Double-Shell Tank Remaining Useful Life Estimates

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DOUBLE-SHELL TANK REMAINING USEFUL LIFE ESTIMATES

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ABSTRACT

The existing 28 double-shell tanks (DSTs) at Hanford are currently planned to continue operation through the year 2028 when disposal schedules show removal of waste. This schedule will place the DSTs in a service life window of 40 to 60 years depending on tank construction date and actual retirement date. This paper examines corrosion-related life-limiting conditions of DSTs and reports the results of remaining useful life models developed for estimating remaining tank life.

Three models based on controllable parameters such as temperature, chemistry, and relative humidity are presented for estimates to the year in which a particular DST may receive a breach in the primary tank due to pitting in the liquid or vapor region. Pitting is believed to be the life-limiting condition for DSTs, however, the region of the most aggressive pitting (vapor space or liquid) requires further investigation.

The results of the models presented suggest none of the existing DSTs should fail by through-wall pitting until well beyond scheduled retrieval in 2028. The estimates of tank breach years (the year in which a tank may be expected to breach the primary tank wall) range from 2056 for pitting corrosion in the liquid region of tank 104-AW to beyond the next millennium for several tanks in the vapor region.

Keywords: double-shell tanks, useful life estimates, pitting corrosion, carbon steel, vapor phase, liquid phase, Hanford, corrosivity factor

INTRODUCTION

The Hanford site manages 209,310 m^3 (55.3 Mgal) of radioactive waste currently stored in 149 single-shell tanks (SSTs) and 28 DSTs. This waste must be retrieved from the inactive SSTs and processed through the active DSTs for eventual disposal. The DSTs are essentially free standing mild-carbon steel primary tanks contained within concrete tanks with mild-carbon steel liners[1]. The nominal capacity of DSTs is 1 million gallons each. The actual total operating capacity

of the existing 28 DSTs is 118,470 m^3 (31.3 Mgal). The DSTs were constructed between 1967 and 1986 with reference design lives of 50 years. The current long-term planning requires retrieval of wastes currently in SSTs by 2018 and retrieval of wastes in DSTs by 2028[2].

Table 1, taken from Abatt, et al.[3], (modified by assuming year of construction completion as service start year), provides reference windows by calendar year for DST service lives. The expected retirement for current DSTs is some time between 2012 and 2028 with final closure sometime after retirement[4]. This time schedule will place the DST service lives roughly in a 40 to 60 year window depending on the exact sequencing of tanks for retrieval.

In 1995, a project to design and construct additional DSTs was terminated[5] based on (1) assumptions that the waste volume flow through DSTs could be managed below the current 118,470 m^3 (31.3 Mgal) DST capacity through the year 2004 and (2) an initial report on the remaining useful life of the current 28 DSTs that concluded there was a low probability of DST failure before the year 2005[6].

Schwenk[6] reported that various types of metal corrosion are the dominant aging mechanisms for the steel tanks and piping. A DST Useful Life Analysis[3] issued in March 1996 further refined this conclusion by identifying life-limiting conditions for the DSTs. This analysis examined in-tank coupon data from SSTs, laboratory data for both SSTs and DSTs, and literature from other DOE sites and private industry. Abatt, et al., concluded that pitting corrosion was the life-limiting condition for the DSTs. The present paper presents remaining useful life models based on three scenarios for pitting corrosion in the liquid and vapor spaces of the existing DSTs. Abatt, et al., also reported that support components associated with the primary tanks, such as the concrete, and the secondary containment liner, are expected to last well beyond the useful life of the primary tanks.

The DST useful life estimates presented in this paper are intended to support long-term programmatic decisions such as DST waste retrieval sequence and need for additional DST capacity. These estimates are not intended to support near-term operational decisions such as immediate chemical additions to tanks. The DST useful life estimates are based on Hanford specific laboratory data and relevant data available in the literature. It must be noted that baseline condition surveys of the existing DSTs are necessary to confirm and refine the predictive models presented in this paper.

DST USEFUL LIFE ESTIMATE MODELS

Based on the information available today, the life-limiting condition for Hanford DSTs is believed to be a primary tank breach by pitting corrosion. Abatt, et al.[3], defined the term "Failure" as:

> DST Failure: A physical change in DST geometry or material properties that *could* cause the tank to be removed from service.

In the context of this paper, the breach of a primary tank is a change in DST geometry that could cause the tank to be removed from service.

Three separate models have been developed to describe pitting rates and estimate useful lives in the liquid and vapor regions of DSTs. The models are: Corrosivity Factor model, Atmospheric Corrosion model, and Condensation Corrosion model. All three models have valid technical bases, however, all three models also have significant uncertainties when applied to Hanford DSTs. Descriptions of the models and their technical bases are presented in the following along with a discussion of uncertainties.

Hanford carbon steel pitting corrosion data are presented in Table 2. It is important to recognize that this data set provides less than conclusive information regarding parameters that affect pitting in the vapor space of DSTs. Liquid phase pitting shows a strong correlation with reported corrosivity factor (CF). The CF has been defined and discussed in detail by Anantatmula et al.[7] However, the strongest correlation between pitting in the vapor phase and an experimental parameter appears to be duration of the experiment. The vapor phase pitting corrosion rates vs exposure time data were fitted to a power curve, and both the power curve and the data points are illustrated in Figure 1. Although the fit is not good (as indicated by the value of the coefficient of determination $<<1$), the curve importantly points out that the pitting corrosion rate is a decreasing function of exposure time. This fact has been substantiated by the experimental data reported in the literature[8]. Relative humidity (RH) values for the laboratory vapor data reported in Table 2 are not readily available but are suspected

to be significantly higher than the actual DST service conditions. Similarly, RH values for SST coupon vapor data are not readily available but are also expected to be significantly higher than the actual DST service conditions.

Corrosivity Factor Model For Liquid Phase Pitting

Description. Calculates liquid phase pitting corrosion rate using CF.

$$\text{Pitting Corrosion Rate} = a(CF)^b \qquad \text{equ. (1)}$$

$$\text{Failure Time} = \text{Construction Date} + \frac{\text{Nominal Wall Thickness}}{a(CF)^b}$$

where a=3.3 mils/yr, b=0.2, and CF is the corrosivity factor (Nitrate/[Nitrite+Hydroxide]).

Technical Basis. During the course of the DST Useful Life Analysis[3], a strong correlation was identified for pitting in the liquid regions of DSTs and CF (Figure 2). It was assumed in Abatt, et al.[3], that the condensed phase in the vapor space may behave similar to the liquid phase below, allowing the pitting corrosion rates in vapor space to follow a similar relationship with the CF. On this basis, a bounding value of a=12.7 was obtained in equation (1) for the vapor space corrosion rates, with the b value the same as that for the liquid phase corrosion rates.

Further discussion and analysis of the vapor space data in support of the present paper leads to the conclusion that there is no correlation between vapor space corrosion rates and CF. This conclusion is based largely on an examination of partial pressures associated with the ionic species of nitrate, nitrite, and hydroxide that indicates these species will not be found as major constituents in vapor phase chemistry.

The results presented in Table 3 are for liquid phase corrosion based on the correlation presented in Figure 2. The wall thicknesses in Table 3 are taken from the wall thicknesses at maximum waste height. The data in Table 3 indicate that the earliest DST breach by liquid phase pitting will not occur before the year 2056, which is almost 30 years later than the scheduled DST waste retrieval date.

Uncertainties. This model uses a limited set of data over an extreme range of CFs. There may be more aggressive effects of nitrate in a film just above the waste surface resulting from the rise and fall of waste height due to changes in atmospheric pressure. More laboratory work is needed to determine if this effect may be significant. In addition, empirical data from baseline condition surveys such as those planned for the DST Integrity Assessment Program are necessary for confirmation of the model.

Atmospheric Corrosion Model for Vapor Phase Pitting

Description. Uses time, RH and temperature to correlate tank conditions and corrosion rates.

Technical Basis. Incorporates considerations that are believed to be important to vapor phase corrosion.

Lee et al.[9], developed humid-air corrosion models based on a total of 166 sets of atmospheric corrosion data (up to 16 years) of cast irons and carbon steels which have corrosion behaviors similar to the DST steels. The data base for these models are from various exposure conditions in tropical, urban, rural and industrial test locations. The test exposure conditions for the data collected by Lee et al., range from 5 to 27°C average temperature, 63 to 85% average RH, and 2 to 406 μg SO_2/m^3 average SO_2 content. Because SO_2 is not expected to be present in the DST vapor space at a significant level, the SO_2 term is omitted from the model equation of Lee et al., (see equation (2) below) for the present atmospheric corrosion calculations.

The following humid-air general corrosion model equation was developed by Lee et al., based on dependencies of general corrosion on humid-air exposure conditions obtained from the literature data.

$$\ln D_g = a_0 + a_1 \ln(t) + a_2/RH + a_3/T \qquad \text{equ. (2)}$$

where D_g is corrosion depth in μm, t is time in years, T is temperature in °K, and a_0, a_1, a_2 and a_3 are constants. Equation (2) can be solved for t as

$$t = \exp((\ln D_g - a_0 - a_2/RH - a_3/T)/a_1) \quad \text{equ. (3)}$$

Linear regression of the fit of equ.(2) to the data by Lee et al., yielded the following parameter values:

$a_0 = 16.9865 \pm 2.873$
$a_1 = 0.6113 \pm 0.0295$
$a_2 = -893.76 \pm 231.04$
$a_3 = -833.53 \pm 381.97$

For the humid-air pitting corrosion model, Lee et al., used a pitting factor, which is defined as the ratio of maximum pit depth to the general corrosion depth at a given exposure time. From a review of results of extensive corrosion testing programs in inland tropical environments in Panama, Lee et al., concluded that the pitting factor ranges from 2 to 6. The pitting factor was also assumed to be normally distributed with a mean of 4 and a standard deviation of 1. For additional details of the humid-air corrosion models, the reader is referred to the publication of Lee et al., (Reference 9). For the present DST atmospheric pitting corrosion calculations, equ. (2) above is used with a pitting factor of 4. Because of the unavailability of RH data for the AN tank farm, a conservative value of 80% was assumed for all the AN farm tanks. Representative RH data for the other DSTs and vapor space temperature estimates for all the DSTs were obtained from Anantatmula and Ohl[10].

The results of the present calculations are presented in Table 4. As can be seen from the table, the results indicate that breach of the DSTs by vapor space atmospheric pitting corrosion will not occur until far beyond the end of their scheduled retrieval in 2028.

Uncertainties. The RH is not the same for all the DSTs and there is uncertainty in the measurement of RH. However, the RH may be as low as 20% and is not expected to be over 80%. Although the aging waste DSTs were at boiling temperature when they first started receiving waste, the current DST temperature is a maximum of 66°C. The vapor space is not expected to contain any SO_2. The model used for the present calculations[9] did not include data from marine environments. In spite of the uncertainties listed above, the atmospheric pitting corrosion in the vapor space is not a cause for concern since the earliest tank breach is not until well beyond the end of the scheduled DST waste retrieval in 2028.

Atmospheric Corrosion Model for Vapor Phase Pitting with 25% Condensing Conditions

Description. Uses results of atmospheric corrosion model in conjunction with similar aqueous corrosion model to estimate remaining useful life of DSTs subject to water condensing on the tank walls 25% of the year.

Technical Basis. In addition to the atmospheric corrosion models, aqueous corrosion models were also developed recently by Lee et al.[9], using long-term corrosion data on cast iron and carbon steel available in the literature.

The following aqueous general corrosion model equation was developed by Lee et al., based on dependencies of general corrosion on aqueous exposure conditions obtained from the literature data.

$$\ln D_g = b_0 + b_1 \ln(t) + b_2/T + b_3 T^2 \quad \text{equ. (4)}$$

where D_g, t and T have the same significance as before, and b_0, b_1, b_2 and b_3 are constants.
Equation (4) can be solved for t as

$$t = \exp((\ln D_g - b_0 - b_2/T - b_3 T^2)/b_1) \quad \text{equ. (5)}$$

Linear regression of the fit of equ. (4) to the data by Lee et al., yielded the following parameter values:

$b_0 = 111.506 \pm 10.804$
$b_1 = 0.532 \pm 0.0272$
$b_2 = -23303.2 \pm 2296.2$
$b_3 = -3.193 \times 10^{-4} \pm 3.526 \times 10^{-5}$

Similar to the humid-air pitting corrosion model, Lee et al., modeled aqueous pitting corrosion by using a pitting factor with the assumption that it is normally distributed with a mean of 4 and a standard deviation of 1. For additional details of the aqueous corrosion models, the reader is referred to Lee et al.[9] As for the atmospheric corrosion case, for the present DST aqueous pitting corrosion calculations, a pitting factor of 4 was used with equation (5). Also similar to the atmospheric corrosion case, a conservative RH value of 80% was assumed for all the AN farm tanks and representative RH data for the other DSTs and vapor space temperature estimates for all the DSTs were obtained from Anantatmula and Ohl[10].

The results in Table 5 show application of the atmospheric corrosion model (discussed in the previous section) and the aqueous corrosion model (discussed above) active for 75% and 25% of the time respectively during the year. Even under these conservative conditions, the model does not indicate a single breach of tank wall in the vapor space until well beyond the end of the scheduled DST waste retrieval in 2028.

Uncertainties. The RH for the DSTs may be as low as 20% and is not expected to be over 80%. Although the aging waste DSTs were at boiling temperature when they first started receiving waste, the current DST temperature is a maximum of 66°C. At these RHs and temperatures, aqueous conditions are not expected to be present on the tank walls in the vapor space above the liquid waste. It is quite conceivable that some DSTs may have condensation on the tank walls in the dome space some of the time. Since the RH data of the DSTs gathered over the last few years indicate that 100% RH conditions are only possible a few days during the year, it is reasonable to assume that aqueous conditions existed in the DST dome space only for a fraction of the time (<<25%) even for the aging waste tanks.

DISCUSSION

Effects of Chloride

Brevick[11] estimates total chloride inventories in the DSTs to range from 70 ppm to 4580 ppm. Table A-3 from Anantatmula and Ohl[10] presents the individual tank estimates for chloride. The corrosion of steel in alkaline solutions does not occur unless oxygen is available for depolarization of the cathode and sufficient chloride ions are available to permit release of ferrous ions at the anode[12]. The threshold chloride concentration for carbon steel corrosion drops to low levels with decreasing alkalinity of the solution. Based on the results of Hausmann[12] and Table A-3 from Anantatmula and Ohl, there is enough chloride present in the majority of the DSTs to be a cause for concern if the pH of the waste solution drops below 11. Therefore, the environmental conditions become favorable for chloride corrosion of steel in the vapor space of the DSTs (especially near the waste surface), where the solutions present are oxygenated and of low pH.

Effects of Ammonia

Brevick[11] estimates ammonia inventories of the DSTs to range from 50 ppm to 8480 ppm. Table A-3 from Anantatmula and Ohl[10] presents the individual tank estimates for ammonia. The presence of ammonia is not detrimental to the DST steel walls because of the moisture in the dome space air. In fact, ammonia combined with the moisture may provide higher pH condition that will place the steel in the passive region. Support for this hypothesis is obtained from the recent 3-month DST pitting kinetics testing performed at the Pacific Northwest National Laboratory[13]. Results from these experiments indicate that carbon steel experiences extremely low corrosion rates in the vapor space containing 100 ppm of ammonia.

Representative Conditions vs Extreme Conditions

It is nearly impossible to pinpoint the exact locations of the pitting attack within the tank that would be life limiting. We can safely say that the regions of the tank dome that are far removed from the waste surface will only experience the more benign atmospheric pitting attack. The pitting attack by the moist waste films above the waste surface may be more widespread and is expected to be more severe compared to the atmospheric corrosion above. For tanks containing sizable quantities of chloride, the attack will be more severe and may be global in the immediate vicinity of the waste surface.

The modeling presented in the present paper only addresses controllable parameters such as chemistry, temperature, and RH. The models used representative conditions for each individual DST to arrive at the estimated time for a breach in the primary tank. The models do not address variables associated with control of these parameters that affect the representative conditions presented. Extreme conditions that fall well outside the representative conditions such as localized areas of extremely aggressive chemistry or reduction in primary tank ventilation sufficient to create condensing conditions greater than 25% of the time are likely to cause a breach in the primary tank wall sooner than the representative conditions.

Low Hydroxide Tanks

Hydroxide concentration (in the waste below), lower than that specified by the DST waste specification limits, is not expected to significantly affect corrosion of tank wall in the vapor space. However, this condition can be detrimental to corrosion in the liquid phase of the low hydroxide tanks. Hydroxide, along with nitrite, inhibits the cathodic reaction associated with nitrate-assisted stress corrosion cracking and nitrate pitting attack.

Relationship of Liquid Chemistry to Vapor Chemistry

It is well established that the primary constituents in the waste liquids are nitrate, nitrite and hydroxide. The water vapor evaporating from the waste liquid is not expected to contain any of these components to a measurable extent. The gas (air) in the dome space primarily contains the water vapor evaporating from the waste surface combined with any flammable or other gases escaping from the waste. Since the DSTs are vented with outside air sweeping over the dome space at 50-600 cfm, the gases evolving from the waste cannot accumulate in the dome space in sufficient quantities or durations to significantly contribute to vapor space corrosion.

However, moist waste films may be present on the tank walls above the current waste surface level of the tanks, where the chemistry is expected to be somewhat similar to that of the waste liquid below. These waste films could be from waste transfers into and out of the tanks, the rise and fall of the waste surface in response to changes in the barometric pressure, or a spray from running air lift circulators. In addition, gas bubbles escaping from the liquid waste below and bursting in the vapor space could deposit liquid droplets containing nitrate, nitrite, and hydroxide on the tank walls. It should be emphasized that these waste films would be more dilute with respect to the major waste constituents compared to the liquid waste below. This is especially true of the hydroxide, which is readily consumed by a reaction with the carbon dioxide in the dome air.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1) None of the models presented suggest an imminent DST failure prior to the completion of DST waste retrieval in 2028. The earliest predicted through wall breach is in tank 104-AW in the year 2056 by pitting in the liquid region of the tank. This estimate is conservative in that it assumed the tank was filled up into the 3/8" thick region of the tank wall very soon after construction.

2) The data available today do not support a correlation between current waste chemistry composition specifications in liquid phase and corrosion rates in vapor phase.

3) Empirical data from baseline condition surveys of the DSTs is necessary for confirmation of models presented. At this time, insufficient data exist to develop a single use model for DST remaining useful life. Ammonia and chlorides have not been adequately factored into the models or into the existing waste chemistry composition specifications.

4) Pitting corrosion is expected to be the life-limiting condition for DSTs. Further laboratory work is necessary to quantify differences in vapor phase pitting, liquid phase pitting, and liquid/vapor interface pitting.

5) The models presented in this paper only address corrosive attack for representative conditions in individual DSTs. Extreme conditions such as abnormal chemistry or defective fabrication cannot be modeled and can only be detected by surveillance and inspection. Although the models presented do not predict imminent breach of DST walls, chemistry and tank conditions should be monitored for indications of change.

Recommendations

1) Perform baseline condition surveys of DST primary tanks. This can be accomplished via the DST integrity assessment program. Particular attention should be given to lower knuckle regions for evidence of cracking and quantification of pitting differences between liquid and vapor regions.

2) Adjust DST pitting experiments to reflect actual DST service conditions for temperature and RH. The experiments should also include the effects of the simultaneous presence of chloride and ammonia in the waste liquid on the corrosion of the tank wall adjacent to the waste surface. Under-deposit (crevice) pitting experiments should be initiated to quantify pitting rates under saltcake and DST sludges.

3) Place vapor phase pitting coupons in at least one DST for retrieval at 6 mo, 1 year, 2 year, and 4 year intervals to verify models presented for vapor space corrosion.

4) Compare Hanford specific laboratory data to similar data available through general literature.

REFERENCES

1. B. M. Hanlon, "Waste Tank Summary Report for Month Ending November 30, 1995," Westinghouse Hanford Company, Richland, Washington, WHC-EP-0182-92, Rev. 0, 1996.

2. Ecology, EPA, DOE, "Hanford Federal Facility Agreement and Consent Order," as amended, Washington State Department of Ecology, U. S. Environmental Protection Agency, and U. S. Department of Energy, Olympia, Washington, 1994.

3. F. G. Abatt, R. P. Anantatmula, N. G. Awadalla, C. E. Jensen, L. J. Julyk, P. C. Ohl, L. Muhlestein, "DST Useful Life Analysis," Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-ER-556, Rev. 0, March 29, 1996.

4. B. Knutson, P. Baynes, "TWRS Mission Analysis," Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-MAR-008, Rev. 0, 1995.

5. C. E. Jensen, "Multi-Function Waste Tank Facility, Phase Out Basis," Westinghouse Hanford Company, Richland, Washington, WHC-SD-W236A-ER-021, Rev. 3, 1995.

6. E. B. Schwenk, "Evaluation of Remaining Life of the Double-Shell Tank Waste Systems," Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-ER-432, Rev. 0, 1995.

7. R. P. Anantatmula, M. J. Danielson, E. B. Schwenk, "Characterization of the Corrosion Behavior of the Carbon Steel Liner in Hanford Site Single-Shell Tanks," Westinghouse Hanford Company, Richland, Washington, WHC-EP-0772, Rev. 0, June 20, 1994.

8. Metals Handbook, Corrosion, Ninth Edition, Volume 13 (ASM International, Metals Park, Ohio, 1987), p. 512.

9. J. H. Lee, J. E. Atkins, R. W. Andrews, "Humid-Air and Aqueous Corrosion Models for Corrosion-Allowance Barrier Material," Scientific Basis for Nuclear Waste Management XIX, Vol. 412, p. 571, (Pittsburgh, PA: Materials Research Society, 1996).

10. R. P. Anantatmula, P. C. Ohl, "DST Remaining Useful Life Estimates," Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-ER-585, Rev. 0, June 28, 1996.

11. C. H. Brevick, L. A. Gaddis, W. W. Pickett, "Historical Tank Content Estimate for the Southeast Quadrant of the Hanford 200 Area," Prepared by ICF Kaiser Hanford Company for Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-ER-350, Rev. 0, 1995.

12. D. A. Hausmann, Materials Protection, November Issue (1967): p. 19.

13. R. P. Anantatmula, "DST Pitting Annual Report," Testing performed by M. J. Danielson at the Pacific Northwest National Laboratory for Westinghouse Hanford Company, Richland, Washington, WHC-SD-WM-PRS-016, Rev. 0, 1996.

TABLE 1
SERVICE LIFE REFERENCE FOR HANFORD DSTs

Tank	Service Life (Yrs)			
	1996	2012	2028	2050
241-AY-101 through -102	26	42	58	80
241-AZ-102	19	35	51	73
241-SY-101 through -103	20	36	52	74
241-AZ-101	25	41	57	79
241-AW-101 through -106	16	32	48	70
241-AN-101 through -107	15	31	47	69
241-AP-101 through -108	10	26	42	64

TABLE 2
PITTING CORROSION DATA OF CARBON STEEL OBTAINED AT HANFORD

Waste Type	Corrosivity Factor (CF)	Duration (hours)	Temperature (°C)	Pitting Corrosion L (mpy)	Pitting Corrosion L/V (mpy)	Pitting Corrosion V (mpy)
Purex (Lab)	19.09	2160	104	-	-	7
Purex (Lab)	19.09	730 2,190 7,300	104	ND	-	24 8.4 4.8
Purex (101)	19.09	3,120	-	6.4	-	2.0
Redox (S-104)	6.53	6,570	82 - 127	5.3	-	-
$BiPO_4$ (Lab)	2.75	4,380	80	- ND ND	2.4 2.8 1.8	8.6 5.5 3
$BiPO_4$ (Lab)	2.75	450	102 (boil)	ND	35 (max)	37 (max)
$BiPO_4$ (TX-105) (TX-109)	2.75 2.75	5,400		- 4 (max)	-	16 2 (max)
TBP (Lab)	81.67	730 2,190		10 8	-	8 7

ND = not detected; L = liquid; V = vapor; L/V = liquid/vapor interface; TBP = tributyl phosphate;
- = no coupon data available

TABLE 3
DST USEFUL LIFE ESTIMATES USING CORROSIVITY FACTOR MODEL
FOR
LIQUID PHASE PITTING

Tank	Thickness	CF(Max)**	Pitting	Breach Year
	(mils)		Rate (mpy)	
104-AW	375	5.85	4.9	2056
* 107-AN	375	2.69	4.0	2072
* 102-AN	375	2.37	3.9	2075
* 107-AP	375	4.13	4.5	2096
101-SY	375	0.73	3.1	2099
101-AN	375	0.73	3.0	2104
105-AN	375	0.6	2.9	2109
101-AW	375	0.57	2.9	2110
* 104-AP	500	2.38	4.0	2111
102-SY	500	1.63	3.7	2112
103-AN	375	0.54	2.8	2112
102-AZ	500	1.51	3.6	2116
104-AN	375	0.46	2.7	2117
103-AW	500	1.46	3.6	2120
* 101-AY	500	0.81	3.1	2130
* 102-AY	500	0.74	3.1	2133
103-SY	500	0.86	3.2	2134
106-AN	500	0.89	3.2	2137
101-AZ	500	0.65	3.1	2139
105-AW	500	0.78	3.1	2141
106-AW	500	0.74	3.1	2143
102-AW	500	0.73	3.1	2144
101-AP	500	0.81	3.1	2146
103-AP	500	0.79	3.1	2147
* 108-AP	500	0.76	3.1	2148
105-AP	500	0.74	3.1	2149
106-AP	500	0.74	3.1	2149
102-AP	500	0.6	2.9	2157
Number of tanks breaching				
prior to year 2028				0

* Tanks recently operated or currently operating outside corrosion specification (Low Hydroxide Tanks)
** Taken from Abatt et al., (Reference 3)

TABLE 4
DST USEFUL LIFE ESTIMATES USING ATMOSPHERIC CORROSION MODEL
FOR
VAPOR PHASE PITTING

Tank	Thickness	Relative	Temperature	Pitting Rate	Breach Year
	(mils)	Humidity (%)	(deg.C)	(mpy)	
* 102-AN	375	80	33	0.18	2593
103-AN	375	80	33	0.18	2593
104-AN	375	80	34	0.18	2584
105-AN	375	80	32	0.17	2602
* 107-AN	375	80	32	0.17	2602
101-AN	375	80	22	0.15	2704
106-AN	375	80	19	0.14	2739
102-AW	375	75	24	0.05	>3000
106-AW	375	73	34	0.03	>3000
104-AW	375	71	18	0.01	>3000
* 101-AY	375	20	19	< 0.01	>3000
* 102-AY	375	20	17	< 0.01	>3000
101-SY	375	51	16	< 0.01	>3000
102-SY	375	63	16	< 0.01	>3000
103-SY	375	57	16	< 0.01	>3000
101-AZ	375	43	55	< 0.01	>3000
102-AZ	375	43	49	< 0.01	>3000
101-AW	375	56	30	< 0.01	>3000
103-AW	375	69	17	< 0.01	>3000
105-AW	375	53	19	< 0.01	>3000
101-AP	500	64	18	< 0.01	>3000
102-AP	500	65	19	< 0.01	>3000
103-AP	500	65	13	< 0.01	>3000
* 104-AP	500	68	15	< 0.01	>3000
105-AP	500	61	18	< 0.01	>3000
106-AP	500	64	17	< 0.01	>3000
* 107-AP	500	62	15	< 0.01	>3000
* 108-AP	500	66	18	< 0.01	>3000
Number of tanks breaching prior to year 2028					0

* Tanks recently operated or currently operating outside corrosion specification (Low Hydroxide Tanks)

TABLE 5
DST USEFUL LIFE ESTIMATES USING A COMBINATION OF ATMOSPHERIC AND AQUEOUS CORROSION MODELS

Tank	Thickness (mils)	Relative Humidity (%)	Average Temperature (deg C)	Atmospheric Corrosion (mils) (75% of time)	Aqueous Corrosion (mils) (25% of time)	Pitting Rate (mpy)	Breach Year
101-AZ	375	43	55	3.70E-03	375	4.1	2063
102-AZ	375	43	49	3.85E-03	375	3.5	2083
104-AN	375	80	34	7.24E+01	302	2	2171
* 102-AN	375	80	33	7.54E+01	300	1.8	2187
103-AN	375	80	33	7.54E+01	300	1.8	2187
105-AN	375	80	32	7.87E+01	297	1.7	2205
* 107-AN	375	80	32	7.87E+01	297	1.7	2205
106-AW	375	73	34	2.90E+01	346	1.5	2225
101-AW	375	56	30	9.59E-01	374	0.9	2410
101-AN	375	80	22	1.27E+02	248	0.7	2551
102-AW	375	75	24	6.61E+01	309	0.6	2623
106-AN	375	80	19	1.48E+02	227	0.5	2751
104-AW	375	71	18	5.78E+01	317	0.2	>3000
* 101-AY	375	20	19	7.33E-13	375	0.2	>3000
105-AW	375	53	19	8.87E-01	374	0.2	>3000
103-AW	375	69	17	4.60E+01	329	0.2	>3000
* 102-AY	375	20	17	8.82E-13	375	0.1	>3000
102-SY	375	63	16	1.63E+01	358	1.5	>3000
102-AP	500	65	19	2.62E+01	474	0.2	>3000
103-SY	375	57	16	3.82E+00	372	1.5	>3000
101-SY	375	51	16	6.09E-01	375	1.4	>3000
* 108-AP	500	66	18	3.46E+01	465	0.1	>3000
101-AP	500	64	18	2.33E+01	477	0.1	>3000
105-AP	500	61	18	1.20E+01	488	0.1	>3000
106-AP	500	64	17	2.55E+01	474	0.1	>3000
* 104-AP	500	68	15	6.41E+01	436	0.1	>3000
* 107-AP	500	62	15	2.00E+01	480	0.1	>3000
103-AP	500	65	13	4.52E+01	455	0.1	>3000
Number of tanks breaching prior to year 2028							0

* Tanks recently operated or currently operating outside corrosion specification (Low Hydroxide Tanks)

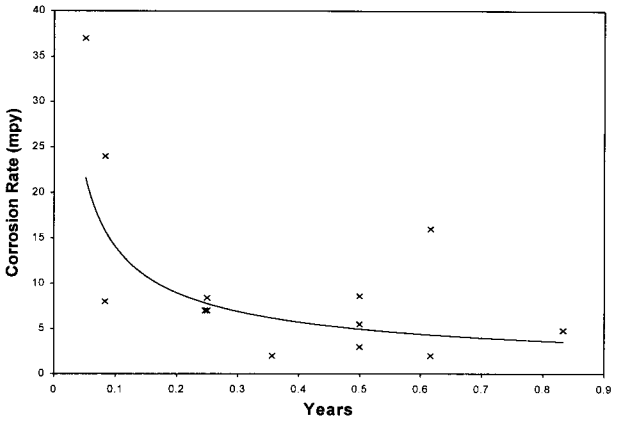

FIGURE 1 - Hanford vapor space pitting data vs exposure time

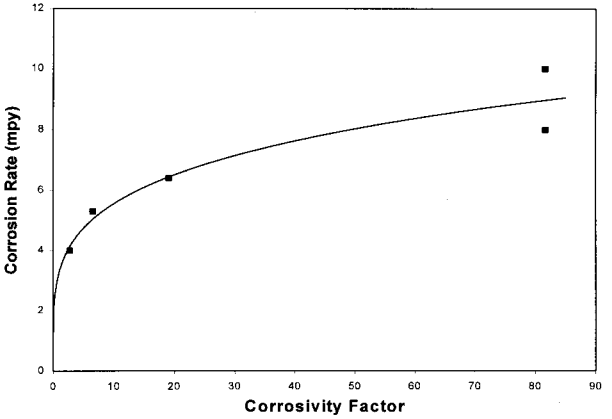

FIGURE 2 - Pitting corrosion in liquid region