LIMITS ON ANNULUS AIR OUTAGES IN TYPE I, II, AND III WASTE TANKS (U)

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Limits on Annulus Air Outages in Type I, II, and III Waste Tanks (U)

1.0 Summary

An evaluation was performed on the impact of abnormal air flow conditions on the structural integrity of Type I, II, and III waste tanks. Warm, dry air in the annular space is necessary to preclude low temperature embrittlement and corrosive conditions for the carbon steel materials. For Type I and II tanks the annulus air system should be repaired within a month to minimize the potential for low temperature embrittlement and corrosive conditions. For Tanks 29-34, which are Type III tanks, it is recommended that the system be repaired within two months to minimize the potential for low temperature embrittlement. For all other Type III tanks repair of the system within six months is adequate to minimize general corrosion.

Three recommendations were made to ensure that the general corrosion mechanism is not active during future annulus air outages: 1) Monitor the annulus air temperature daily during the outage to ensure that it is above the ambient temperature. 2) Minimize the time water is allowed to stand in the annulus. 3) If only the steam is off-line, continue to blow air through the annulus periodically to prevent the build-up of NO_2 . If any of these three conditions exist (i.e., annulus air temperature less than the ambient air temperature, standing water, or stagnant air), it is preferable to bring the annulus air system back on line within one to two weeks. However, significant degradation should not occur up to six months. Therefore, six months would be the maximum permissible time to allow any of these conditions to exist.

An estimate of the evaporation rate of standing water in the annulus was calculated. Under normal annulus temperature and humidity conditions (i.e., exit air temperature greater than 40°C and relative humidity of exit air approximately 40 %), an annulus air flow rate of approximately 2000-300 cfm will evaporate 1-2 inches of standing water per day.

2.0 Background

Warm, dry air is circulated through the annuli of the double shell tanks. The temperature of the circulated air is controlled so that either the annulus exit air temperature is a preset value (40°C) or 10°C greater than the ambient air temperature [1]. The primary purpose for the circulated air is to prevent low temperature embrittlement by maintaining the temperature of the steel above the Nil Ductility Transition Temperature (NDTT). Below this temperature, the carbon steel material may be susceptible to brittle fracture [2]. Table 1 below summarizes the NDTT for each of the steels from which the waste tanks were constructed.

The annulus air also provides benefits from the standpoint of leak minimization through the primary confinement barrier and avoidance of wall thinning. Some of the Type I and II tanks contain stress-corrosion cracks which have leaked waste into the annulus. The circulated air evaporated water from the leaking waste and a solid deposit formed which plugged the crack and prevented further leakage. These deposits begin to dissolve and leakage of waste into the annulus resumes once the annulus air is turned off [3]. The dissolution of the salt deposits is likely due to the formation of condensation on the tank walls as the air cools. The presence of condensate or standing water in the annulus may also result in general corrosion (i.e., wall-thinning) of the tank primary or secondary [4]. Thus, by evaporating the condensation or any standing water in the annulus, the circulated air also prevents degradation of the materials of the primary tank.

Table 1. NDTT of Steels Used in Waste Tank Construction

Tank Design	Material, Steel Alloy	Maximum NDTT, °C
Types I and II Type III	A285 Grade B	15*
Tanks 29-34 Tanks 25-28 and 35-37	A516-70 A516 Normalized	15 -18
Tanks 38-51	A537 Class I	-45

* This temperature corresponds to the highest temperature at which an absorbed energy equal to 15 ft-lbs was reported for A285 Grade B carbon steel.

High Level Waste Engineering requested that an evaluation of the impact of abnormal air flow conditions on the structural integrity of Type I and Type II tanks, and Type III tanks not involved in either the ITP or ESP process be performed. Specifically, a time limit for which these conditions would be acceptable was desired. There are two abnormal conditions to consider: 1) steam outage while annulus air continues to blow, and 2) both steam and airflow are disabled. Changes in the temperature and moisture conditions in the annulus and their influence on brittle fracture behavior, salt deposit dissolution, and general corrosion are evaluated in this memorandum.

3.0 Temperature Data for Annulus Air Under Abnormal Operating Conditions

The impact of steam and blower outages on the annulus air and steel temperature has been studied in Type I and II waste tanks [5,6]. The temperature transients for the annulus air and tank steel temperatures during a 30 hour steam outage in Tank 9H in 1975 are shown in Figure 1 [5]. Air continued to blow into the annulus at a rate of approximately 1500 cfm. The coolest region of the tank was near the tank bottom where there was a 15° C decrease in the tank steel temperature and an 18° C decrease in the annulus air temperature. The air at the top of the tank on the other hand experienced only a 8° C decrease in temperature. These measurements were made in January, typically the coldest time of the year.

A steam outage test was also conducted in Tank 13H in January 1975, where the initial temperature of the steel was lower than in Tank 9H. The temperature transients for the annulus air and the tank steel are shown in Figure 2 [5]. A 10° C decrease in the tank steel and 14° C decrease in the air temperature was observed. More significantly the absolute temperatures (27° C for the steel and 23° C) were beginning to approach the NDTT for A285.

During a test in Tank 9H in November 1974, the blower fan failed in addition to there being a steam outage. The temperature transients for the annulus air and the tank steel in Tank 9H are shown in Figure 3 [5]. The decrease in temperature during this test was much less severe (approximately 6° C from initial temperature) for the steel near the tank bottom than that for the steam outage test in January 1975. The annulus air temperature near the top of the tank decreased by approximately 4° C which was also less than the decrease in January 1975.

4.0 Influence of the Abnormal Operating Conditions on the Three Degradation Mechanisms

4.1 Low Temperature Embrittlement

Rapid, unstable flaw growth may occur if the combination of a large flaw [7], high stresses and low temperature embrittled material coexist in a local region. Several of the Type I and II tanks contain cracks. Literature data showed that maintaining the tank temperature above 21 °C prevents brittle fracture mode behavior of all tank materials [2]. Above the NDTT temperature, ductile fracture may occur at stresses near the yield stress in tank material containing a flaw. Tank fill limits are specified to prevent ductile failure in tanks containing flaws up to eleven inches for both normal and seismic loading conditions [8]. A reference flaw size (i.e., maximum flaw size) of six inches was identified for the Types I and II tanks [7]. This flaw size is less than the length assumed in the fill limit calculations.

The NDTT for the material of the Type III tanks is generally much lower than that for the Type I and II. Thus brittle fracture is not as great a concern; particularly if the tanks are constructed of A537 carbon steel or A516 normalized carbon steel. The only exception would be for Tanks 29-34, which are made of A516 carbon steel. The maximum NDTT for this material is 15° C, which is close to the 21° C limit. This situation for Tanks 29-34 is not as critical as the Type I and II tanks due to the lack of flaws.

4.2 Salt Deposit Dissolution

The annulus air also evaporates water from the annulus (see Section 5.0 for an estimate of the evaporation rate). A comparison of the temperature data in Figures 1 and 3 shows that if there is a steam outage, turning the blower off would minimize the temperature decrease experienced by the tank steel. However, in Type I and II tanks, if the temperature in the annulus decreases below the ambient temperature, condensation may form on the tank walls and dissolve the solids which are plugging the cracks. The colder regions of the tank (i.e., near the tank bottom for tanks which are not fresh waste receivers) will likely experience the condensation. If waste was being removed (i.e., dissolved salt) from these tanks and the annulus air was malfunctioning, leakage of the dissolved salt solution may occur. Salt deposit dissolution is not a concern for the Type III tanks due to the lack of flaws.

4.3 General Corrosion

The presence of condensation or standing water may also result in general corrosion. A mechanism for general corrosion occurred in the reactor process room at SRS and needs to be evaluated as to its potential occurrence and/or severity in the annulus [9]. This mechanism is initiated by gamma rays which irradiate the annulus air to produce NO₂ gas [10]. The rate at which NO₂ gas is produced is given by equation 1.

$$\text{moles NO}_2 = 6.9 \times 10^{-13} (\text{grams of air})(\text{gamma dose}) \quad (1)$$

A nitric acid solution will form wherever air containing NO₂ is in contact with moisture. The reaction producing the nitric acid is:

For this reaction the equilibrium constant is given by [11]:

$$\frac{[\text{HNO}_2][\text{H}^+][\text{NO}_3^-]}{(\text{P}_{\text{NO}_2})^2} = 106.86 \quad (3)$$

where $[\text{HNO}_2]$, $[\text{H}^+]$, and $[\text{NO}_3^-]$ are molar concentrations of the indicated species dissolved in water and P_{NO_2} is the partial pressure of NO_2 in the air. Assuming that no other chemical reactions occur and there are no other sources of H^+ , HNO_2 , or NO_3^- , then $[\text{HNO}_2] = [\text{H}^+] = [\text{NO}_3^-]$ and equation 3 can be further reduced to:

$$\text{pH} = -2.29 - 0.67 \log (\text{P}_{\text{NO}_2}) \quad (4)$$

If it is assumed that the dose rate is 1000 R/hr (a representative value for annulus air [12]) and the volume of air in the annulus is approximately 23,000 ft³, the production of NO_2 gas is 1.9×10^{-8} atm/hr. Substituting this value into equation 4, and assuming that equilibrium is instantaneously established, the pH of the condensate or standing water could reach 2.9 within an hour. At this pH, carbon steel corrodes at a rate of approximately 0.1 inches/yr [4]. If these conditions were allowed to exist for six months, the tank wall may begin to become significantly degraded.

Visual examinations of the annular space, however, have not revealed indications of excessive general corrosion [13] even with occasional steam and blower outages. There are several possible explanations for the lack of observed general corrosion. First, the rate at which the nitric acid production reaction occurs in cold dilute solutions is slow [11], and therefore, the reaction does not attain equilibrium rapidly. Second, the contents of the tank may have contributed sufficient heat to maintain the temperature of the annulus air above the ambient temperature. Condensate would not form under these conditions. Third, the above calculations assume that the air in the annulus is stagnant. A small air flow in the annulus may dilute the NO_2 concentration sufficiently. Fourth, in tanks which have salt deposits, the condensate or standing water will contain other dissolved salts. The presence of these dissolved salts would likely decrease the absorption of the NO_2 gas into the water and the formation of nitric acid.

On the basis of past inspections, accelerated general corrosion due to nitric acid formation has not occurred during past outages. However, in order to assure that this mechanism is not active during future annulus air outages, recommendations which should be implemented are: 1) Monitor the annulus air temperature daily during the outage to ensure that it is above the ambient temperature to prevent excessive condensation. 2) Minimize the time water is allowed to stand in the annulus. 3) If only the steam is off-line, continue to blow air through the annulus to prevent the build-up of NO_2 and subsequent general corrosion. If any of these three conditions exist (i.e., annulus air temperature less than the ambient air temperature, standing water, or stagnant air), it is preferable to bring the annulus air system back on line within one to two weeks. However, significant degradation should not occur up to six months. Therefore, if general corrosion is the significant degradation mechanism, six months is the maximum permissible time to allow any of these conditions to exist.

4.4 Limits on Annulus Air System Outages

In addition to an assessment of the degradation mechanisms, the time necessary to make repairs to the annulus air system must be accounted for when making time limit recommendations. Although sufficient time must be allowed for repairs, limits which minimize conditions which may lead to degradation are necessary. On the basis of low

temperature embrittlement and salt deposit dissolution, the systems in Types I and II tanks are the most critical. These systems should be repaired as soon as possible. The situation is more critical during the colder winter months. For these tanks a reasonable time limit to allow for repairs is one month. The primary mechanism for Tanks 29-34 is low temperature embrittlement. These tanks have the same NDTT as the Type I and II tanks. Due to the lack of flaws in the tank wall, however, these tanks are not as great of a concern. A reasonable time limit for the repairs to these tanks is two months. The only mechanism of concern for the remaining Type III tanks is general corrosion. Although general corrosion has not been observed during inspections in the past, if nitric acid production occurs, accelerated general attack at an estimated rate of 0.1 inches/yr may occur. A reasonable time limit for Type III tanks, other than Tanks 29-34 is six months.

5.0 Evaporation Rate of Water in the Tank Annulus

Evaporation of condensate or standing water in the annulus depends on several variables such as the mass flow rate of air in the annulus, heat transferred from the tank contents to the annulus, and the temperature and relative humidity of the air in the annulus. An estimate of the evaporation rate may be calculated by performing an overall energy balance on the tank.

$$m_a(H_{out} - H_{in}) = m_w \lambda_v \quad (5)$$

where m_a is the mass flow rate of air in the annulus (lb/hr), H_{out} is the enthalpy of the air exiting the annulus (BTU/lb), H_{in} is the enthalpy of the ambient air, m_w is the evaporation rate of the water in the annulus, and λ_v is the latent heat of vaporization for water. The left hand side of the energy balance calculates the energy that is available to evaporate water. The equation assumes that no heat is lost to the ground surrounding the tanks.

Case studies were performed to study the effects of temperature and relative humidity of the ambient and exit air and the mass flow rate of air on the evaporation rate. The conditions chosen for the analysis are shown in Table 2 and are based on actual measurements of the conditions of the annulus air and expected ambient air conditions [14,15]. The ambient air conditions are representative of the extremes experienced at SRS. Measurements of the exit air relative humidity showed a range in relative humidity, 20-50 %, and a range in the difference between the relative humidity of the ambient air and the exit air of 14-44%. Taking these data into consideration, a representative value for the exit air relative humidity of 40% was chosen for the studies. An average value for the latent heat of vaporization within the exit air temperature range was also chosen (1060 BTU/lb). The enthalpies at the various temperatures and relative humidities were determined from psychrometric charts [16].

The results of the case studies are shown in Figures 4-7. Three observations can be made from these results. First, an increase in the exit air temperature will increase the evaporation rate. Second, the evaporation rate increases with the mass flow rate of the air. Finally, the evaporation rate decreases as the ambient temperature and relative humidity increase.

These figures can be utilized to make estimates of the evaporation rate of water in the annulus. For example, the case of 1-2 inches of standing water in the annulus was examined. To remove this water from the annulus within a day, the evaporation rate would need to be approximately 100 lb/hr. A comparison between cases where the exit

air temperature is 90 °F and 110 °F is shown in Tables 3 and 4. The minimum air flow rates necessary to remove 100 lb/hr of water from the annulus are shown in the Tables for

Table 2. Environmental Conditions for the Case Studies

Environmental Conditions	Range
Ambient Air Temperature	45, 60, and 90 °F (7, 15, 32 °C)
Ambient Air Relative Humidity	60, 90 %
Exit Annulus Air Temperature	90, 110 °F (32, 40 °C)
Exit Annulus Air Relative Humidity	40 %
Mass Flow Rate of Annulus Air	2200-22,000 lb/hr (500-5000 cfm)

various ambient air conditions. One recommendation from these results is to maintain the exit air temperature above 110 °F (approximately 40 °C) when evaporation of standing water is necessary. In this case, the blower requirements would be much lower (2000-3000 cfm vs. >5000 cfm) at the extreme ambient conditions. This may be significant to tanks which have limited blower capacity or heating coil capacity. It should also be recognized that at ambient temperatures greater than 90 °F, exit air temperatures higher than 110 °F would be needed to provide for evaporation.

Table 3. Required air flow rate (cfm) to evaporate 100 lb/hr of water from the annulus. Exit air temperature is 110 °F (40 °C).

Ambient Air Relative Humidity (%)	Ambient Temperature (°F)		
	45-70	70-90	> 90
60	1000	2000	3000
90	1000	2000	NE

NE - No evaporation of water will take place at these conditions

Table 4. Required air flow rate (cfm) to evaporate 100 lb/hr of water from the annulus. Exit air temperature is 90 °F (32°C).

Ambient Air Relative Humidity (%)	Ambient Temperature (°F)		
	45-70	70-90	> 90
60	2000	>5000	NE
90	4000	>5000	NE

NE - No evaporation of water will take place at these conditions

6.0 Conclusions

The recommended time limits for annulus air outages for the double shell tanks are presented in Table 5. These limits were decided on the basis of the impact of changes in the annulus environment on three mechanisms: 1) brittle fracture, 2) salt deposit dissolution and 3) general corrosion.

Table 5. Time Limits for Annulus Air Outages

Tank Number	Tank Type	Recommended Time Limit
1-16	I and II	One Month or Less
29-34	III	Two Months
25-28, 35-39, 41,43,44-47	III	Six Months

Three recommendations were made to assure that the general corrosion mechanism is not active during future annulus air outages: 1) Monitor the annulus air temperature daily during the outage to ensure that it is above the ambient temperature. 2) Minimize the time water is allowed to stand in the annulus. 3) If only the steam is off-line, continue to blow air through the annulus periodically to prevent the build-up of NO₂. If any of these three conditions exist (i.e., annulus air temperature less than the ambient air temperature, standing water, or stagnant air), it is preferable to bring the annulus air system back on line within one to two weeks. However, significant degradation should not occur up to six months. Therefore, six months would be the maximum permissible time to allow any of these conditions to exist.

Estimates for evaporation rates of standing water in the annulus were also calculated. Case studies that indicate that maintaining the annulus exit temperature above 40 °C will lower the air flow requirements necessary to evaporate the water.

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Figure 1. Effect of 30-hour Steam Outage at Tank 9

Figure 2. Tank 13 Temperatures During a 30-hour Steam Outage

Figure 3. Comparison of Blower Failure with Steam Outage, Tank 9

Figure 4. Evaporation Rate as a Function of Ambient Air Temperature. Exit Air Temperature = 90 °F; Exit Air Relative Humidity = 40%; Ambient Air Relative Humidity = 60%.

Figure 5. Evaporation Rate as a Function of Ambient Air Temperature. Exit Air Temperature = 90 °F; Exit Air Relative Humidity = 40%; Ambient Air Relative Humidity = 90%.

Figure 6. Evaporation Rate as a Function of Ambient Air Temperature. Exit Air Temperature = 110 °F; Exit Air Relative Humidity = 40%; Ambient Air Relative Humidity = 60%.

Figure 7. Evaporation Rate as a Function of Ambient Air Temperature. Exit Air Temperature = 110 °F; Exit Air Relative Humidity = 40%; Ambient Air Relative Humidity = 90%.