is predicted to reach the design limit of 200 °F about 250 hours (~10 1/2 days) after the cooling systems are disabled. This should be ample time for the tank operators to reduce the heat load by shutting off the mixing pump. If the mixing pump continues to run and the heat load remains at the Extreme Case value, the maximum haunch temperature is predicted to reach 211 °F in about 500 hours (~3 weeks)

The tank dome temperature is calculated to be a few degrees less than the maximum haunch temperature throughout the transient and the primary tank wall temperature will be just a few degrees higher than the haunch temperature. All temperature gradients within the tank will be small because the mixing pump is presumed to continue running.

Figure 8. Initial Condition Temperatures for Loss of Electric Power
Transient, °F.

Figure 9. Temperatures 100 Hours after Loss of all Electric Power, °F.

Figure 10. Temperatures 200 Hours after Loss of all Electric Power, °F.

Figure 11. Temperatures 300 Hours after Loss of all Electric Power, °F.

Figure 12. Loss Of All Electric Power

**Figure 13. Maximum Temperature in Haunch Region
During Loss of Flow Transients**

**Figure 14. Maximum Temperature in Haunch
Region After Earthquake**

5.0 REFERENCES

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Appendix A. Properties of Materials.

Appendix A. Properties of Materials.

	<u>Thermal Conductivity</u> <u>Btu/hr-ft-F</u>	<u>Density</u> <u>lb/ft³</u>	<u>Heat Capacity</u> <u>Btu/lb-F</u>
Concrete	0.6	144.0	0.20
Soil	0.35	98.0	0.23
Waste	---	82.2	1.0

Steel Plate Properties
(AISI 1025 Carbon Steel)

<u>Temperature, °F</u>	<u>Thermal Conductivity</u> <u>Btu/hr-ft-F</u>	<u>Density</u> <u>lb/ft³</u>	<u>Heat Capacity</u> <u>Btu/lb-F</u>
32	29.99	489.0	0.116
70	29.89	489.0	0.116
100	29.76	489.0	0.116
200	29.22	489.0	0.116
300	28.52	489.0	0.116

Air Properties

<u>Temperature, °F</u>	<u>Thermal Conductivity</u> <u>Btu/hr-ft-F</u>	<u>Density</u> <u>lb/ft³</u>	<u>Heat Capacity</u> <u>Btu/lb-F</u>	<u>Viscosity</u> <u>lb/ft-hr</u>
32	0.0140	0.0810	0.240	0.0419
100	0.0154	0.0710	0.240	0.0463
200	0.0174	0.0600	0.241	0.0518
300	0.0193	0.0520	0.243	0.0580

**Appendix B. Drawings of Structural Tank Cross Section
and Supporting Pad Plan.**

R ENCLOSURE

ANNULUS PUMP PIT

HAUNCH DETAIL

$\frac{3}{4}'' = 1'-0''$

SECONDARY
CONCRETE
STRUCTURE

BASE DETAIL

$\frac{3}{4}'' = 1'-0''$

200 EAST/200 WEST

6
CS-11
1994

PRELIMINARY

NOT APPROVED FOR CONSTRUCTION

DESIGNED BY L. K. MILLER		CHECKED BY	
DRAWN BY		DATE	
APP'D BY		DATE	
SCALE		DATE	
SHEET NO.		SHEET TOTAL	
U.S. DEPARTMENT OF ENERGY RICHLAND FIELD OFFICE KAISER ENGINEERS MANFORD COMPANY STRUCTURAL TANK CROSS SECTION			
PROJECT NO. W-236A, W-236B, W-236C, W-236D, W-236E, W-236F, W-236G, W-236H, W-236I, W-236J, W-236K, W-236L, W-236M, W-236N, W-236O, W-236P, W-236Q, W-236R, W-236S, W-236T, W-236U, W-236V, W-236W, W-236X, W-236Y, W-236Z			
F 2-3 JC 8-37		ESW236AZ001 1	
SCALE		DATE	

2 PLOT SCALE: 1:1 KENCAD

B-1

INSULATING/SUPPORTING PAD PLAN

SCALE: 1/4"=1'-0"

SUMMARY TABLE FOR AIR FLOWS

LOCATION	FLOW (cfm)	VELOCITY (fps)
LEAK DET. PIPE	80.1	27.2
SLOTS (EA.)		
A	63.7	30.6
B	31.9	15.3
C	15.9	8.7

Rev. O.

B-2

**Appendix C. Preliminary Evaporation Test Results Used
in MWTF Thermal Analysis.**

(2D) II Print II 30 Jun 1995 II corr.plt II RESULTS FROM CORRELATING MWTF EVAPORATIVE TEST DATA

MWTF LATENT HEAT REMOVAL (90-150F)

MWTF LATENT HEAT REMOVAL (150-200F)

Appendix D. Nomenclature.

Appendix D. Nomenclature.

Nu = dimensionless Nusselt number, hL/k

Re = dimensionless Reynolds number, $\rho vL/\mu$

Pr = dimensionless Prandtl number, $c_p\mu/k$

Ra = dimensionless Rayleigh number, $c_p\rho^2g\beta (T-T_b)L^3/\mu k$

c_p = specific heat at constant pressure

g = acceleration of gravity

h = convection heat transfer conductance

k = thermal conductivity

L = characteristic length

T = fluid temperature at surface

T_b = temperature of bulk of fluid

v = velocity

β = temperature coefficient of volume expansion

ρ = mass density

μ = absolute viscosity

Appendix E. MWTF Design Position Papers.

**KAISER
ENGINEERS
HANFORD**

W-236A-470

KAISER ENGINEERS HANFORD COMPANY
POST OFFICE BOX 888
RICHLAND, WASHINGTON 99352

REG. NO. KAISEEH134BM

May 4, 1994

Mr. G. G. Renfro, Manager
Project Engineering
Multi-Function Waste Tank Facility
P. O. Box 1970
Richland, Washington 99352

Dear Mr. Renfro:

PROJECT W-236A "MULTI-FUNCTION WASTE TANK FACILITY"
TANK INLET AIR TEMPERATURE POSITION PAPER

Please find attached six copies of the approved Tank Inlet Air
Temperature Position Paper.

Should you have any questions, please advise.

Sincerely,

J. D. Cloud
Project Manager

JDC:plb

Attachment

cc: G. D. O'Brien (w/o Att.)
G. R. Konzek
G. M. Ramin

Position Paper
Project W236A
Multi-Function Waste Tank Facility
Tank Inlet Air Temperatures

Prepared By:	<u><i>G. K. Goolsby</i></u>	<u>4/22/94</u>
	G. K. Goolsby, ICF KH/HVAC Engineering Discipline	Date
Concurrence:	<u><i>G. G. Renfro</i></u>	<u> </u>
	G. G. Renfro, WHC/Mgr., MWTF Project Engineering	Date
Concurrence:	<u><i>R. L. Fritz</i></u>	<u>4-28-94</u>
	J. M. Light, WHC/Mgr., MWTF Tech. Studies/Proj. Int.	Date
Concurrence:	<u><i>T. B. McCall</i></u>	<u>5/3/94</u>
	T. B. McCall, WHC/Mgr., Thermal Hydraulics Analysis	Date
Concurrence:	<u><i>T. C. Oten</i></u>	<u> </u>
	T. C. Oten, ICF KH/MWTF Engineering Manager	Date
Concurrence:	<u><i>J. R. Nicholson</i></u>	<u>4/27/94</u>
	J. R. Nicholson, ICF KH/MWTF Consulting Engineer	Date
Concurrence:	<u><i>J. D. Cloud</i></u>	<u>4-27-94</u>
	J. D. Cloud, ICF KH/MWTF Project Manager	Date
Concurrence:	<u><i>R. L. Fritz</i></u>	<u>4-25-94</u>
	R. L. Fritz, WHC/MWTF Project Manager	Date

Position Paper
Project W236A
Multi-Function Waste Tank Facility
Tank Inlet Air Temperatures

1.0 Purpose

The purpose of this paper is to document the project's position on the design inlet air temperature of the heat removal system for the waste storage tanks currently being designed by project W-236A, the Multi-Function Waste Tank Facility (MWTF).

2.0 Background

The Title I Design primary tank heat removal system consists of two systems:

- 1) A primary tank vapor space ventilation system
- 2) An annulus ventilation system

The primary system provides a substantial part of the tank's cooling capacity. The system passes air through the vapor space above the liquid waste in the tanks, thus removing and diluting harmful or potentially explosive vapors. In the process, both sensible and latent heat are removed; sensible heat due to the temperature differential between the inlet/outlet air and the tank waste, and latent heat from vapors evolved from the waste by evaporation.

The annulus ventilation system airflow provides both leak detection and sensible heat removal capabilities. Cooling system heat removal efficiency (both primary and annulus) is dependent on the inlet air temperature.

3.0 Discussion

The following discussion describes the basis for the design inlet air temperature. The primary and annulus systems draw air from the Weather Enclosure. The temperature within the Weather Enclosure is regulated to a maximum of 90° F and minimum of 40° F. Preliminary analysis of the MWTF Weather Enclosure shows a parallel correlation between average monthly inside air temperature patterns and average monthly outside air temperature patterns. Therefore, the average monthly outside air temperature can be used to provide a conservative representation of average inlet air temperatures (to the waste tanks).

Attachment A shows a breakdown of monthly average outside air temperatures taken from Bin data provided in the Hanford Plant Standard for Heating, Ventilation, and Air Conditioning (ref 1). The average yearly air temperature is approximately 53° F. However, the Bin data shows a peak average outside air temperature in July of approximately 77° F, well above the yearly average of 53° F. In addition, the Bin data indicates that the average outside temperature is above 53° F for a 5-month period from May through September.

The 5-month period that the average outside air temperature is above the yearly average temperature of 53° F is a significant factor in determining the design inlet air temperature. For example, preliminary calculations indicate that the primary ventilation system air flow rate required to maintain the tank waste temperature at 190° F is 399 scfm, using the following input values:

- Heat load 700,000 Btu/hr
- Annulus air flow 1,100 scfm
- Design inlet air temperature 53° F
- Design inlet air relative humidity 40% RH
- Tank waste temperature 190° F

Raising the design inlet air temperature to the maximum monthly average temperature of 77° F at the same primary ventilation rate of 399 scfm (all other inputs as defined above) reduces the total heat removed to 645,000 Btu/hr. In order to remove the same amount of heat (i.e., 700,000 Btu/hr), airflow at 77° F would have to be increased to 455 scfm. Repeating the calculation using the maximum hourly design temperature of 101° F (refs 1&3) further reduces the heat removed to 577,000 Btu/hr. At 101° F, airflow would have to be increased from 399 to 540 scfm to attain to the same heat removal levels achieved at 53° F. The results shown here illustrate that a cooling shortage is predicted any time the inlet air temperature rises above the yearly average of 53° F.

To evaluate the change in waste temperature with respect to time using a higher inlet air temperature, another calculation was prepared by ICF Kaiser Hanford (ICF KH) (see Attachment B). The calculation shows the waste temperature increasing by 3° F (from 190° F to 193° F) in a 45-day period due to the reduced cooling capacity when the design inlet air temperature climbs from 53° F to 77° F. (It should be noted that 3° F is also the maximum increase in tank waste temperature predicted by the empirical calculations when the inlet air temperature is increased from 53° F to 77° F.). The same hand calculation shows that an inlet air temperature of 101° F results in a 7° F tank waste temperature rise in a 45-day period.

These results indicate that if the primary ventilation system is sized using 53° F as the design inlet air temperature, the waste may exceed the tank operating temperature limit of 190° F. This could occur if waste is transferred into the tanks during the months of May through September, when the average temperature exceeds 53° F. Use of the higher inlet temperature of 101° F is also not considered reasonable since this is the maximum hourly temperature for the hottest day and will not continue for 45 days. By definition, the maximum monthly average temperature (77° F) is expected to occur for 45 days. Using the monthly average outside air temperature of 77° F provides a margin of safety in the design without adding unnecessary conservatism.

4.0 Conclusions and Recommendations

For optimum performance and efficiency, the MWTF primary and annulus ventilation systems require a steady-state inlet air design temperature. In selecting the appropriate steady-state temperature for design, a level of conservatism is necessary to ensure that ventilation system capacities are adequate for proper waste temperature control. The average monthly outside air temperature (i.e., 77° F) provides a reasonable safety margin without being too conservative.

Based on the preceding discussion, ICF KH concludes that the MWTF project should use an inlet air temperature of 77° F as its cooling system design temperature basis.

5.0 References

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2. *Analysis of Tank Bump Potential During In-Tank Washing Operations Proposed for the 241-AZ Tanks*, WHC-SD-WM-ER-114 Rev. 0.
3. *General Design Criteria*, DOE 6430.1A

Attachments

Attachment A
SDC-5.1 Bin Data Averages

		AVG		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		TEMP													
		RANGE													
105	109	107		0	0	0	0	0	0	4	3	0	0	0	0
100	104	102		0	0	0	0	0	4	19	14	0	0	0	0
95	99	97		0	0	0	0	1	14	41	31	4	0	0	0
90	94	92		0	0	0	0	7	30	63	54	13	0	0	0
85	89	87		0	0	0	1	14	43	76	71	27	1	0	0
80	84	82		0	0	0	4	29	68	100	94	47	6	0	0
75	79	77		0	0	0	13	49	86	110	109	67	14	0	0
70	74	72		0	0	4	26	78	112	113	117	96	30	1	0
65	69	67		0	1	11	47	105	116	99	111	114	56	1	0
60	64	62		1	7	36	87	124	113	72	85	124	91	11	1
55	59	57		8	19	77	118	122	83	35	41	108	114	30	8
50	54	52		29	51	118	141	113	40	11	12	73	140	74	20
45	49	47		45	83	150	127	67	10	1	2	33	131	112	41
40	44	42		74	121	149	97	28	1	0	0	11	89	157	82
35	39	37		112	144	102	44	7	0	0	0	3	48	135	120
30	34	32		160	139	62	13	0	0	0	0	0	18	115	186
25	29	27		127	57	24	2	0	0	0	0	0	5	50	128
20	24	22		83	24	8	0	0	0	0	0	0	1	19	90
15	19	17		47	11	3	0	0	0	0	0	0	0	7	34
10	14	12		30	7	0	0	0	0	0	0	0	0	4	14
5	9	7		17	3	0	0	0	0	0	0	0	0	1	6
0	4	2		7	3	0	0	0	0	0	0	0	0	0	5
-5	-1	-3		3	1	0	0	0	0	0	0	0	0	0	2
-10	-6	-8		1	0	0	0	0	0	0	0	0	0	0	2
AVG MONTHLY TEMP				30.97	37.73	45.33	52.82	61.64	70.32	76.97	75.52	65.64	52.95	40.1	31.63

Attachment B

Tank Temperature Use Calculation

The following calculation shows the time duration required to affect a tank waste temperature rise of approximately 3 F.

Assume:

Tank volume (approx) = 1,000,000 gallons

Specific gravity (approx avg) = 1.2

Specific heat (approx) = 1.0

Using the results of the empirical correlations with inputs as follows:

399 scfm primary ventilation flow rate
1100 scfm annulus ventilation flow rate
40% relative humidity

Heat removal at 53 F inlet air temperature (primary and annulus) = 700,000 Btu/hr

Heat removal at 77 F inlet air temperature (primary and annulus) = 645,000 Btu/hr

(Heat removal shortage) Difference = 55,000 Btu/hr

Heat removal shortage for 24 hour period = $H_{short} := 55000 \cdot 24$

$H_{short} = 1.32 \cdot 10^6$ Btu/day

Tank contents mass = 1,000,000 gallons (Sg = 1.2) (ft³ / 7.48 gallons)

Mass := 1000000 · (62.4 · 1.2) · 1.337

Mass = $1.001 \cdot 10^7$ lbs Where: $C_p := 1.0$ $\Delta T := 3$

Using the heat transfer equation $Q := m \cdot C_p \cdot \Delta T$ $m := \text{Mass}$

Solve the following:

(Heat load shortage Btu/day) / (193 F - T F / 3 F) dt = $m \cdot C_p$ dT

$440,000(193 - T) dt = 10,010,000 dT$

$0.044 dt = 1/(193 - T) dT$ Let $193 - T = x$

$-0.044 dt = dx/x$ $e := 2.7183$

$-0.044 t = \ln x$ $t := 45$ time = 45 days

$x := C_0 \cdot e^{-0.044t}$ At $t = 0$, $x = 3$, $C_0 := 3$

$x = 0.414$

$T := 193 - x$

$T = 192.59$

$\Delta T_{final} := T - 190$

$\Delta T_{final} = 2.6$ Degree F temperature change in 45 day period

Say approximately 3 degrees F

~~A-2~~

**KAISER
ENGINEERS
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W-236A-472

KAISER ENGINEERS HANFORD COMPANY
POST OFFICE BOX 888
RICHLAND, WASHINGTON 99352

REG. NO. KAISEEH134BM

May 5, 1994

Mr. G. G. Renfro, Manager
Project Engineering
Multi-Function Waste Tank Facility
Westinghouse Hanford Company
P. O. Box 1970
Richland, Washington 99352

Dear Mr. Renfro:

PROJECT W-236A "MULTI-FUNCTION WASTE TANK FACILITY"
TANK VENTILATION SYSTEM DESIGN AIR FLOW RATES POSITION PAPER

Please find attached six copies of the approved Tank Ventilation System
Design Air Flow Rates Position Paper.

Should you have any questions, please advise.

Sincerely,

J. D. Cloud
Project Manager

JDC:plb

Attachment

cc: G. D. O'Brien (w/o Att.)
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Position Paper
Project W236A
Multi-Function Waste Tank Facility
Tank Ventilation System Design Air Flow Rates

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Position Paper
Project W-236A
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Tank Ventilation System Design Air Flow Rate

1.0 Purpose

The purpose of this paper is to document a project position on required ventilation system design air flow rates for the waste storage tanks currently being designed by project W-236A, the Multi-Function Waste Tank Facility (MWTF).

2.0 Background

The Title I design primary tank heat removal system consists of two systems:

- 1) A primary tank vapor space ventilation system
- 2) An annulus ventilation system

At the conclusion of Title I design, air flow rates for the primary and annulus ventilation systems were 960 scfm and 4400 scfm, respectively, per tank (ref 1). These design flow rates were capable of removing 1,250,000 Btu/hr from each tank (ref 2). However, recently completed and ongoing studies have resulted in a design change to reduce the extreme case heat load to 700,000 Btu/hr. This revision of the extreme case heat load, coupled with results of scale model evaporative testing performed by WHC Thermal Hydraulics (ref 3), allow for a reduction of the design air flow rates for both primary and annulus ventilation systems.

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3.0 Discussion

The air flow rates for both the primary and annulus ventilation systems are determined by the heat removal requirements. The revised extreme case heat removal requirements (ref 4) are listed as follows:

- Mixer Pump 382,500 Btu/hr
- Radionuclide 250,000 Btu/hr
- Contingency 67,500 Btu/hr
- Total 700,000 Btu/hr

These reduced heat loads allow for lower air flow rates through both the primary and annulus ventilation systems. Required air flow rates for the MWTF design were determined using empirical correlations (ref 5). The empirical correlations were modified using evaporation rate data obtained from tank scale model testing provided by WHC Thermal Hydraulics. The empirical correlations are incorporated into a computer code originally developed for analysis of the 241-AZ tank ventilation system (ref 5). Computer code verification of the empirical correlations will be performed as part of the Title II design effort. Preliminary analysis using modified empirical correlations specify that approximately 455 scfm of primary ventilation air flow is required to maintain the tank waste temperature at 190°F using the following inputs:

- Heat load 700,000 Btu/hr
- Design inlet air temperature 77° F
- Design relative humidity 40% RH
- Annulus air flow 1,100 scfm

A safety factor of approximately 10% was applied to the primary air flow rate (455 scfm), as predicted by the modified empirical equations. This results in a maximum design air flow rate for the primary ventilation system of 500 scfm (an approximately 48% reduction from the Title I design air flow rate of 960 scfm). This reduction in the design heat load allows for a larger proportion of the total heat removal to be performed by the primary ventilation system (as opposed to the annulus ventilation system). With an air flow of 500 scfm, the primary ventilation system will be able to remove approximately 605,000 Btu/hr without assistance from the annulus ventilation system.

ICF KH selected a maximum design air flow rate of 1,100 scfm for the annulus ventilation system to enable the primary ventilation system air flow rate to be regulated to a maximum of 500 scfm. The annulus design air flow reduction from the Title I design rate of 4400 scfm to 1100 scfm allows for the removal of the annulus circular header, distribution piping, and the annulus supply fans, and for the downsizing of the annulus system.

Design air flow rates for the heat removal system are based on the ability to provide adequate cooling at the extreme case heat load (as defined in ref 4). Limited control of tank waste temperature at the nominal heat load (ref 4) is possible using variable air volumes in the ventilation systems.

4.0 Conclusions and Recommendations

Based on the preceding discussion, ICF Kaiser Hanford Co. (ICF KH) concludes that the design should incorporate the following design air flow rates:

- Primary ventilation system: 500 scfm maximum
- Annulus ventilation system: 1100 scfm maximum.

In addition, the minimum air flow rates in the primary and annulus ventilation systems will be investigated during Title II design. The results of the Title II investigation will determine the range of available temperature control using variable air flows to both ventilation systems.

5.0 References

1. Title I Design Report, *Multi-Function Waste Tank Facility*, WHC-SD-W236A-RPT-002, Rev. 0, prepared by ICF Kaiser Hanford Company, February 1994.
2. Functional Design Criteria, *Multi-Function Waste Tank Facility*, WHC-SD-W236A-FDC-001, Rev. 1, prepared by Westinghouse Hanford Company, October 1993 (draft).
3. Internal Memo, B. A. Crea (WHC Thermal Hydraulics) to J. M. Light (WHC), *Design Values from the Evaporation Test*, 7E870-BAC-94-045, April 11, 1994.
4. Groth, B. D. , Position Paper, *Project W-236A Tank Heat Loading*, Rev. 1. March 30, 1994.
5. *Analysis of Tank Bump Potential During In-Tank Washing Operations Proposed for the 241-AZ Tanks*, WHC-SD-W-E-114 Rev. 0, prepared by Westinghouse Hanford Company, (date).