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EVAPORATION ANALYSIS FOR TANK SX-104

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October 1994

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EVAPORATION ANALYSIS FOR TANK SX-104

1.0 INTRODUCTION

An evaporation analysis of tank SX-104 was requested by Shift/Surveillance Engineering to determine if the measured decrease in the interstitial liquid level (ILL) was consistent with a level decrease due to evaporation. This report documents the evaporation analyses that were performed for tank SX-104.

Tank SX-104 has a porous crust over its surface. The evaporation analyses documented by the following sections utilize a methodology first developed for tanks SX-103 and SX-106 (Claybrook 1993), which was later modified to account for the diffusion of water vapor through a porous crust and applied to tanks SX-105 (Heard 1993) and SX-102 (Wood 1993).

2.0 EXECUTIVE SUMMARY

A methodology based on parallel evaporation and diffusion paths of water vapor from a free liquid surface and through a porous crust, respectively, was used to estimate the total evaporation loss rate (in./yr) from tank SX-104. The results of this analysis indicate that the decrease in the ILL can be attributed to evaporation. However, the modeling sensitivities associated with some of the assumed physical properties and dimensions are large. To improve confidence in the data used for this analysis, a new photograph of the crust should be taken.

3.0 DATA

A 1988 composite photograph of the surface of SX-104 was obtained. This photograph indicates that the crust is not uniform and smooth. It shows an off-white, lumpy, and cracked surface near the tank wall where the angle of sight is small. Some cracks near the tank wall contain dark material which could be liquid just below the level of the upper crust surface.

Toward the center of the tank, where the camera view is closer to perpendicular to the waste surface, dark islands appear. However, by visually comparing neighboring regions of the composite photograph, it is apparent that the contrast of features on the surface of the waste are exaggerated as the view approaches the waste surface normal, making it difficult to discern areas

of open liquid, if any. A discussion with a photographer who photographs tank waste surfaces confirms this interpretation. However, jagged lines of colored material are visible in the photograph in the central region of the crust, indicating that salt solutions have entered cracks there, evaporated, and left deposits.

Based upon the above information, the waste crust must be considered as discontinuous, with a small fraction of open liquid surface.

Information provided by Shift/Surveillance Engineering is as follows:

Ventilation flow rate:	60 cfm
Crust thickness:	12-18 inches
Peak temperature:	170 °F
Historical level data:	Plotted in Figure 1

The crust thickness has been estimated through the level observation differences between the Food Instrument Corporation (FIC) gauge and liquid observation well (LOW) data as 13 inches (see Figure 1); this value will be used in evaporation calculations.

4.0 DESCRIPTION AND RESULTS OF THE TANK THERMAL ANALYSIS

There are six thermocouples located axially from 4 inches to 366 inches above the bottom of the tank. Thermocouple No. 1 is inoperable. Thermocouple No. 2 is 2 feet 4 inches above the bottom of the tank. The sixth thermocouple is located within the air space, 366 inches (approximately 30.5 feet) above the bottom of the tank. Temperature data near the liquid waste-to-crust interface (approximately 20 feet above the bottom of the tank) is not available. Figure 2 presents the thermocouple data through 1992.

From (Heard 1993), the temperature profile within tank SX-105 is very similar to the profile within tank SX-104. The geometry and waste volume of tank SX-105 are also very similar to tank SX-104. Tank SX-105 also has a crust, which is similar in appearance to the crust in tank SX-104. Temperature data for tank SX-104 is compared with corresponding data for tank SX-105 in Figure 3. Temperatures in tank SX-104 average 28 degrees cooler than temperatures in tank SX-105.

Figure 1. Historical SX-104 Level Data.

Figure 3. Comparison of SX-104 and SX-105 Thermocouple Data.

Due to the similarity between tanks SX-104 and SX-105, the thermal analysis used for tank SX-105 will be relied upon. The results of that thermal analyses indicate an average liquid waste-to-crust interface temperature of 125 °F in tank SX-105. Because temperatures in tank SX-104 average 28 degrees lower, the waste-to-crust interface temperature in tank SX-104 is estimated as 97°F.

5.0 DESCRIPTION OF CRUST DIFFUSION EVAPORATION MODEL

A numerical model based on the diffusion of water vapor through a porous crust was used to estimate the evaporation losses from SX-105 (Heard 1993). This model was reused here for tank SX-104. The subject model was derived from an analytical mass transport model. A numerical model was originally developed (Claybrook 1993) from this analytical model to calculate evaporation from actively ventilated tanks with a free liquid surface. This numerical model was recently revised to incorporate diffusion through a porous crust (Heard 1993). The following paragraphs highlight the derivation of the crust diffusion model.

The diffusion of water vapor into an air volume from a porous crust involves the mass transfer of water vapor from the crust surface into the air by eddy diffusion and the transfer of water from the ILL through the crust by molecular diffusion. Figure 4 illustrates these processes.

The mass transfer rate from the ILL through the crust to the crust surface is;

$$\dot{m}_D = \frac{D}{\Delta X} A (C_s - C_c) \quad (1)$$

Where, $\dot{m}_D$ = mass transfer rate (lbm/h)
D = diffusion coefficient through the crust (ft²/h)
 ΔX = distance from ILL level to surface of crust (ft)
A = surface area (ft²)
 C_c = concentration at crust surface (lbm/ft³)
 C_s = concentration at water surface (lbm/ft³)

Figure 4. Mass Diffusion and Transport Processes for the Crust Diffusion Model.

The mass transfer rate from the crust surface into the air is (Claybrook 1993);

$$\dot{m}_D = h_D A (C_c - C) \quad (2)$$

Where, $\dot{m}_D$ = mass transfer rate (lbm/h)
 h_D = eddy diffusion mass transfer coefficient
 $= 0.039 V_s \text{Re}^{-0.206} \text{Sc}^{-1.5}$ (ft/h)
 A = surface area (ft²)
 C_c = concentration at crust surface (lbm/ft³)
 C = concentration in tank air/vapor volume (lbm/ft³)
 V_s = velocity of air across the crust surface (ft/h)
 Re = Reynolds number ($\rho V_s L / \mu$) (dimensionless)
 Sc = Schmidt number ($\mu / \rho D$) (dimensionless)
 ρ = density of air (lbm/ft³)
 μ = viscosity of air (lbm/ft-h)
 D = diffusion coefficient of water vapor through the crust (ft²/h)
 L = characteristic length (ft)

Setting equations 1 and 2 equal to one another and solving for C_c yields;

$$C_c = \frac{h_D C + \frac{D}{\Delta X} C_s}{(h_D + D/\Delta X)} \quad (3)$$

The following mass conservation equation accounts for the water vapor transported out of tank SX-104 through the ventilation system:

$$(Q_i \times C_{AMB}) - (Q_o \times C) + (h_D A (C_c - C)) = \text{Vol} \times dC/dt \quad (4)$$

Where, Q_i = volumetric flow rate into the tank (ft³/min)
 Q_o = volumetric flow rate out of the tank (ft³/min)
 C_{AMB} = ambient atmospheric water vapor concentration (lbm/ft³)
 Vol = tank air/vapor volume (ft³)
 dC/dt = time rate of change for the vapor concentration within the tank volume (lbm/ft³-h)

Substituting equation 3 into 4 yields;

$$Q_i C_{AMB} - Q_o C + h_D A \left(\frac{(h_D C + \frac{D}{\Delta X} C_s)}{(h_D + \frac{D}{\Delta X})} - C \right) = \text{Vol} \frac{dC}{dt} \quad (5)$$

Casting equation 5 in implicit finite difference form yields;

$$Q_i C_{AMB} - Q_o C^{j+1} + \frac{h_D^2 A C^{j+1}}{(h_D + \frac{D}{\Delta X})} + \frac{h_D \frac{D}{\Delta X} A C_s}{(h_D + \frac{D}{\Delta X})} - h_D A C^{j+1} = \frac{Vol C^{j+1}}{\Delta t} - \frac{Vol C^j}{\Delta t} \quad (6)$$

Where, the superscript j refers to the old time value and j+1 refers to the new time value. Rearranging equation 6 yields;

$$C^{j+1} = \frac{C^j \frac{Vol}{\Delta t} + Q_i C_{AMB} + \frac{h_D \frac{D}{\Delta X} A C_s}{(h_D + \frac{D}{\Delta X})}}{\frac{Vol}{\Delta t} + Q_o + h_D A - \frac{h_D^2 A}{(h_D + \frac{D}{\Delta X})}} \quad (7)$$

Taking the limit of equation 7 as Δt approaches infinity, yields;

$$C^{j+1} = \frac{Q_i C_{AMB} + \frac{h_D \frac{D}{\Delta X} A C_s}{(h_D + \frac{D}{\Delta X})}}{Q_o + h_D A - \frac{h_D^2 A}{(h_D + \frac{D}{\Delta X})}} \quad (8)$$

which gives the steady-state concentration of the tank air/vapor volume. Dividing the right hand side numerator and denominator of equation 7 by $Vol/\Delta t$ yields;

$$C^{j+1} = \frac{C^j + B_1 \Delta t}{1 + A_1 \Delta t} \quad (9)$$

$$\text{Where } A_1 = \frac{\left(Q_o + h_D A - \frac{h_D^2 A}{(h_D + \frac{D}{\Delta X})} \right)}{Vol}$$

$$B_1 = \frac{\left(Q_i C_{AMB} + \frac{h_D \frac{D}{\Delta X} A C_s}{(h_D + \frac{D}{\Delta X})} \right)}{Vol}$$

Taking the limit of equation 9 as Δt approaches 0 yields;

$$C^{j+1} = C^j \text{ (as expected).}$$

The crust diffusion model as described by equation 7 was translated to computer code and compiled for an 80386 microprocessor. The resulting program (WVPCRUSTR) incorporates a tank schematic similar to Figure 4 to aid the user in preparing the input. The WVPCRUSTR program was verified and validated as part of the SX-102 evaporation analyses (Wood 1993).

The following paragraphs discuss the methodology to convert from a volumetric to a linear loss rate.

The ILL loss rate can be obtained by dividing the volumetric loss rate by the surface area of the crust. However, since the crust is partially solid and is fixed by supporting solids, the ILL is a function liquid volume, but the elevation of the crust surface is not.

Porosity (ϕ) can be defined as the volume of interstitial liquid (V_i) over the liquid-saturated volume (V_t).

$$\phi = \frac{V_i}{V_t} = \frac{V_i/\Delta t}{V_t/\Delta t} = \frac{\dot{V}_i}{\dot{V}_t} \quad (10)$$

The rate of change in the interstitial liquid level is related to the rate of change in liquid volume by:

$$\dot{V}_i = A_t * \phi * \dot{L} \quad (11)$$

Where,

- $\dot{L}$ = ILL loss rate
- $\dot{V}_i$ = estimated liquid volume loss rate,
- A_t = total surface area of tank
- ϕ = assumed liquid porosity value of 35%.

(The 35% porosity value is consistent with current pumping practices.)

Therefore,

$$\dot{L} = \dot{V}_i / (A_t * \phi) \quad (12)$$

6.0 EVAPORATION RESULTS AND REFERENCE INPUT

Tank SX-104 has a porous crust over its surface. As discussed in Section 3.0 the crust appears to have cracks which could be liquid. Therefore, the mass-transfer model must consider parallel paths: diffusion through the crust and evaporation from open liquid surfaces.

The crust diffusion model and WVPCRUSt calculational procedure described in Section 5.0 was used to estimate the evaporation rates and corresponding liquid level decreases for tank SX-104. The following paragraphs document the "best-estimate" reference input values and present the results of the reference analyses.

To use the crust diffusion model, it is necessary to know the internal tank temperatures, ventilation system flow rates, surface areas available for evaporation and diffusion, and air velocities at the crust's surface. Ambient temperatures, pressure, and relative humidity are also required. The partial pressure of water over the waste solution is specified as a fraction of the pure water vapor pressure. The following "best estimate" data was used to determine a reference mass loss rate from tank SX-104;

Crust Diffusion Input

<u>Liquid Waste Data:</u>	Temperature,	97°F
<u>Diffusion Path Data:</u>	Surface Area,	4376 ft ² (99%)
	Air Velocity across the crust,	0.2 ft/sec
	Characteristic Length,	37.5 ft (tank radius)
	Crust Thickness,	1.08 ft
	Diffusion Coefficient,	0.017 ft ² /hr
<u>Tank Air Space Data:</u>	Temperature,	82.6°F
	Volume (Above Waste),	83,100 ft ³
	Outlet Flow,	60 cfm
<u>Ambient Atmospheric Data:</u>	Temperature,	54°F
(Hanford Average)	Pressure,	14.35 psia
	Relative Humidity,	42 %
<u>Vapor Pressure Multiplier:</u>	Vpr,	0.72
	(saturated sodium nitrate solution)	

Pool Evaporation Input

<u>Liquid Waste Data:</u>	Temperature,	97°F
<u>Evaporation Path Data:</u>	Surface Area,	44 ft ² (1%)
	Air Velocity across the surface,	0.2 ft/sec
	Characteristic Length,	37.5 ft (tank radius)
	Crust Thickness,	small (1E-6 ft)
	Diffusion Coefficient,	large (10 ⁶ ft ² /hr)
<u>Tank Air Space Data:</u>	Temperature,	82.6°F
	Volume (Above Waste),	83,100 ft ³
	Outlet Flow,	60 cfm

Ambient Atmospheric Data: Temperature, 54°F
(Hanford Average) Pressure, 14.35 psia
Relative Humidity, 42 %

Vapor Pressure Multiplier: Vpr, 0.72
(saturated sodium nitrate solution)

With the exception of three of the above data pieces, all were obtained from reference tank dimensions, tank thermocouple data, and previous analyses (Claybrook 1993 and Heard 1993).

The exceptions are the vapor pressure multiplier, which accounts for the reduction in water vapor pressure over saturated aqueous salt solutions, the diffusion coefficient of water through the crust, and the crust thickness. The vapor pressure multiplier, diffusion coefficient, and the crust thickness were estimated as follows;

- o Dean 1985, Table 10-25, provides a vapor pressure reduction multiplier versus temperature for saturated aqueous solutions in contact with an excess of a definite solid phase of various salts. Since a solid crust is present, a saturated solution at the interface between the liquid waste and the crust was assumed. Based on a saturated sodium nitrate (NaNO_3) solution and a predicted interface temperature of 97 °F, a vapor pressure reduction multiplier of 0.72 was input to WVPCRUSt. Figure 5 presents the vapor pressure reduction multipliers as a function of temperature for a saturated solutions of sodium nitrate and sodium nitrite (NaNO_2).
- o No diffusivity values for water through salt cake could be located. Values for concrete have been previously been used successfully (Heard 1993). However, (Claybrook and Muhlestein 1984), Section 5.2.3, provides the following equation for calculating the diffusion coefficient of water through concrete as a function of temperature and pressure:

$$D = 5.386 \times 10^{-4} \frac{(T + 460)^{1.75}}{P} \quad (13)$$

Where:

D = diffusivity (ft^2/hr)
T = temperature (°F)
P = pressure (psf)

The value of the diffusion coefficient of water through concrete was calculated to be 0.017 for 97 °F and 14.35 psia. Figure 6 presents the diffusion coefficient for concrete as a function of temperature. It was expected that the use of a diffusion coefficient for concrete would result in a conservative estimate of the amount of evaporation losses from tank SX-104. The actual diffusion coefficient may differ by an order of magnitude.

Figure 5. Water Vapor Pressure Depression for Saturated Solutions of Sodium Nitrate and Sodium Nitrite.

Figure 6. Diffusion Coefficient for Water through Concrete.

- o The crust thickness was determined to be approximately 13 inches. This value was derived from the difference between FIC surface level readings and the ILL level as discussed in Section 3.0. The crust surface level was determined from FIC readings through the first half of 1991.

A steady-state mass loss rate of 0.11 lbm water per hour (960 lbm/yr) was determined based on the data above except that the crust was assumed to be fully covering the surface (no liquid surface area). Dividing this loss rate by the density of water at 97 °F (62.0 lbm/ft³), where 97 °F corresponds to the liquid waste-to-crust interface temperature, results in a volumetric loss rate of 15.6 ft³/yr, which corresponds to an estimated ILL loss rate of 0.12 in/yr obtained using a porosity value of 35% as discussed in Section 5.0. It is clear that the observed level decrease (0.76 in/yr) could not be explained by diffusion alone if tank SX-104 had a full crust.

A certain amount of free area is necessary in the model for the model to reflect the observed ILL loss rate. From a composite photograph of the crust, it was estimated that one percent or more of the waste surface was free liquid in 1988. Two input modifications to WVPCRUSTR must be made to model evaporation from free surfaces.

1. The crust thickness (ΔX) must be set to a very small value, 10^{-6} ft.
2. The crust diffusion coefficient (D) must be set to a very large value, 10^6 ft²/h.

This effectively removes any resistance to diffusion through the crust and effectively rewrites equation 8 as

$$C^{j+1} = \frac{Q_i C_{AMB} + h_D A C_s}{Q_o + h_D A}$$

With this additional consideration, the volumetric loss rate for a one-percent free liquid surface was determined to be 46 ft³/yr. The estimated ILL loss rate from the liquid surface becomes 0.205 in/yr.

The total loss rate is then 0.325 in./yr, the sum of the crust diffusion and surface evaporation losses. A greater amount of free liquid surface area is required to explain the observed loss rate.

For completeness, the liquid level loss rate without a crust was determined to be approximately 5.7 in./yr. The presence of the crust limits the evaporation losses. (The ILL loss rate for tank SX-104 is diffusion limited.)

Obviously, the crust within SX-104 is not concrete. Visual examination of photographs taken of the waste surface in SX-104 indicate that the crust is not uniform and smooth. Based on a recent literature search by the Battelle Technical Library (Heard 1993), no direct references are available documenting

the diffusion coefficient of water vapor through sodium nitrate. Therefore, the sensitivity of the model to the diffusion coefficient is examined in the following section.

7.0 SENSITIVITY ANALYSES

SENSITIVITY ANALYSIS

The objective of sensitivity analysis is to quantify the effect of data precision on the precision of the model results. This analysis technique regards the model as perfect and examines the uncertainty of results that occur only from uncertainty in data. A complete sensitivity analysis determines the sensitivity of behavior of each model output to the value of each parameter used as data. The sensitivities are therefore the first partial derivatives of the model output with respect to each piece of input data.

The method used to obtain sensitivity predictions was to first run the model using the best estimates of all parameters and then vary one parameter and rerun the model. A change is observed in selected output parameters. The sensitivity of a selected output parameter to the input parameter being varied is taken as the ratio of the change in output to the change in input.

Estimates of relative sensitivity are made using the following equations:

$$S_{rq} = \frac{q_i - q_o}{q_o \cdot x} \quad (14)$$

and

$$x = \frac{p_m - p_o}{p_o} \quad (15)$$

where:

- S_{rq} = Relative sensitivity of q to p
- q = Model output parameter
- q_i = Value of q using p_m
- q_o = Value of q using p_o
- x = Fractional change in p between p_o and p_m
- p = Input parameter
- p_m = Modified estimate of p
- p_o = Best estimate of p.

Absolute sensitivity is given by:

$$S_{aq} = q_o \cdot x \cdot S_{xq} = (q_i - q_o) \quad (16)$$

The values used for x were subjective estimates of how accurately each parameter has been estimated. It is important to note that uncertainties in x do not proportionately influence the relative sensitivities. Uncertainty in x does, however, affect values of absolute sensitivities proportionately.

A series of sensitivity analyses were performed using the crust diffusion model. The following paragraphs present the results of the sensitivity analyses.

The sensitivity of the ILL loss rate ($\dot{L}$) determined for nine variables as input to the crust diffusion model (WVPCRUSTR). The variables were:

- (1) Area of the crust surface
- (2) Area of the liquid surface
- (3) Temperature of the liquid waste
- (4) Temperature of the tank air space
- (5) Crust diffusion coefficient
- (6) Crust diffusion length
- (7) Vapor pressure reduction due to aqueous salt solutions
- (8) Exhaust flow rate
- (9) Crust surface air velocity.
- (10) Porosity of the crust

The sensitivity to the tenth variable, "crust porosity," was determined from input to equation 12 alone, so the obtained sensitivity does not account for the relationship between porosity and the crust diffusion coefficient.

As previously described, the sensitivities were numerically estimated by independently perturbing each of the above parameters by a small amount, and estimating the partial derivatives of ILL with respect to that parameter. Table 1 presents the results of the sensitivity analyses.

The absolute sensitivity results presented by Table 1, Column 3 are based on a change in the reference parameter and must be multiplied by the actual change in the parameter to obtain an estimated change in the ILL loss rate.

For example, from Table 1 the sensitivity in the ILL loss rate for a change in porosity is -0.9 inches/(yr-%porosity). If an increase in porosity from 35% to 40% was postulated, the estimated change in the ILL loss rate can be calculated as follows;

$$\Delta \dot{L} = \frac{\Delta \dot{L}}{\Delta X} (X_2 - X_1) = -0.9 (.40 - .35) = -0.9 (0.05) \quad (17)$$

$$\Delta \dot{L} = -0.045 \text{ inches/year}$$

Therefore, for a 5% increase in porosity the ILL loss rate is estimated to decrease by 0.045 in./yr from the reference value of 0.325 in./yr to approximately 0.32 in./yr. Conversely, if a 5% decrease in porosity was postulated the affects reverse. The ILL loss rate would be estimated to increase by 0.045 in./yr to approximately 0.330 in./yr. This technique can be used to estimate the affect on the ILL loss rate for changes from any reference condition (see Table 1, Column 3).

The sensitivity data presented in Table 1, Column 4 are based on a form of dimensionless sensitivity coefficients identical to equation 14 defined by the following equation;

$$\left(\frac{\Delta \dot{L}}{\Delta X} \right) \left(\frac{X}{\dot{L}} \right)_{Ref} \quad (18)$$

Where:

$\Delta \dot{L} / \Delta X$ is the absolute sensitivity from Column 3
 X is the reference parameter
 $\dot{L}$ is the reference ILL loss rate of 0.325 in./yr.

For example, if the temperature of the air space increases to 90 °F, that is an increase of about 10%. The expected change in evaporation rate would be:

$$10\% \times 0.04 = 0.4\% \text{ increase.}$$

However, if the waste temperature increases by about 10% to about 107 °F, the evaporation rate should change by about:

$$10\% \times 3.467 \cong 35\% \text{ increase.}$$

Physically, the relative sensitivity represents a ratio of the fractional change in $\dot{L}$ and the corresponding fractional change in X that produced it. This form essentially normalizes the sensitivity data from Column 3 and removes the dependency on knowing the absolute change in X to estimate the sensitivities in the ILL loss rate.

Table 1. Sensitivity of the ILL Loss Rate ($\dot{L}$) to Various Parameters as Input to the Crust Diffusion Model.

Parameter (X)	X	Absolute Sensitivity ($\Delta L/\Delta X$)	Relative Sensitivity ($\Delta L/\Delta X$) (X/L)
Crust area (ft ²)	4376	-4E-3	-53.5
Free liquid surface area (ft ²)	44	+4E-3	0.540
Air space temperature (°F)	82.6	+2E-4	0.040
Liquid waste temperature (°F)	97	+1E-2	3.467
Crust diffusion coefficient (ft ² /hr)	0.017	+4E+0	0.199
Vapor pressure multiplier	0.72*	+5E-1	1.162
Porosity (from [12] only)	0.35	-9E-1	-1
Exhaust flow rate (cfm)	60	+2E-4	0.043
Crust diffusion length (ft)	1.08	-6E-2	-0.188
Surface air velocity (ft/s)	0.2	+8E-1	0.515

* Reference vapor pressure reduction due to a saturated solution of NaNO₃.

From Table 1, Column 4 the sensitivity coefficients indicate that the ILL loss rate is most sensitive to the liquid waste temperature and crust area. The crust area shows a high sensitivity because a small percentage change in crust surface area causes a large percentage change in liquid surface area. The sensitivity to the liquid waste temperature was expected because the partial pressure of water vapor is highly dependent on temperature. However, since the liquid waste temperature is known reasonably well, uncertainties in the liquid waste temperature are not expected to be a large source of error. The ILL loss rate is also sensitive to the vapor pressure multiplier (i.e., reduction in the partial pressure of water vapor due to sodium nitrate), free liquid surface area, and the surface air velocity. None of these are well known, but all have a varying degree of influence on the model as based on the relative sensitivities in Column 4. The ILL loss rate is relatively insensitive to the temperature of the air space, the crust diffusion coefficient, the exhaust flow rate and the crust thickness.

The ILL loss rate is sensitive to material properties and dimensions (i.e, vapor pressure reduction and crust area) which we have imprecise information about.

The results of the "best-estimate" analyses indicate that the decrease in the ILL can be attributed to evaporation. Table 2 presents a summary of the analytical results and comparison with the observed ILL loss rate.

Table 2. Best Estimate ILL Loss Rate due to Evaporation and Comparison to the Observed ILL Loss Rate.

Model	Assumptions	Total ILL loss rate (in./yr)
WVPCRUSTR	1% free liquid 99% crust	0.325
WVPCRUSTR	2% free liquid 98% crust	0.548
WVPCRUSTR	3% free liquid 97% crust	0.746
Observed		0.756 $\pm$ 0.231

8.0 CONCLUSIONS

The results of the crust diffusion analysis used to estimate the evaporation loss rate (in/yr) from tank SX-104 are indistinguishable from the observed ILL loss rate provided that there is approximately 3 percent free liquid area in the crust surface.

The sensitivity analyses performed for the crust diffusion model indicate that the results are most sensitive to the liquid waste temperature and free liquid surface area. The crust area also shows a high sensitivity because a small percentage change in crust surface area causes a large percentage change in liquid surface area. However, since the liquid waste temperature is reasonably well known, it is not expected to be a large source of error. The ILL loss rate is also sensitive to the water vapor pressure reduction due to aqueous salt solutions, and the surface air flow velocity. These parameters are not well known and are considered to have a large capacity to produce error. The ILL loss rate appears to be relatively insensitive to the temperature of the air space, the exhaust flow rate, and crust thickness and diffusion coefficient.

Although these analyses indicate that the observed ILL decrease can be attributed to evaporation, the modeling sensitivities associated with some of the assumed material properties and tank conditions are very large (the ILL loss rate is sensitive to material properties and parameters which we have imprecise information about). In particular, a better photograph of the waste surface would improve confidence in the estimate of free surface area of liquid.

9.0 REFERENCES

- Allen, G. K., 1992, "HEATING7.1 Code Validation/Verification," EDT-121734, WHC-SD-WM-ER-100, Rev. 0, Westinghouse Hanford Company, Richland, Washington
- Baumeister, T., 1978, "Mark's Standard Handbook for Mechanical Engineers," Eighth Edition, Edited by Theodore Baumeister, McGraw-Hill Book Company, New York, New York, 1978.
- Claybrook, S. W. and L. D. Muhlestein, 1984, "WATRE: An Improved Computer Program to Analyze Water and Gas Released from Heated Concrete," HEDL-TME-84-27.
- Claybrook, S. W., 1993, "An Evaporation Analysis for Tanks 241-SX-103, 241-SX-105, and 241-SX-106," WHC-SD-WM-ER-182, Rev. 1, ECN 187408, Westinghouse Hanford Company, Richland, Washington.
- Dean, John A., "Lange's Handbook of Chemistry," 13th Edition, McGraw-Hill Book Company, New York, New York, 1985.
- Heard, F. J., 1993, "Evaporation Analysis for Tank SX-105," WHC-SD-WM-ER-202, Rev 0, Westinghouse Hanford Company, Richland, Washington.
- Wood, S. A., 1993, "Evaporation Rate Predictions for Waste Tank SX-102," WHC-SD-WM-ER-213, Rev. 0, Westinghouse Hanford Company Richland, Washington.