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Chemistry Envelope for Pitting and Stress Corrosion Cracking Mitigation

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September 2019

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EXECUTIVE SUMMARY

The present waste chemistry controls for the Hanford double-shell tanks (DST) were established in the 1980s in response to tank failures caused by stress corrosion cracking (SCC) at the DOE Savannah River Site (SRS). Portions of the SRS chemistry limits [1] were coupled with corrosion testing results from PNL [2,3] and adopted for corrosion control of the DST waste at the Hanford Site [4].

Since that time, the temperatures of many DST wastes have decreased to less than 50 °C as the radioactive material has decayed, the testing program in Argentina [5] demonstrated that chloride ion in Hanford Site waste could cause pitting, and other work showed that dilute solutions could cause pitting at the liquid air interface. Moreover, future transfers from the single shell tanks and the waste treatment plant [6] and process changes may shift the DST waste chemistries to a broader range of compositions with higher aggressive anion concentrations than the wastes that are presently stored.

The decreasing temperatures led to the formulation of new chemistry controls for the minimization of SCC risks for operations below 50 °C in 2010 [7], and these controls were partially adopted. The remaining concerns about pitting corrosion are addressed in this report.

Savannah River National Laboratory (SRNL) investigated the propensity for pitting of the carbon steel waste tanks at current and projected DST waste chemistries. A statistically designed series of tests provided a pitting factor that relates the ratio of the inhibitor species to the aggressive species and the probability of observing pitting. An acceptable pitting factor was determined and utilized for the development of a new waste chemistry envelope. The new waste chemistry envelope for pitting was compared to the limits that were established for SCC and determined to be bounding by the evaluation of numerous test results including dilute solutions and work at the liquid air interface. The limits are summarized in the table below.

Control Limits for Pitting and Stress Corrosion Cracking

Quantity	Minimum	Maximum
Temperature, °C		75
Hydroxide, M	0.01	6.0
Nitrite, M	0.20	
Nitrate, M		5.5
Nitrite/Nitrate Ratio	0.15	
Pitting Factor	1.2	

Validation of the new waste chemistry envelope was performed via comparison with historical pitting and SCC testing data. The new waste chemistry envelope will eventually be part of an overall assessment of the condition of the tanks and any changes made to the overall structural integrity program for the Hanford DSTs.

The outcome of the testing and validation program showed that this chemistry envelope is conservative for pitting corrosion for temperatures up to 75 °C and that the same envelope is conservative for SCC at temperatures up to 50 °C. There is also evidence that the envelope is conservative for SCC at temperatures up to 75 °C. For example, simulants of the tank wastes that are presently stored at temperatures above 50 C did not cause cracking at 95 C. However, uncertainties remain about the risks associated with novel new compositions, potential drift and the critical cracking potential at temperatures greater than 50 °C.

At this time, it is recommended that the waste chemistry envelope in the table be adopted for the control of pitting and cracking for temperatures up to 75 °C. The risks associated with the present compositions of the DST wastes are very well controlled by these limits. It is also recommended that additional SCC studies be carried out to determine the risks associated with other compositions at the margin of the control limits and to establish critical cracking potentials in the region between 50 and 75 °C. This work should be designed to establish a robust coverage for plausible new waste chemistries, determine the pitting risks associated with higher chloride ion contents and determine the critical cracking potentials of the wastes that may be delivered to the tanks during future operations at temperatures up to 75 °C.

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LIST OF ABBREVIATIONS

BBI	Best Basis Inventory
CPP	Cyclic Potentiodynamic Polarization
CSG	Corrosion Sub-Group
DNV-GL	Det Norske Veritas – Germanischer Lloyd
DST	Double Shell Tank
LAI	Liquid Air Interface
OCP	Open Circuit Potential
OSD	Operational Specifications Document
PF	Pitting Factor
PNL	Pacific Northwest Laboratory
SCC	Stress Corrosion Cracking
SCE	Saturated Calomel Electrode
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
THE	Tsujikawa-Hisamatsu Electrochemical
TIEP	Tank Integrity Expert Panel
WRPS	Washington River Protection Solutions

1.0 Background

The present waste chemistry controls for the Hanford double-shell tanks (DSTs) were established in the 1980s in response to tank failures caused by stress corrosion cracking (SCC) at the DOE Savannah River Site (SRS). Portions of the SRS chemistry limits [1] were coupled with corrosion testing results from Pacific Northwest Laboratory (PNL) [2, 3] and adopted for corrosion control of the DST waste at the Hanford Site. The operational specification document (OSD) limits [4] that were adopted in 1985 for the operation of the tanks at less than 75 °C are shown in Table 1.

Table 1. 1985 Chemistry Control Limits For DST Operation at Less Than 75°C

Waste Nitrate Content	Control Variable	Control Limit
$[NO_3] \leq 1.0$ M	[OH]	$0.010 \leq [OH] \leq 8.0$
	$[NO_2]$	$0.011 \leq [NO_2] \leq 5.5$
	$[NO_3]/([OH] + [NO_2])$	< 2.5
$1.0 \leq [NO_3] \leq 3.0$ M	[OH]	$0.1[NO_3] \leq [OH] < 10$
	$[OH] + [NO_2]$	$\geq 0.4[NO_3]$
$[NO_3] > 3.0$ M	[OH]	$0.3 \leq [OH] < 10$
	$[NO_2]$	> 1.2
	$[NO_3]$	≤ 5.5

Since that time, the temperatures of many DST wastes have decreased to less than 50 °C as the radioactive material has decayed, the testing program in Argentina [5] demonstrated that chloride ion in Hanford Site waste could cause pitting, and other work showed that dilute solutions could cause pitting at the liquid air interface (LAI). Moreover, future transfers from the single shell tanks and the waste treatment plant [6] and process changes may shift the DST waste chemistries to a broader range of compositions with higher aggressive anion concentrations than the wastes that are presently stored.

The decreasing temperatures led to the formulation of new chemistry controls for the minimization of SCC risks for operations below 50 °C in 2010 [7], and these controls were partially adopted.

The Tank Integrity Expert Panel (TIEP) Corrosion Subgroup (CSG) recommended that additional testing be performed to assess the potential for pitting and LAI corrosion [8]. Since 2015, DNV-GL, SRNL, and the Hanford Site laboratory have investigated pitting and LAI corrosion at current and anticipated DST chemistries and Savannah River National Laboratory (SRNL) undertook a statistically based investigation of the role of nitrate and halide ion induced pitting corrosion. The objective was to develop a comprehensive waste chemistry envelope for the simultaneous minimization of the pitting and SCC risks caused by halide and nitrate ions.

This report summarizes the technical basis for the new waste chemistry envelope to minimize the potential for both pitting and cracking corrosion induced by nitrate and halide ions, and the strategies used for the validation of the new controls.

2.0 Pitting Factor Development

2.1 Summary of Laboratory Testing

SRNL has conducted laboratory tests to investigate pitting corrosion at current and anticipated DST waste chemistries for the past 5 years [9-13]. The testing utilized a protocol for cyclic potentiodynamic polarization (CPP), developed in conjunction with the Tank Integrity Expert Panel Corrosion Sub-group (TIEP-CSG), to assess the susceptibility of carbon steel to pitting corrosion in DST chemistries [14]. The "pass" or "fail" condition was determined from the six categories specified by the CPP test protocol. Categories 1 and 2, for which CPP test indicated either a negative hysteresis or a significantly noble repassivation potential with respect to the initial open circuit potential (OCP) (>200 mV), respectively, were assigned a "0" or pass rating. Alternatively, categories 4, 5, and 6, which had positive hysteresis with a repassivation potential that was only slightly noble compared with the initial OCP (< 200 mV), a negative value when compared to the initial OCP, or indicated general corrosion, respectively, were assigned a "1" or fail rating. A category 3, or mixed hysteresis condition that was considered inconclusive, was re-tested using a modified ASTM G192 test method [15]. The modified ASTM G192 method is based on the Tsujikawa-Hisamatsu Electrochemical (THE) method and can be used to determine the repassivation potential. In this case, it was used to provide a definite categorization of pass or fail for borderline cases that showed mixed hysteresis [9-13]. If the results were a pass, "0" was used and if it was a fail "1" was used. The difference between the repassivation potential and the OCP provides assurance that the test interpretation is sufficiently conservative and provides an adequate assurance that pitting susceptibility is unlikely.

Statistically designed test matrices were utilized to explore the boundaries of the DST chemistry envelope as well as interior points within the envelope [9,10]. Since the majority of the tank waste is at lower temperatures, the early testing focused on environments at temperatures less than 50 °C. Table 2 shows the species that were investigated and the ranges of compositions for each.

Table 2. Composition Ranges for Statistical Tests

Entity	Minimum	Maximum
Hydroxide (M)	0.0001	1.2
Nitrate (M)	0.0	5.5
Nitrite (M)	0.0	1.2
Chloride (M)	0.0	0.4
Fluoride (M)	0.0	0.3
Sulfate (M)	0.0	0.2
TIC (M)	0.0	0.1
Temperature (°C)	25	50

During FY16, the major variables affecting pitting corrosion were determined from Plackett-Burman and Box-Behnken statistical design matrices. Nitrate, nitrite, hydroxide, and chloride were initially identified as the statistically significant variables that influenced the CPP results. Temperature was not identified as a significant variable [9,10]. For FY17, the original FY16 test matrix was augmented to include hydroxide concentrations up to 1.2 M given that 0.6 M hydroxide was insufficient to inhibit chloride concentrations up to 0.4 M [11]. These results were combined with the previous results from Plackett-Burman and Box-Behnken statistical design for a total of 80 conditions [11]. Next, 15 interior chemistry conditions were tested to assess the robustness of the statistical model [11]. These 95 data points were utilized to establish a statistical model. Finally, in FY18, margins tests were performed to better understand where the chemistry envelope should be established [12]. A second series of tests was performed to determine if the effects of the fluoride and chloride concentrations could be distinguished. This distinction is particularly significant for solutions with relatively low chloride concentrations, but relatively high fluoride concentrations.

Logistic regression analysis was performed to develop the model for pitting susceptibility prediction [11-13]. Logistic regression assumes a binary response, pass or fail in this instance. The probability of a failure, as determined from the CPP test, is calculated as shown in Equation 1. (Note: "1" is indicative of a failure, while "0" indicates a pass condition). Equation 2 is the linear relationship between the statistically significant variables. The statistically significant variables were hydroxide, nitrate, nitrite, chloride and fluoride. Inhibitor species are indicated by a positive coefficient, while aggressive species have a negative coefficient.

$$P(1)=\frac{1}{1+e^{Lin[0]}} \qquad \text{Equation 1}$$

$$Lin\ (0) = a + b\ [OH^-] + c\ [NO_2^-] - d\ [NO_3^-] - e\ [Cl^-] - f\ [F^-] \qquad \text{Equation 2}$$

The coefficients calculated from the statistical analysis are shown in Equation 3.

$$Lin\ (0) = 1.99 + 15.54\ [OH^-] + 2.99\ [NO_2^-] - 1.93\ [NO_3^-] - 32.11\ [Cl^-] - 10.7\ [F^-] \qquad \text{Equation 3}$$

The probability predicted by this equation is not directly tied to the absolute probability of tank failure as discussed by Dr. N. Sridhar in Appendix A. Time dependent factors such pit induction time, pit growth rate and variability in the repassivation potential and the long-term corrosion potential were not considered in the development of Equation 1. However, the probability in Equation 1 may be considered a "marginal probability" and provides a snapshot in time of the relative probability of whether a given waste chemistry is aggressive or benign.

The coefficients for the species variables generated from the probability model were utilized in the development of an empirical "pitting factor" to provide a criterion for pitting susceptibility [12,13]. Equation 4 shows the final form of the pitting factor. The pitting factor is a weighted ratio of the inhibitor species to the aggressive species.

$$Pitting\ Factor = \frac{8.06*[Hydroxide]+1.55*[Nitrite]}{[Nitrate]+16.7*[Chloride]+5.7*[Fluoride]} \qquad \text{Equation 4}$$

2.2 Establishing the Waste Chemistry Envelope

The probability calculated from Equation 1 was eventually linked to the pitting factor in Equation 4 to estimate an operating envelope that defines aggressive and benign chemistries. Randomized parameter simulation studies were performed to investigate the relative aggressiveness of possible DST chemistries. The simulations were performed with an EXCEL™ spreadsheet. Up to 2000 random waste chemistries were generated from concentrations of hydroxide, nitrite, nitrate, chloride, and fluoride. Ranges on the random compositions for each species were simulated based on the chemistry envelope shown in Table 2 (e.g., a minimum nitrite concentration of 0.20 M, a maximum nitrate concentration of 5.5 M etc.). For each composition, the pitting probability and the pitting factor were calculated. The range for hydroxide ion is expressed in concentration units (0.0001 to 6.0 M). Figure 1 shows the log [OH] vs. the pitting factor and the probability of failure for each of the random simulations. Table 3 shows the relationship between the colors in the figure and the probability of pitting.

For a pitting factor less than 1, the probability of pitting is typically greater than 0.2, with most of this range having a pitting probability greater than 0.5. For a pitting factor greater than 2, the probability of pitting is less than 0.01. For a pitting factor between 1 and 2, the probability ranges between less than 0.01 to less than 0.2. The hydroxide ion concentration has a significant influence on the probability that is observed. For example, when the hydroxide concentration was greater than 0.1 M with a pitting factor greater than 1.2, the pitting probability was always observed to be less than 0.01. However, for a hydroxide concentration less than 0.1 M, but greater than 0.01 M, with a pitting factor between 1.2 and 2, there were several instances where the probability of pitting is up to 0.03.

Utilizing these results, initial boundaries for the waste chemistry envelope were developed. The green area, shown in Figure 1, represents an area where the likelihood of pitting susceptibility is low, while the pink area represented a higher likelihood of pitting susceptibility and is therefore less desirable. This initial envelope was a compromise with the present corrosion chemistry requirements, which allow a minimum hydroxide concentration of 0.01 M hydroxide. However, a review of this proposed envelope during FY19 challenged the use of the higher probability region between 0.01 M and 0.1 M hydroxide [13]. A review of historical pitting data also demonstrated that there was a lack of data in this region.

During FY19, SRNL performed a series of CPP tests between a PF of 1 and 2 and hydroxide concentrations between 0.01 M and 0.1 M [13]. The results for all these CPP tests were a “pass”, which gave greater confidence that the proposed chemistry envelope provided an adequate margin for pitting susceptibility. These results along with the model results were plotted in Figure 2. From this figure it is apparent that the recent pitting corrosion tests support the proposed chemistry envelope.

Figure 2 does not indicate what can happen in relatively dilute nitrate solutions (i.e., on the order of less than 0.1 M). Previous testing at SRS and other labs has shown that, for dilute solutions, a minimum nitrite concentration is required in order to ensure that pitting has been effectively mitigated [16]. At extremely dilute concentrations (e.g., nitrate concentrations less than 0.1 M), higher nitrite/aggressive species ratios are required than are necessary for more concentrated solutions to minimize the likelihood of pitting. This series also demonstrated that, if the nitrite is eliminated, Category 3 and 4 behavior is possible even at PF greater than 1.2 [12].

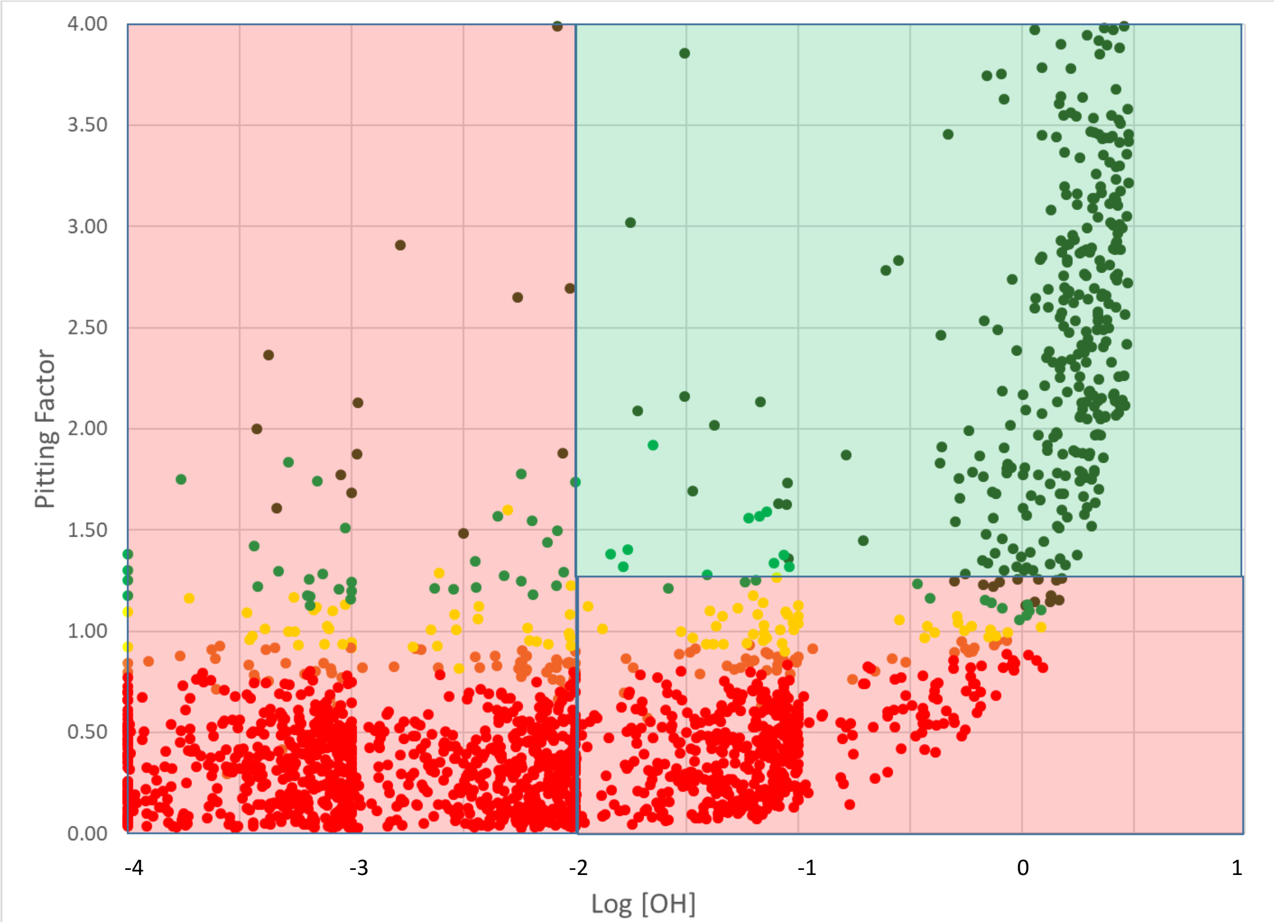

Figure 1. Pitting factor waste chemistry envelope. Marginal probability of pitting less than 0.01 is represented by the dark green circles, while all probabilities greater than 0.01 are represented by the red circles. The green shaded area is an acceptable region, while the pink shaded area is unacceptable.

Table 3. Legend for Figure 1 Probabilities

Color	Marginal Probability of Pitting
Dark Green	< 0.01
Green	0.01 < P < 0.05
Yellow	0.05 < P < 0.20
Orange	0.2 < P < 0.5
Red	P > 0.5

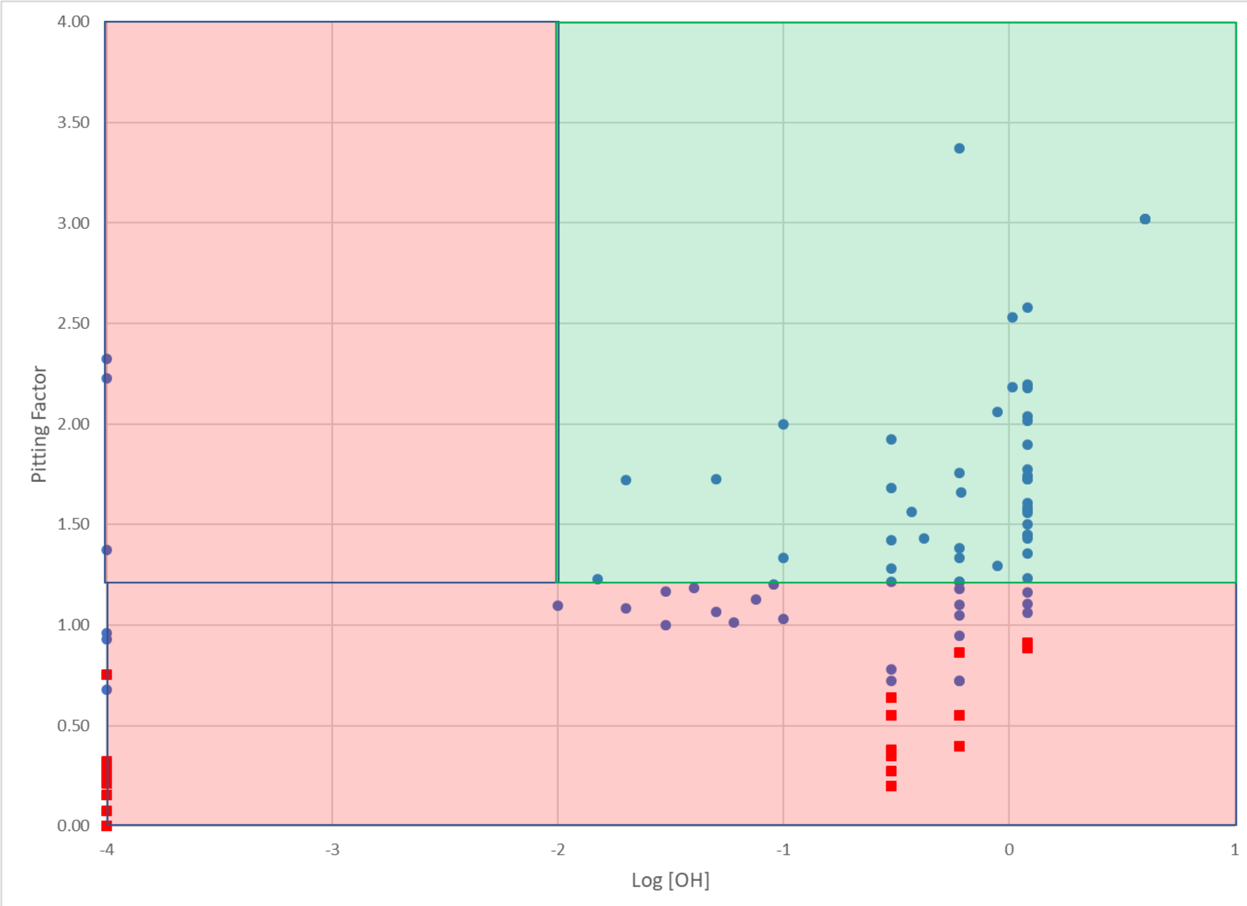

Figure 2. Summary of testing data utilized to develop the logistic regression model for 50 °C or less. The blue circles indicate a "pass" condition, while the red squares indicate a "fail condition. Note that several tests were performed at Pitting Factors greater than 4. All these conditions were a "pass" or no pitting condition.

During FY19, WRPS identified a few cases where the temperature of the interstitial liquid present in the waste exceeded 50 °C. A series of CPP tests was performed at 75 °C, which augmented the 50°C test matrix that was utilized to develop the logistic regression model [13]. The ranges for the chemical components were the same as shown in Table 2. In addition, tests in simulants with hydroxide concentrations between 1.2 and 6 M were performed. It was anticipated that the results of these latter tests would indicate "pass"; however, since they represent current hydroxide concentrations in the DSTs, they were performed to confirm this expectation [13]. The results of both series of tests were combined with the 50°C test data and are shown in Figure 3. Visually these results confirmed the proposed waste chemistry envelope for pitting. These data are summarized in Appendix B.

However, upon updating the logistic regression model, the best-fit model demonstrated a slight temperature dependence [13]. A statistical comparison between the model that included the temperature effect and the original model demonstrated a slightly better fit. A similar observation was made at SRNL for pitting corrosion at temperatures greater than 50°C [10]. A partition analysis was performed to assess regions of the envelope where the temperature was a significant factor [13]. Figure 4 highlights the region where the temperature effect was significant (i.e., at low hydroxide and low PF). At the higher PF and hydroxide concentration (green area), the temperature did not have a significant statistical effect. Thus, utilization of the logistic regression model without the temperature dependence would remain conservative.

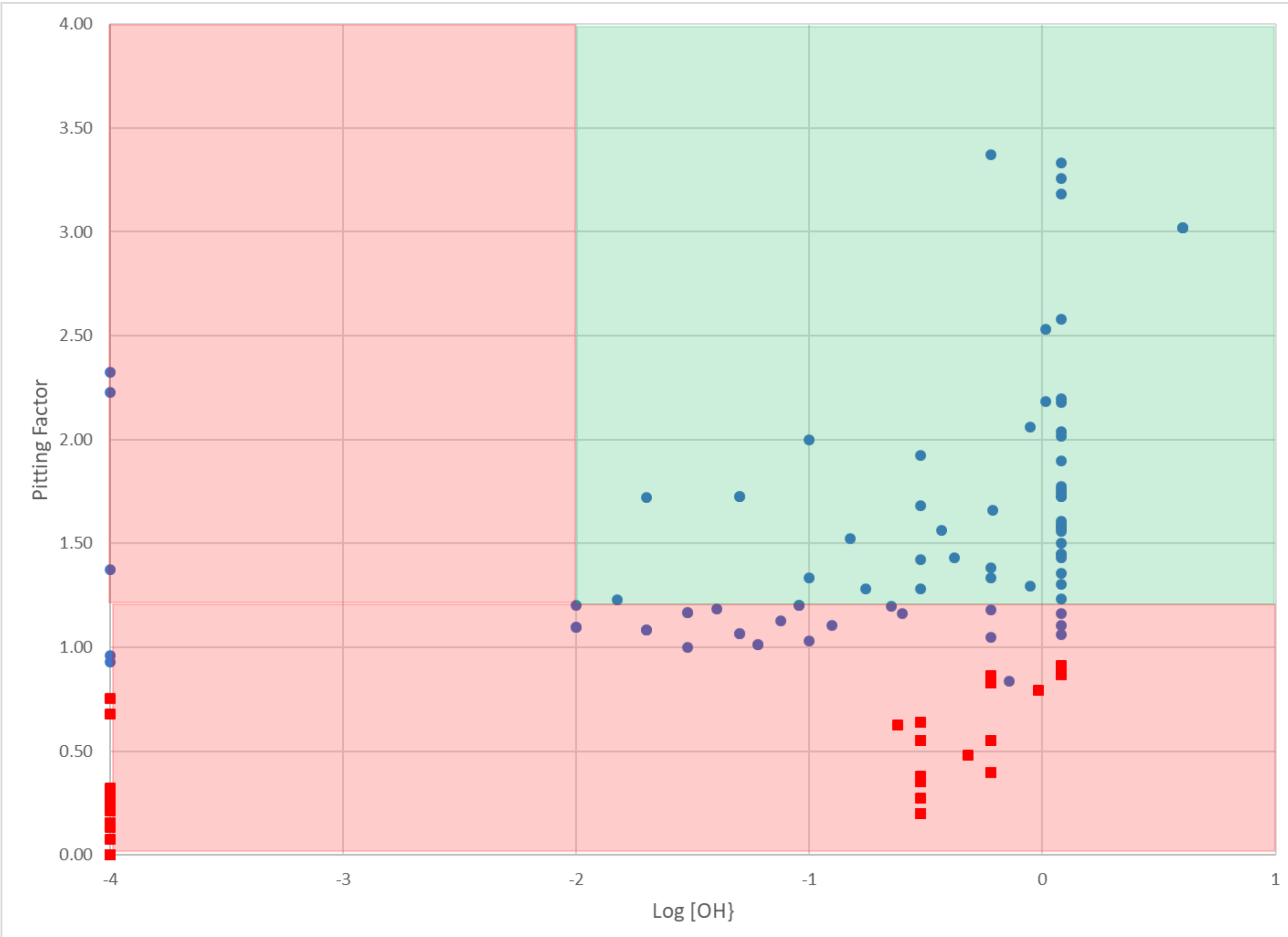

Figure 3. Summary of testing data utilized to develop the logistic regression model for 75 °C or less. The blue circles indicate a "pass" condition, while the red squares indicate a "fail" condition. Note that several tests were performed at Pitting Factors greater than 4. All these conditions were a "pass" or no pitting condition.

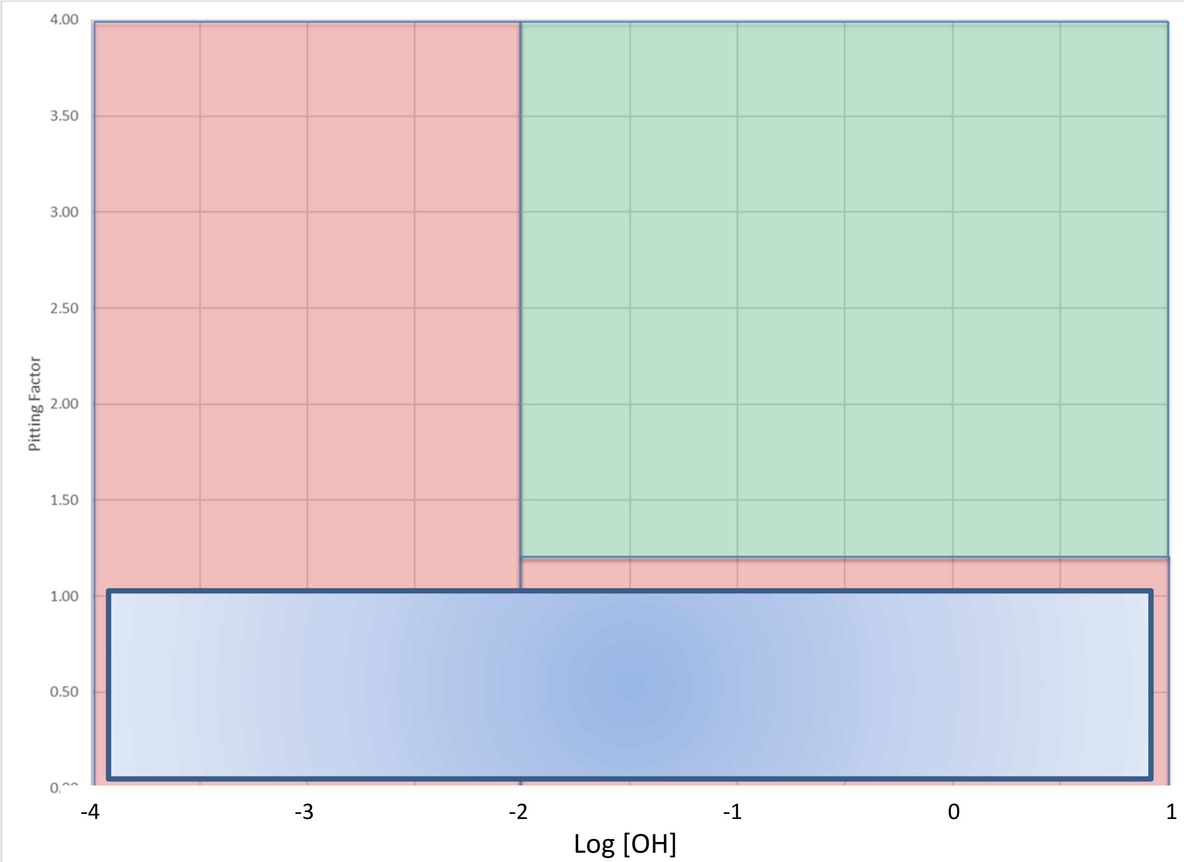

Figure 4. Waste chemistry envelope region most impacted by a temperature increase from 50 to 75 °C is shown by blue shaded box.

2.3 Margins on the Waste Chemistry Envelope Boundary

Figures 2 and 3 appear to indicate that, from a chemistry standpoint, there is sufficient margin at the boundary between the pitting susceptibility and no pitting regions. However, electrochemical measurements, CPP or G192 tests, were utilized to determine a “pass” or “fail” condition [14,15]. The protocol that was established determined a sufficient margin for pitting susceptibility existed if the difference between the repassivation potential and the open circuit potential, which will be designated as Delta, as determined by the CPP test was greater than 200 mV. The values of Delta near the pitting susceptibility envelope boundary were examined and the results are shown in Figure 5.

At PF values greater than 2, Delta values were nearly always greater than 800 mV vs. SCE. In other words, the CPP results indicated negative hysteresis or a Category 1 behavior. For test conditions with PF values between 0.9 and 2, Category 2 behavior was more evident. Approximately 14% of the test conditions indicated Delta values between 400 to 800 mV vs. SCE. The transition from the no-pitting region to the pitting susceptibility region appears to take place at PF values between 0.6 and 0.9. In this range, 67% of the CPP test results were a Category 4 or less (i.e., Delta less than 200 mV). Clearly below a PF of 0.6, all test results were categorized as a “fail”. Thus, for the selection of a PF of 1.2 as a boundary for the chemistry envelope, the difference between the critical repassivation potential and the open circuit potential provides assurance that a significant margin exists.

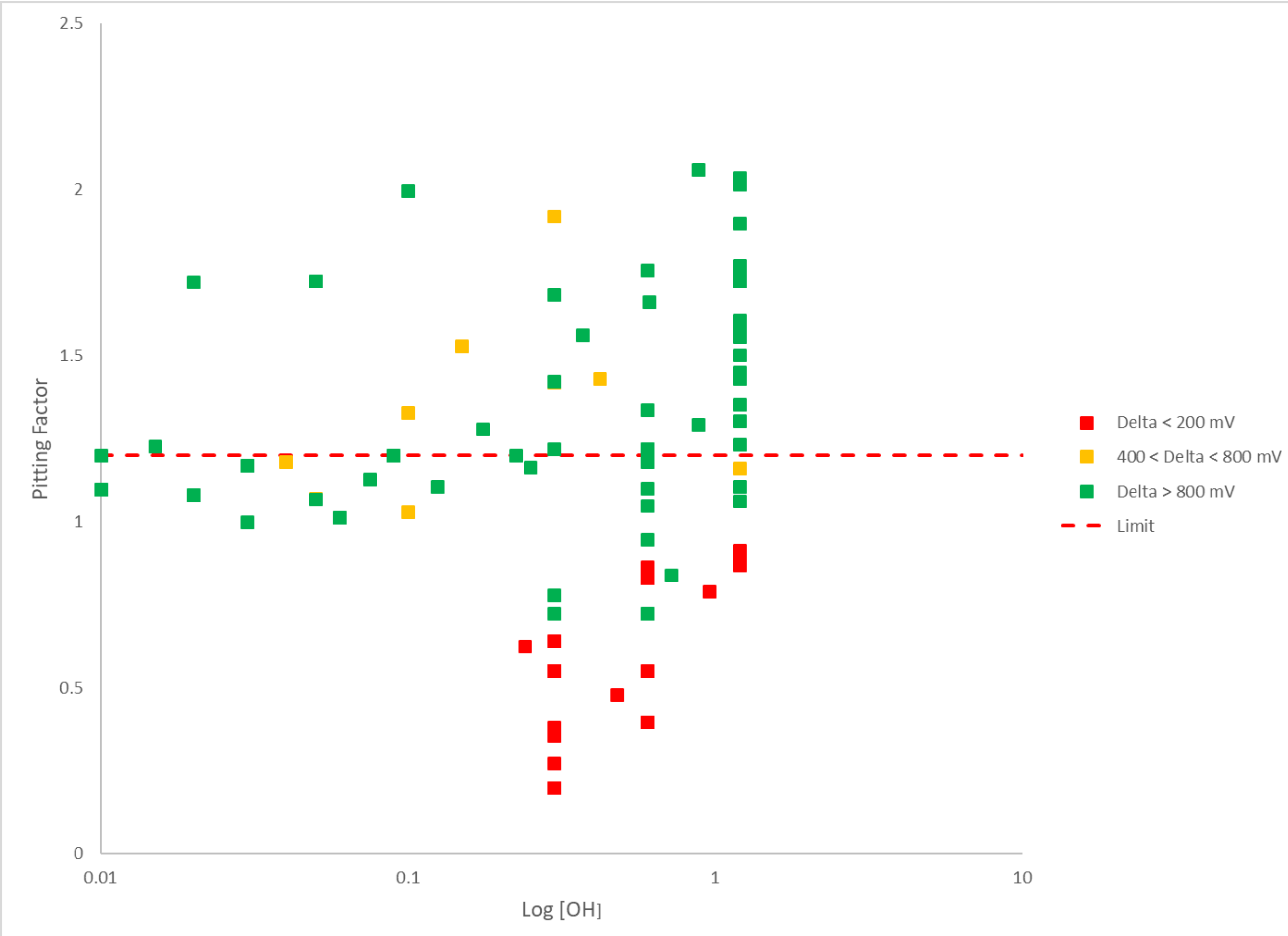

Figure 5. Summary of the difference between the repassivation potential and the open circuit potential (Delta) at conditions near the boundary of the pitting susceptibility envelope.

Delta is based on both the repassivation potential and the OCP measured after 2 hours. Laboratory tests have shown that the OCP may drift in a noble direction for several weeks (see Figure 6 [16]. The danger is that with this drift, Delta may decrease to less than 200 mV and hence reduce the margins for the envelope. Studies on the drift have shown that the final potential for the drift is determined primarily by the pH of the solution (see Figure 7) [17]. The chemistry envelope requires that the free hydroxide concentration be greater than 0.01 M (i.e., pH greater than 12). From Figure 7 it is estimated that the maximum open circuit potential drift would be to a final potential on the order of -150 mV vs. SCE. Given that the repassivation potentials that were measured by the CPP or the G192 test were all typically greater than 300 mv vs. SCE [13], Delta would still be large enough to provide assurance of adequate margin on the boundary of the chemistry envelope.

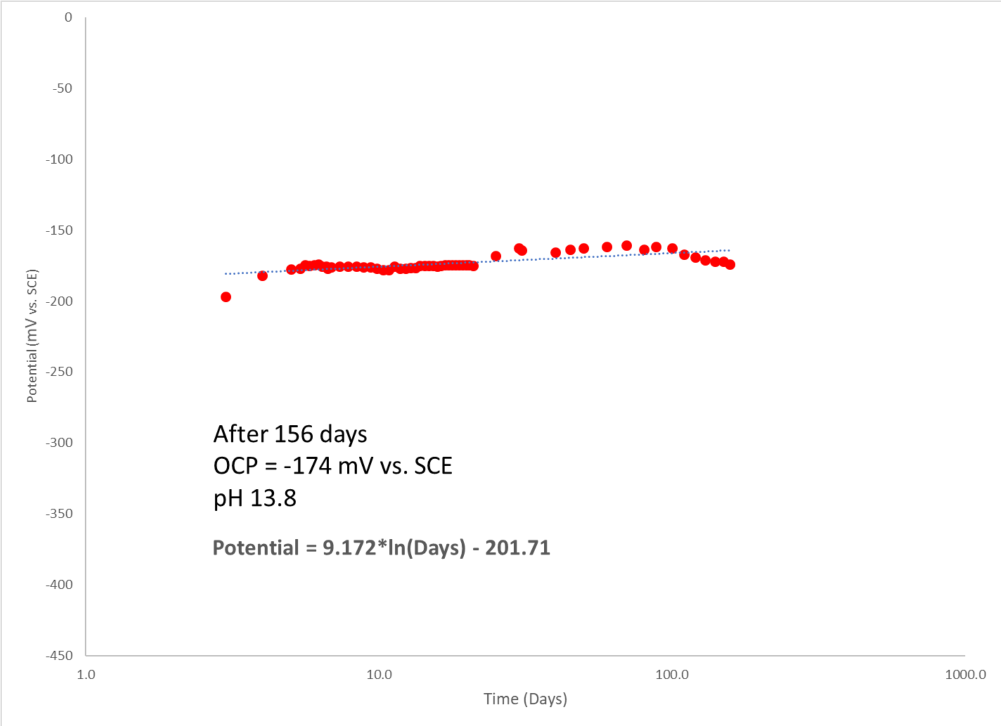

Figure 6. Open circuit potential drift in a pH 13.8 waste simulant [13]

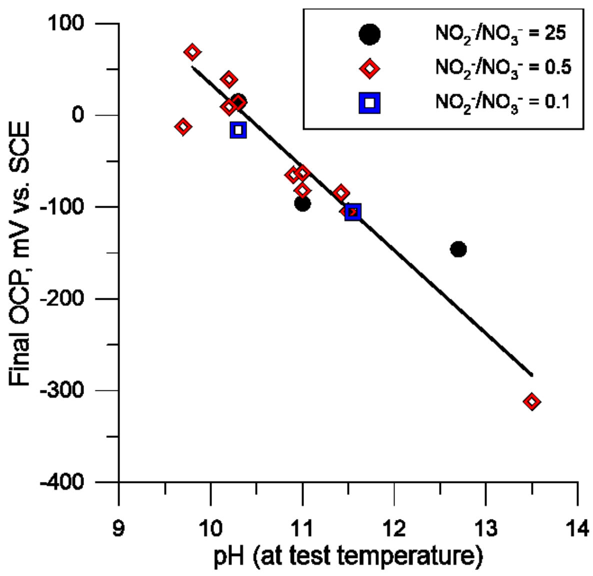

Figure 7. Final open circuit potential as a function of the pH of the simulant [17].

2.4 Validation of the Waste Chemistry Envelope

Two approaches were utilized to validate the envelope necessary to minimize the probability for pitting corrosion: 1) Comparison with historical CPP data, and 2) Long-term total and partial immersion coupon tests. The former comparison evaluates the model regarding data obtained from several laboratories that have performed work in simulated radioactive wastes and actual waste over the past several years (ca. 2005-2018). The latter set of tests evaluates longer-term (i.e., 4 months) exposures of steel coupons in representative wastes at the open circuit condition. In particular, the partial immersion tests evaluate the potential for LAI corrosion.

The historical CPP results are plotted in Figures 8 and 9. The environmental conditions for the historical tests are shown in Table 4, while specifics of each of the tests that were performed are summarized in Appendix C. Not all tests were performed with the presently accepted pitting protocol test methodology. However, historical results were validated with the new pitting protocol and observed to produce consistent outcomes [14]. Initially, historical data at temperatures less than 50 °C were evaluated given that the majority of tanks were at temperatures less than 50 °C (Figure 5). Later in the process of developing the chemistry envelope, a few tanks with higher interstitial liquid temperatures were considered [13].

Table 4. Range of Compositions and Temperatures for Historical Tests

Species/Temperature	Minimum	Maximum
Hydroxide (M)	0.0001	7.3
Nitrite (M)	0.0	7.0
Nitrate (M)	0.0	5.5
Fluoride (M)	0.0	0.58
Chloride (M)	0.0	0.40
Sulfate (M)	0.0	0.48
TIC (M)	0.0	2.1
Temperature (°C)	20	75

Both sets of historical data provide confirmation of the pitting susceptibility envelope (i.e., red region) at hydroxide concentrations between 0.0001 and 0.01 M and for PF values less than 1. As can be seen from Figure 3, the data collected during the model development did not contain much data in this region. Approximately 80% of the CPP tests performed at waste chemistries with a PF less than 1 failed. This region typically correlates to marginal probabilities as calculated from the model of greater than 0.2. There were no CPP test failures at PF greater than 1.2 and at hydroxide concentrations greater than 0.01 M. For hydroxide concentrations greater than 0.1 M, the marginal probability is less than 0.01, while for hydroxide concentrations between 0.01 M and 0.1 M the marginal probabilities as calculated from the model are less than 0.03. This slightly higher relative probability range demonstrates the influence of the hydroxide concentration on the corrosivity of the waste chemistry.

Although there is less CPP data, it appears that, at PF values greater than 1.2 and hydroxide concentrations greater than 0.0001 M, pitting susceptibility is minimal. From the equation for the PF, it can be shown that, in this region, the nitrite concentration must provide inhibition. While SRS has shown nitrite to be effective at inhibiting dilute solution chemistries [16], inhibition with nitrite at PF values greater than 2 can require significant quantities (i.e., high molar concentrations) if the nitrate concentration is greater than 1 M or the halide concentration (i.e., chloride or fluoride) exceeds 0.1 M. Therefore, from an operational standpoint (i.e., less sodium-based inhibitor additions) it may be more effective to add hydroxide as the inhibitor.

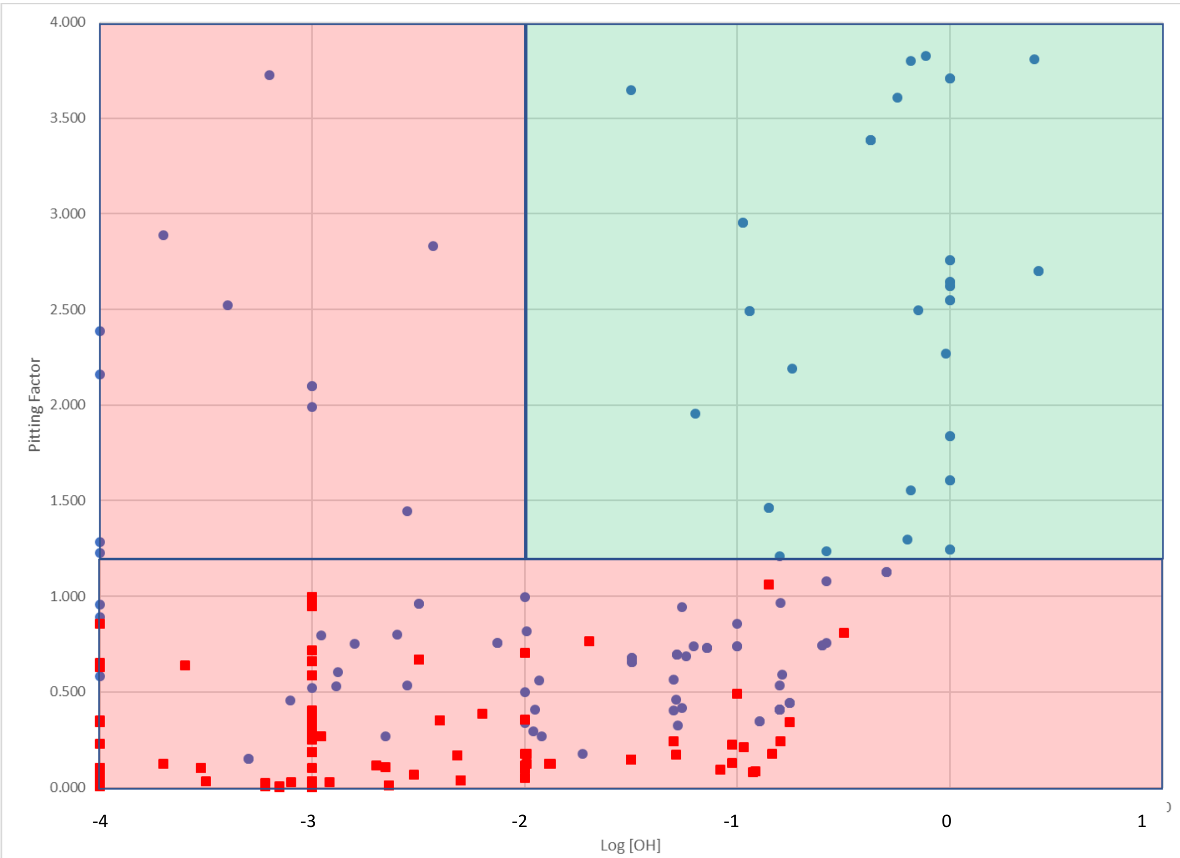

Figure 8. Historical experimental results at temperatures between 25 and 50 °C. Circles indicate a test condition that was a "pass", while squares indicate a test condition that was a "fail". Green shaded area is an acceptable region, while pink shaded area is unacceptable.

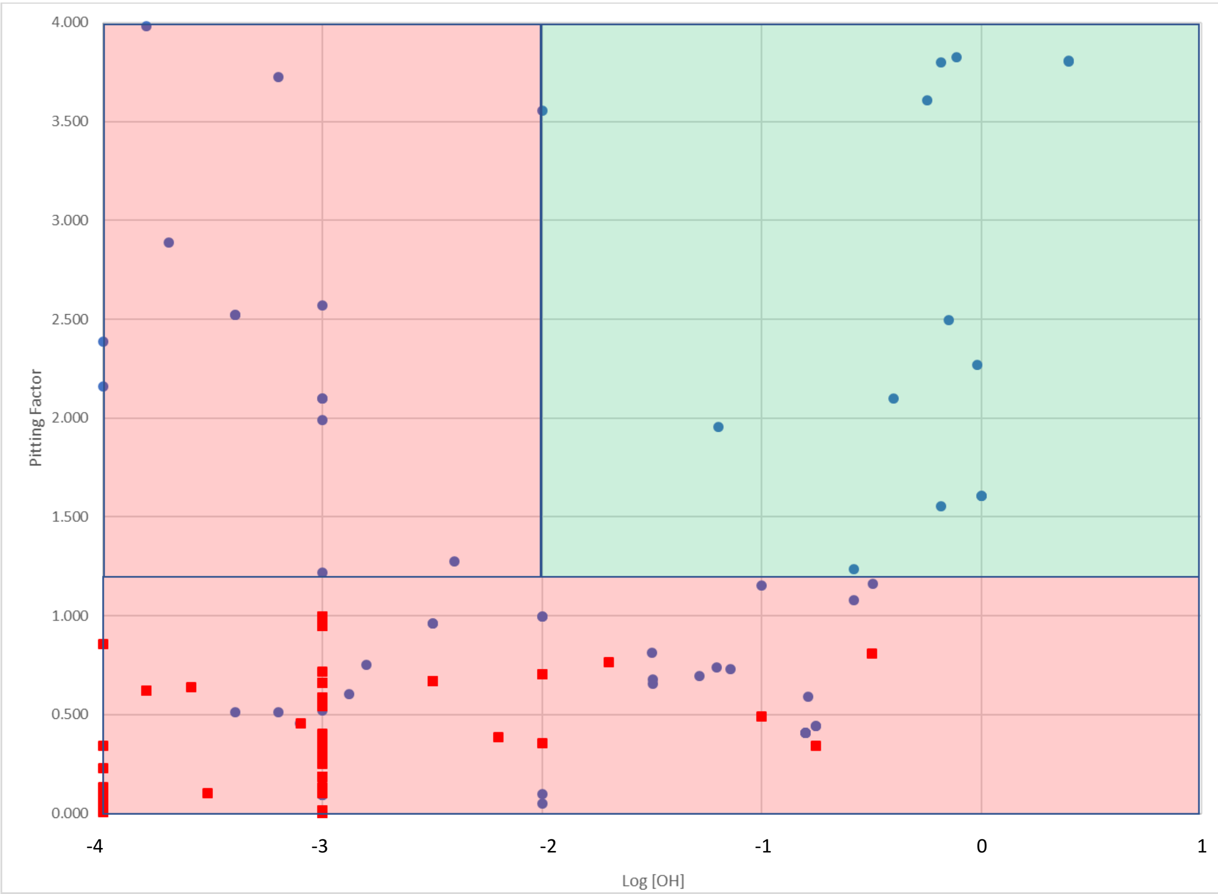

Figure 9. Historical experimental results at temperatures between 50 and 75 °C. Circles indicate a test condition that was a "pass", while squares indicate a test condition that was a "fail". Green shaded area is an acceptable region, while pink shaded area is unacceptable.

Coupon immersion testing has been utilized previously to confirm the results of the CPP tests [16]. As mentioned above, the partial immersion tests are particularly effective at identifying the risk of LAI corrosion. The following subjective criteria were utilized to assess these coupons.

Severe: Significant corrosion occurs both above and below the LAI (i.e., pits from 2-8 mils deep). Allowing the steel surface to be exposed to these conditions could lead to significant degradation.

Minor: Surface corrosion occurs at and above the LAI, with minimal or no corrosion below (<< 1 mpy). Allowing the liquid level to remain constant at this level for a significant period of time while exposed to these conditions increases the possibility of LAI corrosion.

No Attack: Surface corrosion occurs only in the vapor space and is clearly above the LAI. This attack may have initiated due to condensation or humid air. A stagnant liquid-air interface at this waste chemistry is relatively benign and produces only minor attack in the vapor space.

Table 5 summarizes the results of immersed coupons from FY18 [12]. The data indicate that the hydroxide concentration controls the corrosion rate in the bulk solution. The corrosion rates were 1 mpy or less for hydroxide concentrations greater than 0.1 M and decrease with an increase in hydroxide concentration. In general, an increase in the PF, which is associated with an increase in the nitrite concentration at low hydroxide concentrations, resulted in a decrease in the corrosion rate as well. These results indicate that, for the bulk solutions with hydroxide concentrations greater than 0.1 M, the corrosion rate is relatively insignificant (i.e., 1 mpy or less) irrespective of the pitting factor.

Table 5. Corrosion Rates of Completely Immersed Coupons

for Different Hydroxide Concentrations and Pitting Factors.

Hydroxide (M)	Corrosion Rates for Pitting Factor (mpy)		
	< 1	Between 1 and 2	> 2
0.0001	2.04, 1.86	0.41, 0.33	0.30, 0.23
0.1	1.00, 0.18	0.17 - 0.44	N/A
0.3	0.16 - 0.37	0.02 - 0.08	N/A
0.6	0.09 - 0.21	0.03 - 0.17	N/A

Table 6 shows the results for the partially immersed coupons. The behavior at the LAI showed a stronger dependence on the PF than was observed for the totally immersed coupons. These results indicate that, for a pitting factor less than 1, minor or severe attack was observed for for low hydroxide concentrations. For a PF between 1 and 2, minor or no corrosion was observed for all hydroxide concentrations. Additionally, at 0.1 M hydroxide, the addition of nitrite (0.6 M and 1.2 M) either reduced the amount of attack at the interface or eliminated it completely.

Table 6. Corrosion Rates at the LAI of Partially Immersed Coupons

for Different Hydroxide Concentrations and Pitting Factors.

Hydroxide (M)	Severity of corrosion based on Pitting Factor		
	< 1	Between 1 and 2	> 2
0.0001	Severe	Minor/None	Minor/None
0.1	Severe/None	Minor/None	N/A
0.3	None	None	N/A
0.6	Minor/None	None	N/A

Figure 10 shows the areas where LAI corrosion is potentially significant and also compares these data to the proposed waste chemistry envelope. Additional immersion tests were performed from 2013 through 2015 [9,18,19]. There was one result, Test 3, that was near the boundary, however, this again was only superficial attack. Severe attack was only observed at PF values less than 0.5 and typically at hydroxide concentrations less than 0.001 M. The plot in Figure 10 shows regions of concern, in red, that are similar to what was observed based on the CPP tests.

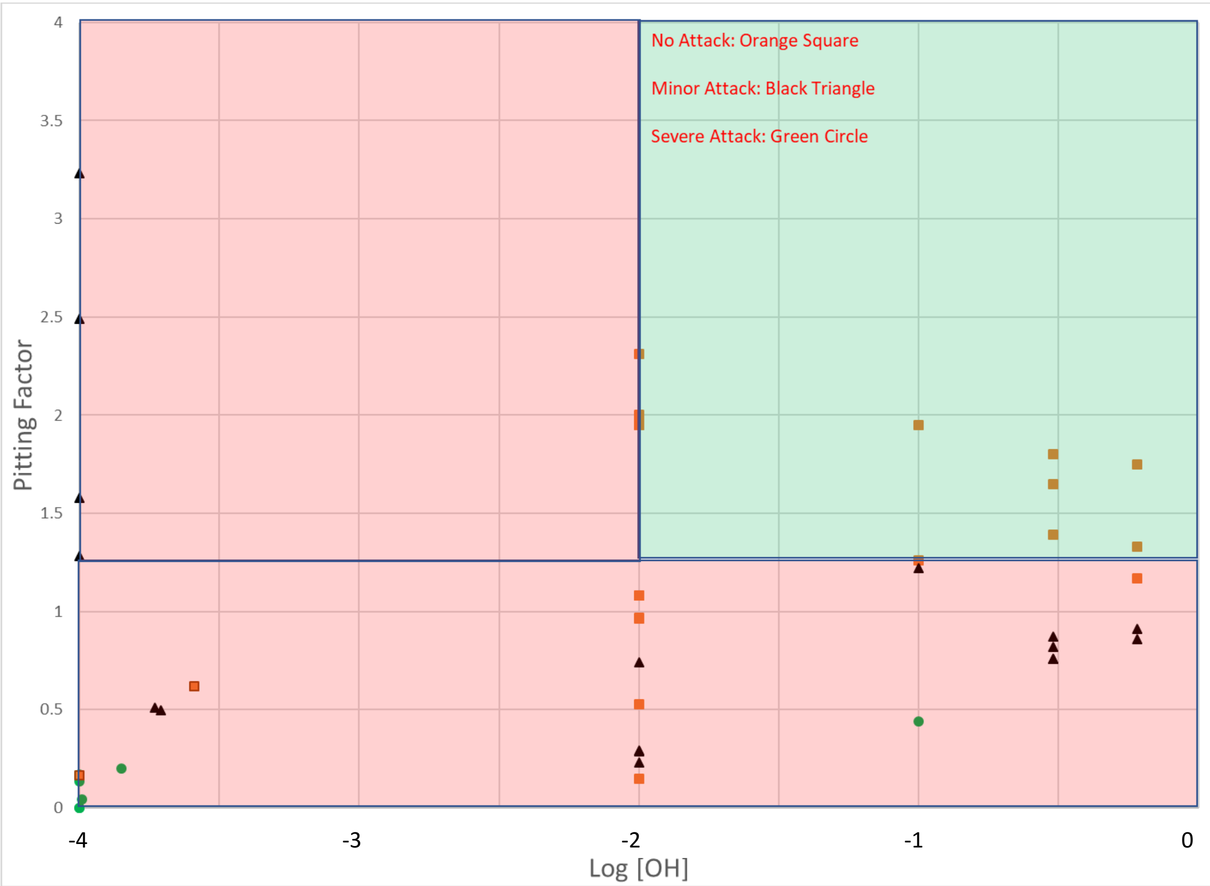

Figure 10. Results of coupon immersion tests plotted on the waste chemistry envelope.

The control limits for pitting that were formulated through these investigations are shown in Table 7.

Table 7. Control Limits for Pitting Corrosion

Limit	Minimum	Maximum
Hydroxide, M	0.01	6.0
Nitrite, M	0.20	
Nitrate, M		5.5
PF	1.2	
Temperature, °C		75

It is clear from the previous discussion that the PF approach minimizes the pitting risks associated with nitrate and halide ions, but no maximum concentrations for fluoride and chloride ions are presented in the table. The upper limits used in the statistical testing program were 0.30 and 0.40 M, respectively. But other observations in the historical work strongly suggest that the risks associated with higher concentrations of halide ions can be controlled by adequate concentrations of hydroxide and nitrite ions. The adoption of the limiting concentrations used in the statistical test work would be premature under these circumstances. It is recommended that additional statistical work be carried out to establish the maximum allowable concentrations of chloride and fluoride ions in the supernatant and interstitial liquids.

3.0 Stress Corrosion Cracking Chemistry Envelope

As pointed out in Section 1.0, the original OSD requirements were principally formulated to control SCC. The decreasing temperatures of the wastes prompted a reconsideration of the controls and led to the recommendation of other limits for the control of cracking in 2010 [7]. These limits are shown in Table 8.

Table 8. Composition Limits for the Control of Cracking at 50 °C

Quantity	Minimum	Maximum
Hydroxide (M)	0.001	6.0
Nitrite (M)	0.05	
Nitrate (M)		5.5
Nitrite/Nitrate Ratio	0.15	
Temperature (°C)		50

The technical basis for the adoption of these limits was provided by the analysis of the results of more than 400 tests of waste simulants that completely encompassed the compositions of the DSTs [7]. The Double-Shell Tank Expert Panel Oversight Committee reviewed and endorsed them [19].

The changes from the OSD requirements included restricting the waste temperatures to 50 °C, requiring that the minimum hydroxide ion concentration be 0.001 M, increasing the minimum nitrite ion concentration from 0.011 M to 0.05 M, and introducing a new specification that the minimum nitrite ion/nitrate ion concentration ratio be 0.15. Examination of the test results revealed that no test solutions with a nitrite ion/nitrate concentration ratio greater than 0.08 had caused cracking within the boundaries of the recommended specifications. The 2010 specifications for the minimization of the SCC hazard set this parameter conservatively at 0.15 [7]. Simulants with the compositions near the margins of the limits were tested. For example, a test solution with 0.575 M nitrite ion and 5.75 M nitrate ion with 0.0001 M hydroxide ion did not cause cracking when tested at 50°C. In addition, the test information showed no compliant composition caused cracking below 75 °C [7]. Consequently, there was at least a 25°C difference between the limiting tank temperature and the possible onset of cracking.

Other simulant testing was performed to assure that the few tank liquids that were stored at temperatures greater than 50 °C did not cause cracking [7]. Similarly, testing was also carried out to assure that the two tank liquids with high inorganic carbon contents did not cause cracking [7]. Hanford Site management did not formally adopt the proposed limits, but a modified version of them was applied to a selective group of tank wastes [7].

As also pointed out in Section 1.0, the objective of the new work was to formulate control limits that would simultaneously control the pitting and cracking corrosion risks.

The application of the new pitting corrosion limits (Table 7) for the control of the risks associated with cracking was examined by consideration of the results of more than 600 tests that have now been conducted to assess the temperature and compositional risks associated with nitrate ion induced SCC of Hanford Site wastes. The hydroxide, nitrite, and nitrate concentrations are summarized in Appendix B, and the relationship between PF and log[OH] for the family of results with PF values less than 10 is shown in Figure

11.

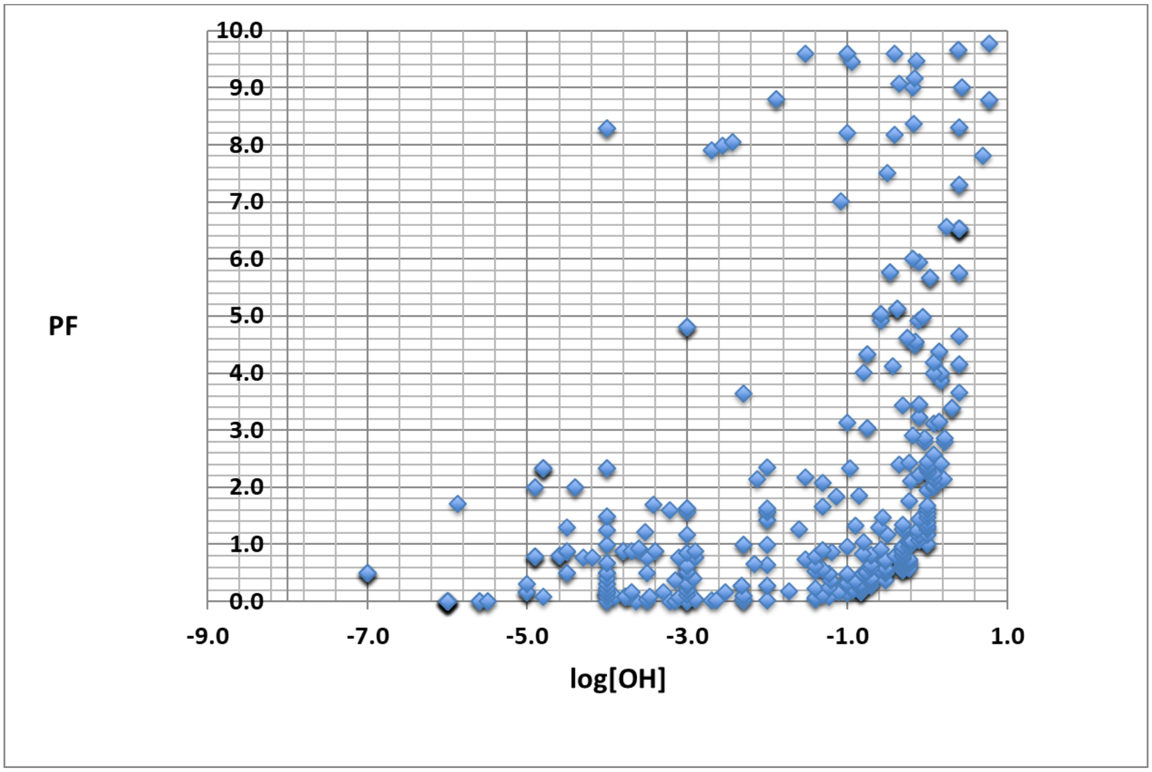

Figure 11. Family of Test Conditions for Stress Corrosion Cracking

3.1 Stress Corrosion Cracking Control Development at 50 °C

The new PF requirements, Table 7, for the control of pitting increase the hydroxide ion requirement from 0.001 to 0.01 M, and the nitrite ion requirement from 0.05 to 0.20 M. These changes reduce the risks for SCC. The cracking risks are also reduced in a more subtle way for dilute solutions of hydroxide ion by the requirement that PF be greater than 1.2. This feature of the PF controls is conveniently shown by consideration of the following relationships.

A useful "maximum value" of PF is given by eliminating the halide ion concentrations in Equation 4 from consideration to obtain Equation 5. If PF is required to be 1.2 for solutions with low concentrations of hydroxide ion, Equation 5 converts to Equation 6, and the required nitrite ion/nitrate ion ratio increases from 0.15 to 0.77 for dilute hydroxide ion solutions.

$$\mathrm{PF} = \frac{8.06*[Hydroxide]+1.55*[Nitrite]}{[Nitrate]+16.7*[Chloride]+5.7*[Fluoride]} \qquad \text{Equation 4}$$

$$\mathrm{PF(Max)} = \frac{8.06*[Hydroxide]+1.55*[Nitrite]}{[Nitrate]} = 1.2 \qquad \text{Equation 5}$$

$\text{PF(Max)} = \frac{[Nitrite]}{[Nitrate]} = 1.2/1.55 = 0.77$ Equation 6

Clearly, the adoption of the PF limits with higher minimum concentrations of hydroxide and nitrite ions will necessarily strengthen the already acceptable chemistry control limits for the minimization of SCC at 50 °C.

3.2 Stress Corrosion Cracking Controls Development at 75 °C

It is well known that SCC is temperature dependent as discussed previously [7] and reaffirmed in recent tests [21]. The applicability of the PF control limits for the minimization of the cracking risk in the temperature region between 50 and 75 °C was investigated by examining the observations for about 275 tests that have been conducted between 55 and 140 °C. This information was compiled from the earlier report [7] and the ongoing testing program at DNV-GL [21-26] and included additional testing at the compositionally significant margins at 95 °C [21]. The compositional ranges for the complete set of tests are shown in Table 9.

Table 9. Composition Ranges in Applicable SCC Tests

Quantity	Minimum	Maximum
Temperature (°C)	55	140
Hydroxide (M)	0.0000001	10.0
Nitrate (M)	0.0	4.4
Nitrite (M)	0.0	8.0
Nitrite/Nitrate Ratio	0.0	1.68
PF (Max)	0.0	362

The relationship between the nitrite ion/nitrate ion concentration ratio (Ratio <3)and log[OH] for the tests in which SCC did not occur is shown in Figures 12.

Only the observations for the tests in which the ratio was less than 5 are shown in the figure to allow the display of the testing for simulants with low ratios. Many early tests were carried out with 0.001 M hydroxide ion to provide “bounding” information.

Approximately 75 of the tests in this group caused cracking over this broad range of compositions and temperatures. These observations are displayed in Figure 13, and the probable causes of cracking are shown in Figure 14.

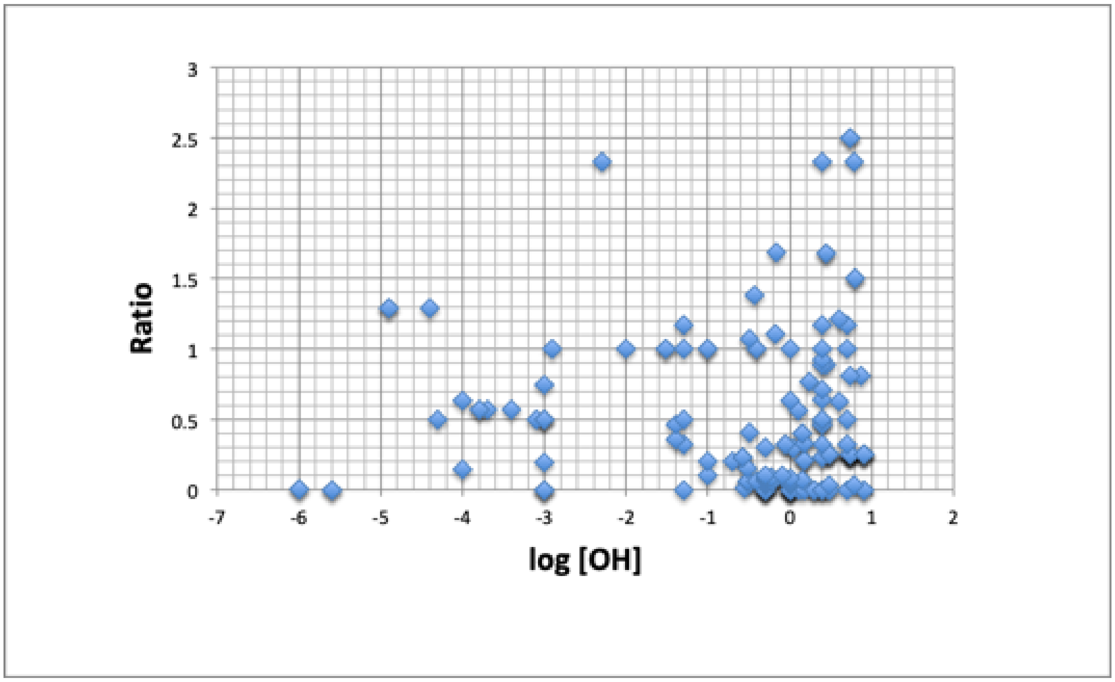

Figure 12. Relationship Between the Nitrite/Nitrate Ratio (Ratio < 3) and Hydroxide Ion Content for Tests That Did Not Result in SCC Between 55 and 140 °C

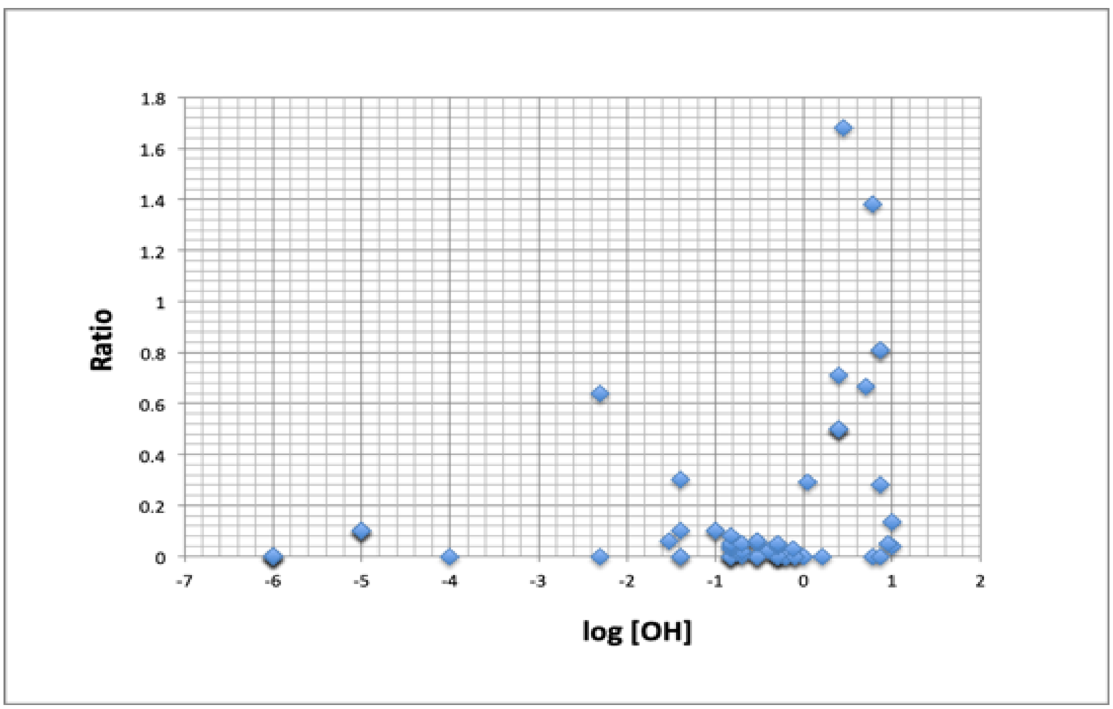

Figure 13. Relationship Between the Nitrite/Nitrate Ratio and Hydroxide Ion Content for Tests that Resulted in SCC Between 55 and 140 °C.

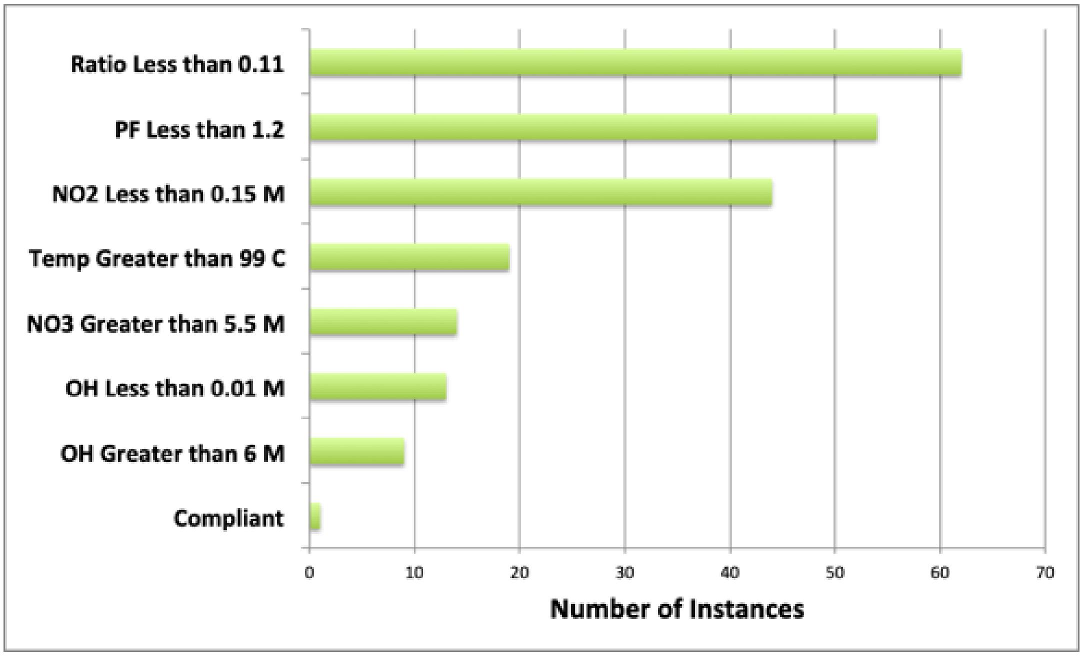

Figure 14. Reasons for Cracking in Tests Between 55 and 140 °C

It is evident from Figure 13 that low nitrite/nitrate concentration ratios are principally responsible for the onset of cracking. The more detailed analysis in Figure 14 confirms the dominant influence of the concentration ratio, and also highlights the individual roles of low nitrite ion concentrations and high nitrate ion concentrations. Non compliant high hydoxide ion concentrations were the cause for failure for another group. Temperatures in excess of 100 °C increased the risks in some instances. The end result of the analysis reveals that only one compliant solution caused cracking in the temperature range of interest.

The one observation, in which a chemically compliant simulant caused SCC, is apparently anomalous and deserves comment. This early test was conducted with A 285 Grade B steel at constant current or galvanostatic conditions in 1978 [27]. A simulant with exactly the same composition was tested at 50 and 75 °C under potentiostatic conditions in 2009 [28] and SCC did not occur. Recently, the same simulant was tested at 95 °C again under potentiostatic and at the same galvanostatic conditions tested previously. SCC did not occur in the 95 °C test; however, SCC was observed at 75 °C under the galvanostatic conditions. The difference arises because the potential achieved during the galvanostatic tests was in the transpassive region (+400 mV), a potential region where the material becomes susceptibile to SCC. This potential is extremely oxidizing and it is unrealistic that it would be achieved under freely corroding conditions. Therefore, the one compliant test that failed may be discounted.

Additional testing was carried out at the marginal values of the new control limits for PF, the Ratio and hydroxide ion at 95 °C to further evaluate the chemical limits. None of the compostions, which are displayed in Figure 15, caused SCC.

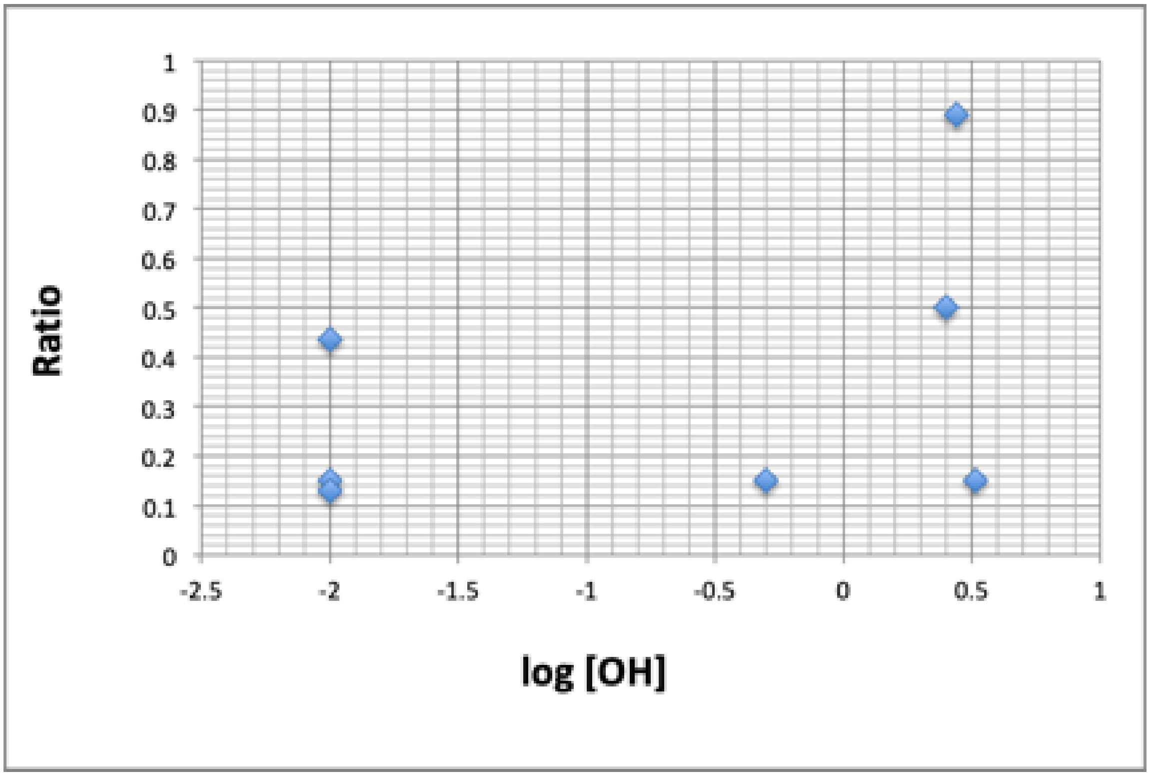

Figure 15. Tests of Marginally Compliant Waste Compositions at 95 °C

In conclusion, the evaluation of the observations for about 275 tests of the cracking risk at temperatures greater than 75 °C suggests that PF limits recommended for the control of the pitting hazard may also be applicable for the control of the SCC hazard. The increases in the required minimum concentrations of nitrite and hydroxide ion that were necessary for the minimization of the pitting risks also reduce the cracking risks. The one compliant test composition that caused cracking at less than 95 °C appears to be anomalous among the broad family of other test results. The principal cause for cracking among the group that has been tested is low nitrite ion contents. The new control requirement that the nitrite ion concentration be at least 0.20 M virtually eliminates this cracking cause. Before a generalized temperature limit can be set however, the margin on the initiation of SCC at the boundary of the chemistry envelope must be assessed.

As with pitting, a consideration of the margins at the boundary for SCC was undertaken. Given that temperature has a strong influence on the observation of SCC, the investigation was categorized in terms of temperature, that is wastes at temperatures less than or equal to 50 °C and at temperatures greater than 50 °C. Two approaches were taken to evaluate the margins for each category. First, the SSR testing performed for the simulants of the five wastes with interstitial liquid at temperatures greater than 50 °C was reviewed. Secondly, data for the critical cracking potential, and the OCP drift, as a function of temperature were reviewed.

3.2.1 Liquids with Very Low Nitrate Ion Contents

The compositions of the interstitial liquids in Tanks AY-101 and AZ-102, which were last measured in 2005 and 2007, are shown in Table 10. These compositions are novel because the nitrate ion concentrations

(0.06 M) are very low and are coupled with high inorganic carbon contents (2.11 and 0.64 M). At low hydroxide ion concentrations, bicarbonate ion-induced SCC could become the principal threat to their integrity [4]. The hydroxide ion concentrations are projected to have decreased to 0.0006 and 0.013 M in 2018 because of the ongoing oxidation reactions of organic constituents [28]. Thermodynamic models suggest that the lowest end state hydroxide ion concentration in the interstitial liquids from Tanks AY-101 would be about 0.0005 M [29]. The testing that was carried out in 2008 focused attention on simulants of the Tank AY-101 with 0.0001, 0.0003 and 0.001 M hydroxide ion [30]. The information in Table 12 indicates that this tank's composition is bounding for the related interstitial liquid in Tank AZ-102. Moreover, slow strain rate tests were carried out with simulants that had hydroxide ion concentrations that were less than 0.0001 M to critically assess the propensity for bicarbonate ion induced SCC.

Table 10. Compositions of Interstitial Liquids in Tanks AY-101 and AZ-102

Concentration	Tank AY-101	Tank AZ-102
	M	M
Hydroxide	0.04	0.02
TIC	2.11	0.64
Bicarbonate	0.011	0.006
Carbonate	2.10	0.63
Nitrite	0.86	0.89
Nitrate	0.06	0.06
Chloride	0.01	0.00
Fluoride	0.13	0.05

Stress corrosion cracking was not observed at either 50 or 77 °C in the potential range anticipated for nitrate ion induced SCC (i.e. near 0 mV SCE) for the simulants. Similarly, SCC did not occur with these waste simulants at their open circuit potentials. However, SCC was observed at low applied potentials where carbonate SCC would be expected. The Expert Panel on Corrosion evaluated the results of the testing program and concluded that there was no credible mechanism that could cause the corrosion potential to move into the carbonate ion cracking range and, therefore, that it is highly unlikely that carbonate SCC is an integrity threat [20].

Additional testing was carried out with the interstitial liquid simulants of Tank AZ-102 in 2019 [21]. These corrosion tests were carried out at 95 °C as a part of the program to determine the corrosion risks for wastes stored between 50 and 75 °C. The simulants of the interstitial liquid of Tank AZ-102 developed a light blue film during their CPP tests, but neither pitting nor SCC was observed at 95 °C.

In summary, although the concentrations are unusual and the hydroxide ion contents are apparently nearing their lower PF limits, the testing implies that the SCC risks are small for storage at 75 °C for these liquids with low nitrate ion and high inorganic carbon contents and that the PF limits are applicable for the wastes in these tanks.

3.2.2 Warm Tanks

The extension of the control limits for SCC from 50 to 75 °C is of special concern because of the dependence of SCC on temperature as has already been discussed. The wastes in several DST layers presently exceed

50 °C[1], and simulants of these liquids were tested at 95 °C to provide assurance that their corrosion risks are small at temperatures less than 75 °C. These tank layers are identified in Table 11 together with their temperatures and compositions [31].

Table 11. Temperatures and Compositions of the Warm Waste Layers

Waste Layer	Temp.	[OH]	[NO_2]	[NO_3]	[Cl]	[F]
	°C	M	M	M	M	M
AZ-101 Supernatant	65.9	0.37	2.07	1.50	0.04	0.10
AZ-102 Supernatant	39.2	1.73	1.98	2.59	0.15	0.01
AN-106 Interstitial (1)	59.8	0.32	0.47	0.44	0.03	0.02
AN-106 Interstitial (2)	59.8	0.38	2.85	3.26	0.20	0.06
AP-102 Interstitial	54.6	0.67	0.82	0.74	0.03	0.07
AZ-101 Interstitial	69.8	0.68	1.60	0.95	0.00	0.12
AZ-102 Interstitial	45.7	0.01	0.88	0.10	0.01	0.001

Note (1) Estimated composition of liquid in contact with tank bottom circa 1990.
Note (2) Average composition of interstitial liquid from 2018 BBI Report.

The interstitial liquid in Tank AN-106 has never been sampled or analyzed. Two compositions are shown in the table, one of which is based on the BBI from 2018 [31] and the other of which is based on the study of early waste transfers [21]. The storage temperatures, pitting factors, which are included for completeness, and nitrite ion/nitrate ion ratios are presented in Table 12 together with the pitting[2] and SCC test results.

No evidence for pitting corrosion was obtained during these tests. However, general corrosion was observed with some similants at the high test temperature. Specifically, in the Tank AP-102 and Tank AZ-101 supernatant simulants, the specimens experienced general corrosion over the entire surface; the Tank AN-106 specimen showed slight general corrosion, and the simulant of the interstitial liquid of Tank AZ-102 developed a light blue film during the CPP tests. The other samples were free of surface corrosion. On balance, the observations at 95 °C imply that these wastes could be stored at temperatures less than 75 °C without undue risks for pitting corrosion in accord with the statistical testing work underpinning the development of the new limits.

Similarly, none of the warm tank simulants caused SCC when tested at OCP at 95 °C. The observations that these liquids do not cause cracking at 95 °C coupled with significant temperature dependence for SCC strongly suggest that the SCC risks at temperatures below 75 °C would be low, although OCP drift is not taken into consideration in this assessment.

[1] Tank AZ-102 is included in this group even though the temperatures of the two layers do not now exceed 50°C.

[2] The pitting observations are included for completeness even though the cracking risks are the main concern.

Table 12. Pitting Factors and Results for Pitting and SCC Tests at 95 °C

Liquid Layer	Temp.	PF	Pitting	Ratio	SCC
	°C		Pass/Fail	$[NO_2]/[NO_3]$	Yes / No
AZ-101 Supernatant	65.9	2.24	Pass	1.4	No
AZ-102 Supernatant	39.2	3.30	Pass	0.8	No
AN-106 Interstitial (1)	59.4	1.07	Pass	0.88	No
AN-106 Interstitial (2)	59.4	3.13	Pass	0.68	No
AP-102 Interstitial	51.4	3.94	Pass	0.99	No
AZ-101 Interstitial	65.9	4.30	Pass	1.7	No
AZ-102 Interstitial	68.6	3.61	Pass	8.8	No

Note (1) Estimated composition of liquid in contact with tank bottom circa 1990.
Note (2) Average composition of interstitial liquid from 2018 BBI Report [31]

3.3 Margins on SCC Chemistry Controls

3.3.1 Critical Cracking Potential and OCP Drift Considerations at Temperatures of 50 °C or Less

Historical SCC data were reviewed to determine the critical cracking potential as a function of temperature [7]. The criterion that was used to assess an acceptable margin was that the critical cracking potential was greater than 200 mV vs. the final open circuit potential (see Figure 7). This difference was defined as Delta SCC. SSR tests were conducted at controlled potential conditions at both DNV-GL and SRS (see Appendix E). In 2009, a statistical test matrix was performed that examined the effect of temperature, composition, and potential on the observation of SCC [30]. The temperature range for these tests was 30 to 50 °C, while the nitrate, nitrite, and hydroxide concentrations for the tests covered a similar range as the pitting tests. The tests did not include halide species. The SRS tests were performed in concentrated nitrate solutions with low hydroxide and nitrite concentrations. Of the 40 conditions, nine were within the acceptable range of the waste chemistry envelope (see Figure 16). The critical cracking potentials for these nine tests were greater than +150 mV vs. SCE. Given that the final OCP for a pH between 12-14 ranges between -150 to -250 mV vs. SCE, the difference between the critical cracking potential and the final OCP is on the order of 300 to 400 mV. It should be noted that even tests that did not meet the criteria for the waste chemistry envelope indicated no evidence of SCC at the open circuit potential. Although, the testing does not cover the whole range, the conditions did include regions near the PF and critical ratio for SCC. These operations coupled with in-tank potential measurements for wastes at temperatures less than 50 °C that are significantly below the critical cracking potential suggest that the pitting limits are satisfactory to mitigate SCC for these conditions.

3.3.2 Critical Cracking Potential and OCP Drift Considerations at Temperatures Greater than 50 °C

On the contrary, there is essentially no critical cracking potential data for temperatures greater than 50 °C. Without knowledge of how this potential range varies with composition, the difference between the final OCP and the critical cracking potential cannot be determined. It is recommended that a statistical matrix be developed to determine the critical cracking potential over the domain of the waste chemistry envelope. This study would provide verification of the margin against SCC at temperatures up to 75 °C.

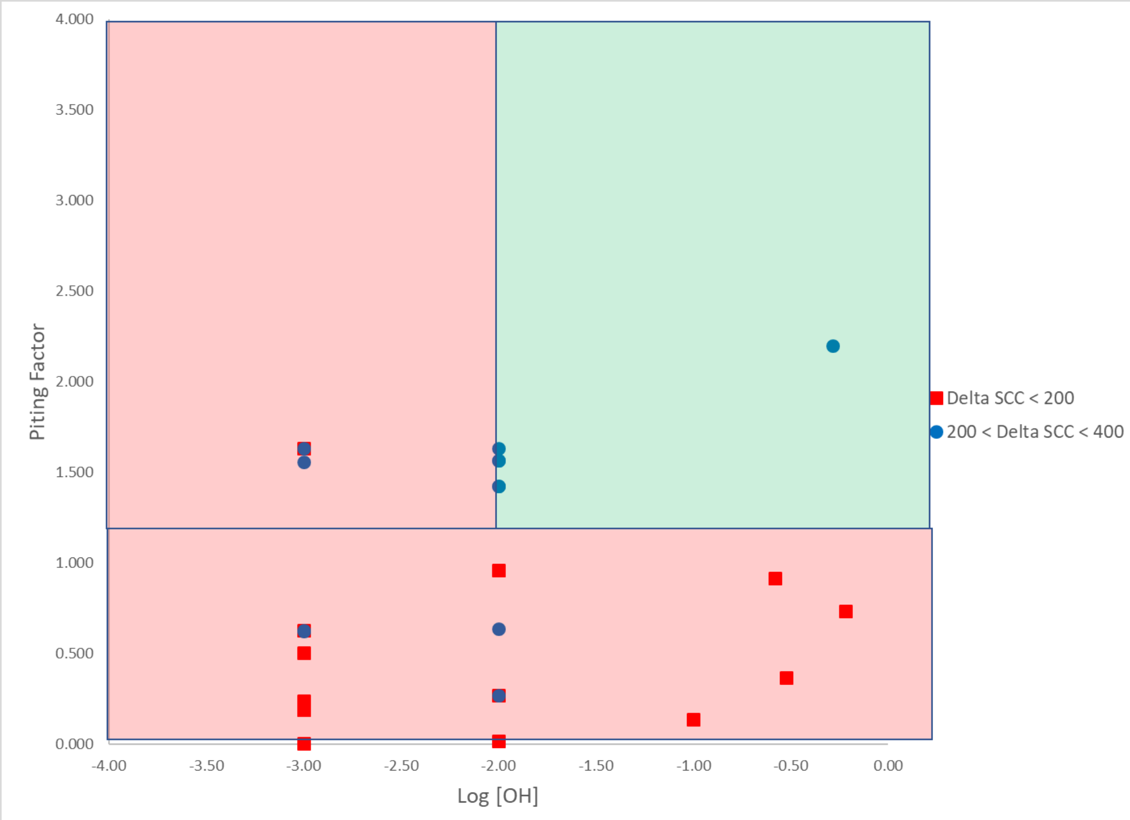

Figure 16. Log [OH] vs. Pitting Factor showing the Delta SCC for tests performed at temperatures less than 50 °C

4.0 Conclusion

In summary, the following conclusions and recommendations may be drawn.

- A comprehensive approach has been applied to the development of SCC and pitting susceptibility determination. The CPP and modified G192 tests provide a conservative, robust test for pitting susceptibility, while the slow strain rate test, which was most commonly employed, provides the same for SCC. A statistically designed matrix effectively enveloped the known waste superantes.
- For pitting corrosion, the waste chemistry envelope is conservative for temperatures up to 75 °C.
- The same envelope is conservative for SCC at temperatures less than 50 °C.
- Five interstitial liquids in the DSTs are at temperatures greater than 50 °C. SCC tests at temperatures up to 95 °C suggest that these compositions are relatively benign with respect to SCC. Although many have low hydroxide concentrations, the nitrite/nitrate critical ratio is high in each case.
- There is evidence that the waste chemistry envelope for pitting corrosion is conservative for SCC at temperatures less than 75 °C. However, uncertainty exists for the critical cracking potential at temperatures greater than 50 °C.
- At this time, it is recommended that the boundaries of the waste chemistry envelope be adopted for temperatures up to 75 °C. The present waste conditions in the waste tanks have been adequately addressed. However, studies on the margin for the critical potential for SCC should be continued

at temperatures between 50 and 95 °C in order to achieve a more robust coverage of the waste chemistry at temperatures up to 75 °C.

- Given the uncertainty of how the chemistry will evolve during waste retrievals, it is recommended that the facility consider expanding the ranges on key parameters such as the chloride and fluoride ions.

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Appendix A. The Meaning of Probability in the Pitting Factor Equation

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Background

The pitting factor is derived by regressing laboratory cyclic potentiodynamic polarization (CPP) data over an environmental space defined through statistically designed experiments. The localized corrosion metric from the CPP tests consists of six categories, five of which are shown schematically in Figure A-1 [1]. Category 3 is indeterminate because it is associated with a mixed hysteresis in the CPP curve.

As shown in Figure 1, the various localized corrosion categories are represented by two parameters measured by CPP tests: The E_{zc} that represents the transition potential from cathodic to anodic currents (i.e. potential at zero net current) and the E_{rp} that represents the repassivation potential at which even a steadily growing pit will cease to grow (repassivate). In Figure 1, these parameters are shown as single valued functions (vertical lines). This means that it is assumed in Figure 1 that, for a given environmental factor combination, these measured potentials have only a single value and not a statistical distribution. In reality, even under identical environmental conditions and test method, these two parameters will vary somewhat. This is addressed in the next section.

The localized corrosion categories are further divided into two classes: Pass (Categories 1 and 2) and Fail (Categories 4 through 6), with Category 3 falling into Pass or Fail class depending on the retest using the modified ASTM G-192 test [1]. The "pass" (classified as "0") or "fail" (classified as "1") is further regressed to yield a linear equation of the chemical variables (nitrate, nitrite, chloride, fluoride, hydroxide, etc.). The probability that an environment combination results in a "fail" class is given as [see discussion in the main body of the report]:

$$P\ (1) = \frac{1}{\left(1+e^{Lin(0)}\right)} \qquad \text{(A-1)}$$

The Lin (0) in Eq. A-1 represents the regression expression for "Pass" Class, defined according to Figure 1.

$$Lin\ (0) = a + b[OH^-] + c[NO_2^-] - d[NO_3^-] - e[Cl^-] - f[F^-] \qquad \text{(A-2)}$$

Equation A-2 relates the "Pass" class to various environmental factors through regression coefficients "a" through "f" (all positive numbers). Note that the negative signs represent aggressive species (those chemical species that enhance pitting) and the positive signs represent inhibitive species (those that mitigate pitting). The probability derived from Eq. A-1 only represents the probability of failure in lab tests as classified using Figure A-1 and constrained by the linear expression (Eq. A-2). The following sections distinguish this probability from the probability of pitting of the tank.

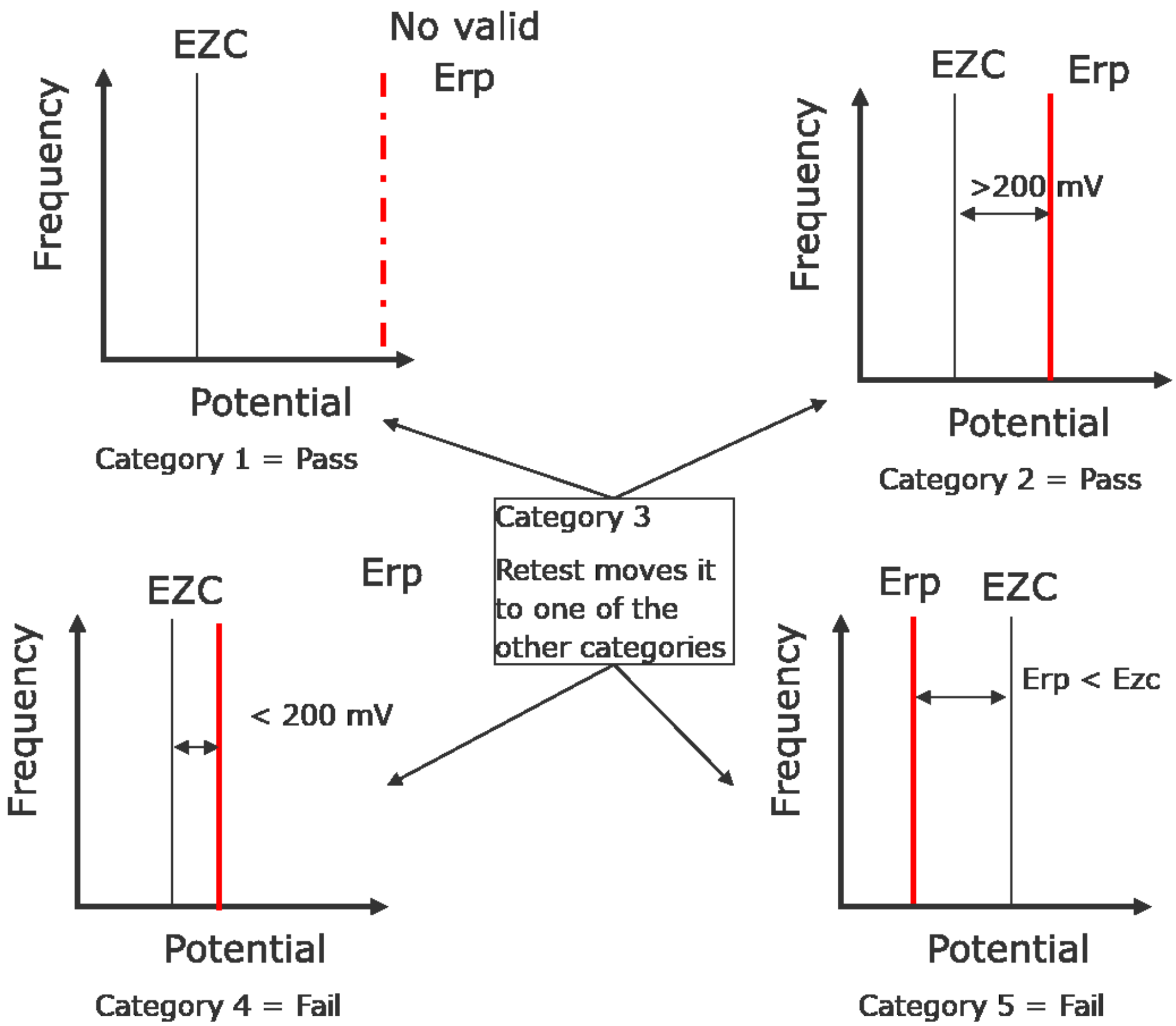

Figure A-1 Categorization of CPP test results. For simplicity, Category 6 is not shown since it is an extension of Category 5 where spontaneous pitting occurs at open-circuit potential.

<u>Probability of Tank Pitting Failure vs. Probability of Failure in CPP tests</u>

To understand the distinction between the probability as defined by Eq. A-1 and the probability of tank pitting, the following factors must be recognized:

Factor 1: The E_{rp} (the repassivation potential) is not a single-valued function as represented in Figure A-1. Even under identical test conditions, the E_{rp} is known to vary by about 50 millivolts. Similarly, the E_{zc} is also not a single valued function. This is illustrated in Figure A-2. Therefore, there is a probability that pitting could occur even if the mean values of these two parameters are considered to be passes. This test variability is considered in deriving Eq. A-2 through its associated goodness of fit, if tests are conducted under identical conditions. However, this goodness of fit (p-value) is not considered in Eq. A-1. In Monte-Carlo simulations of Equation A-2, only the chemical species concentrations are randomly varied.

The regression coefficients, which have errors representing the statistical variability of the parameters, E_{rp} and E_{zc}, are not included.

Factor 2: The E_{zc} does not represent the true corrosion potential (E_{corr}) and the E_{rp} does not represent the true repassivation potential. Both these are functions of test speed (scan rate) and, in the case of E_{zc}, starting surface condition. It is possible to determine asymptotic values of these parameters using different test times and scan rates, but it is not performed in developing Eq. A-1.

Factor 3: The time to initiate the stable pits depends on the difference between the E_{corr} and the E_{rp}. The larger this difference (i.e. the more noble the E_{corr} is above the E_{rp}), the shorter is the time to initiate localized corrosion.

Factor 4: Eq. A-1 does not consider growth rate of pits. Once stable pits are initiated, their growth rate will be controlled by diffusion of dissolved iron-containing species from within the pit to the external solution (tank waste). If the tank waste is more concentrated in nitrate, this diffusion rate will be slower since the concentration gradient of nitrate from within the pit to the external environment becomes less. The growth rate will also be controlled by the corrosion potential, temperature, and the presence of other near-by pits that may create an alkaline condition around them due to cathodic reactions. Thus, the growth rate of pits decreases with time and is a complex function of many factors.

The difference between the lab-based pitting category probability and the actual probability of tank pitting is illustrated in Figure A-3.

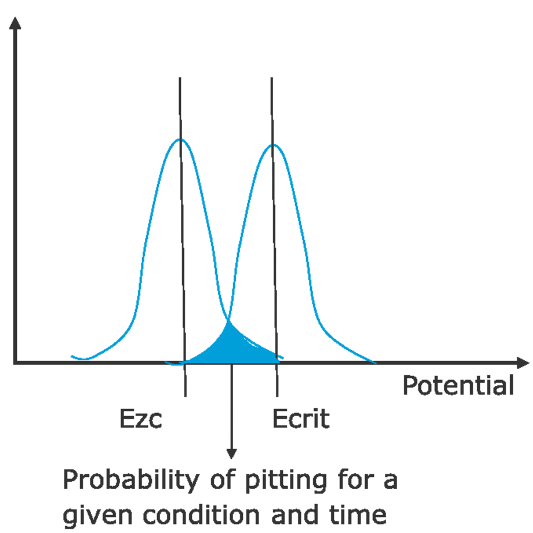

Figure A-2 Distribution of E_{zc} and E_{rp} and the overlap zone indicating pitting

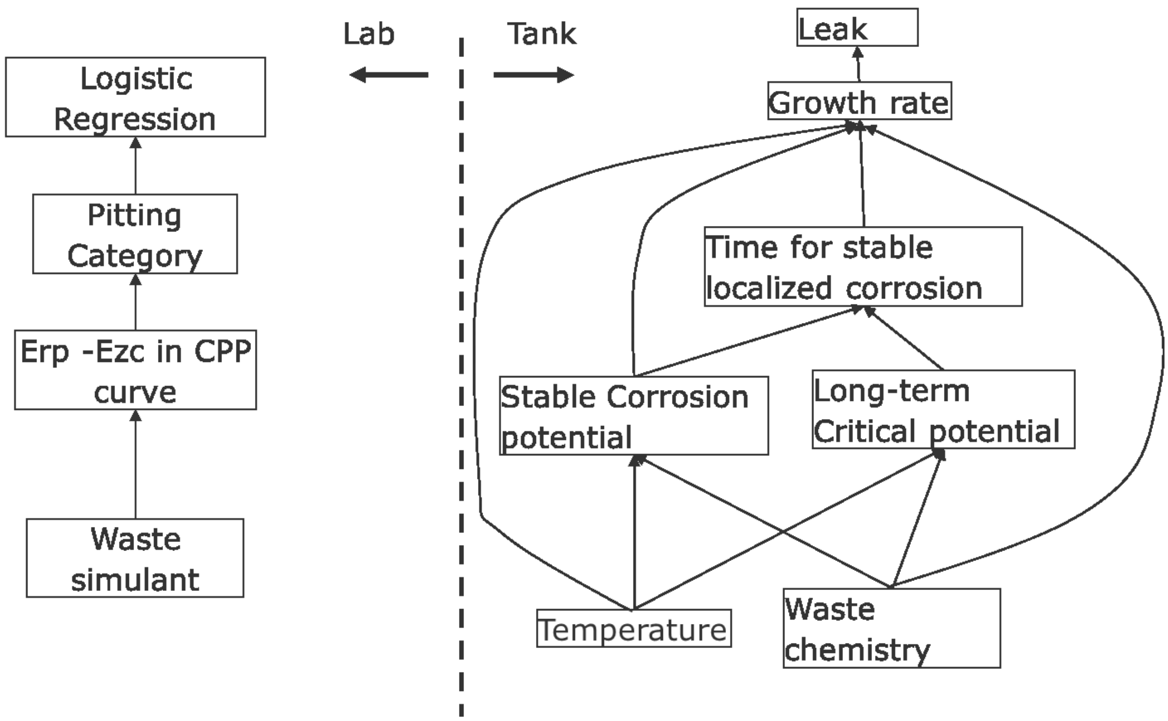

Figure A-3 The distinction between laboratory derived categorical equation (Eq. A-1) and the probability of tank pitting.

Predictions by Eq. A-1 and A-2 are binary (pass or fail); whereas, the tank pitting may take a long time to initiate and grow and is dependent of various time-related operational factors.

Absolute Probability vs. Relative (Marginal) Probability

Eq. A-1 can be regarded as a relative probability (defined in probability theory as marginal probability) of pitting given a certain chemistry control (i.e. Pitting Factor). This means that the change in probability through a change in chemistry going forward is the most important consideration. All other factors (Factors 1 through 4 and other construction-related and historical factors) are regarded as a given, unknown, background probability value. As an analogy, we can think about the probability of cancer by exposure to a carcinogenic chemical. The absolute probability of cancer for an individual depends on a host of factors peculiar to that person (genetics, other historical and life style conditions) and cannot be predicted unless we know these factors and their effects on cancer. However, given a background probability of cancer, we can predict the relative (marginal) probability of cancer through exposure to the carcinogen.

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Appendix B CPP test results that were utilized to develop the pitting factor model.

Table B-1 CPP Results

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
1	1	1	Plackett-Burman	50	0.6	1.2	5.5	0.4	0	0.2	0.1	1	2	4	major	major	332	70	0.55	NA
2	1	2	Plackett-Burman	50	0.6	1.2	5.5	0	0	0	0.1	0	1	1	no	no	>800	>800	1.22	NA
3	1	3	Plackett-Burman	20	0.6	1.2	0	0	0	0	0.1	0	1	1	minor	no	>800	>800	NA	NA
4	1	4	Plackett-Burman	20	0.6	0	5.5	0.4	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.40	NA
5	1	5	Plackett-Burman	50	0.0001	0	5.5	0	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
6	1	6	Plackett-Burman	20	0.0001	0	5.5	0	0	0	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
7	1	7	Plackett-Burman	20	0.6	0	0	0	0	0.2	0.1	0	1	1	no	no	>800	>800	NA	NA
8	1	8	Plackett-Burman	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.55	NA
9	1	9	Plackett-Burman	50	0.0001	1.2	0	0	0	0.1	0.1	0	1	1	no	no	>800	>800	NA	NA
10	1	10	Plackett-Burman	50	0.6	0	0	0.4	0	0.1	0.1	0	1	1	no	minor	>800	>800	0.72	NA
11	1	11	Plackett-Burman	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	minor	minor	< 0	< 0	0.55	NA
12	1	12	Plackett-Burman	50	0.0001	0	0	0.4	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
13	1	13	Plackett-Burman	20	0.0001	1.2	0	0.4	0	0.2	0.1	1	2	2	major	major	280	245	0.28	NA
14	1	14	Plackett-Burman	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	minor	minor	< 0	< 0	0.55	NA
15	1	15	Plackett-Burman	20	0.0001	1.2	5.5	0.4	0	0	0.1	1	2	4	major	major	406	173	0.15	NA
16	1	1	Box-Behnken	35	0.6	1.2	5.5	0.4	0	0.2	0.1	1	3	3	major	major	< 0	< 0	0.55	NA
17	1	2	Box-Behnken	35	0.6	1.2	5.5	0	0	0	0.1	0	1	1	no	no	>800	>800	1.22	NA
18	1	3	Box-Behnken	35	0.6	1.2	0	0	0	0	0.1	0	1	1	no	no	>800	>800	NA	NA
19	1	4	Box-Behnken	35	0.6	0	5.5	0.4	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.40	NA
20	1	5	Box-Behnken	35	0.0001	0	5.5	0	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
21	1	6	Box-Behnken	35	0.0001	0	5.5	0	0	0	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
22	1	7	Box-Behnken	35	0.6	0	0	0	0	0.2	0.1	0	1	1	no	no	>800	>800	NA	NA
23	1	8	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.55	NA
24	1	9	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.55	NA
25	1	10	Box-Behnken	35	0.6	1.2	0	0	0	0.2	0.1	0	1	1	no	no	>800	>800	NA	NA
26	1	11	Box-Behnken	35	0.6	0	0	0.4	0	0.1	0.1	0	1	1	no	no	>800	>800	0.72	NA
27	1	12	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.55	NA
28	1	13	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.55	NA
29	1	14	Box-Behnken	35	0.0001	0	0	0.4	0	0	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
30	1	15	Box-Behnken	35	0.0001	1.2	0	0.4	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.28	NA
31	1	16	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	5	3	major	major	< 0	< 0	0.55	NA
32	1	17	Box-Behnken	35	0.3	0.6	2.75	0.2	0	0.1	0.1	1	3	3	major	major	< 0	< 0	0.55	NA
33	1	18	Box-Behnken	35	0	1.2	5.5	0.4	0	0	0.1	1	5	5	major	major	< 0	< 0	0.15	NA
34	1	19	Box-Behnken	35	0.3	0	0	0.2	0	0.2	0.1	0	1	1	no	no	>800	>800	0.72	NA
35	1	20	Box-Behnken	35	0.6	0	5.5	0.4	0	0	0.1	1	5	5	major	major	< 0	< 0	0.40	NA

Table B-1 (continued)

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
36	1	21	Box-Behnken	35	0.6	1.2	2.75	0.2	0	0.1	0.1	0	1	1	no	no	>800	>800	1.10	NA
37	1	22	Box-Behnken	35	0.3	0	0	0	0	0	0.1	0	1	1	no	no	>800	>800	NA	NA
38	1	23	Box-Behnken	35	0.3	0.6	5.5	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.38	NA
39	1	24	Box-Behnken	35	0.6	0.6	2.75	0.2	0	0	0.1	0	3	3	no	no	NA	NA	0.95	NA
40	1	25	Box-Behnken	35	0.3	1.2	5.5	0	0	0.1	0.1	0	1	1	no	no	>800	>800	0.78	NA
41	1	26	Box-Behnken	35	0.3	0.6	2.75	0	0	0.2	0.1	0	1	1	no	no	823	837	1.22	NA
42	1	27	Box-Behnken	35	0.0001	0.6	0	0.2	0	0	0.1	1	5	5	major	major	< 0	< 0	0.28	NA
43	1	28	Box-Behnken	35	0.0001	1.2	5.5	0.2	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.21	NA
44	1	29	Box-Behnken	35	0.0001	1.2	2.75	0	0	0	0.1	0	1	1	no	no	>800	>800	0.68	NA
45	1	30	Box-Behnken	35	0.6	0	2.75	0	0	0.1	0.1	0	1	1	no	no	>800	>800	1.76	NA
46	1	31	Box-Behnken	35	0.0001	0.6	0	0	0	0.1	0.1	0	1	1	no	no	>800	>800	NA	NA
47	1	32	Box-Behnken	35	0.3	0	5.5	0.2	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.27	NA
48	1	33	Box-Behnken	35	0.6	0.6	5.5	0	0	0.2	0.1	0	1	1	no	no	>800	>800	1.05	NA
49	1	34	Box-Behnken	35	0.3	1.2	0	0.4	0	0	0.1	1	5	5	major	major	< 0	< 0	0.64	NA
50	1	35	Box-Behnken	35	0.6	0.6	0	0.4	0	0.1	0.1	1	3	5	minor	minor	NA	< 0	0.86	NA
51	1	36	Box-Behnken	35	0.0001	0	2.75	0.4	0	0.1	0.1	1	5	5	major	major	< 0	< 0	0.00	NA
52	1	37	Box-Behnken	35	0.3	0.6	2.75	0.4	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.36	NA
53	1	38	Box-Behnken	35	0.0001	0.6	5.5	0.4	0	0.2	0.1	1	5	5	major	major	< 0	< 0	0.08	NA
54	2	1	High Hydroxide	35	1.2	0	3.75	0	0	0.13	0.1	0	1	1	No	No	>800	>800	2.58	NA
55	2	2	High Hydroxide	35	1.2	0	4.75	0	0	0.07	0.1	0	1	1	No	No	>800	>800	2.04	NA
56	2	3	High Hydroxide	35	1.2	0	3.1	0.08	0	0.09	0.1	0	1	1	No	No	>800	>800	2.18	NA
57	2	4	High Hydroxide	35	1.2	0	2.42	0.16	0	0.08	0.1	0	1	1	No	No	>800	>800	1.90	NA
58	2	5	High Hydroxide	35	1.2	0	4.5	0.2	0	0.03	0.1	0	1	1	No	No	>800	>800	1.23	NA
59*	2	6	High Hydroxide	35	1.2	0	0.94	0.24	0	0.01	0.1	NA	3	3	Yes	Yes	NA	NA	1.95	Not Pitting
60	2	6a	High Hydroxide	35	1.2	0.2	0.94	0.24	0	0.01	0.1	0	1	NA	No	NA	>800	NA	2.02	NA
61	2	7	High Hydroxide	35	1.2	0	0.26	0.32	0	0.17	0.1	0	1	1	No	No	>800	>800	1.73	NA
62	2	8	High Hydroxide	35	1.2	0	4.75	0.35	0	0.07	0.1	1	3	3	Yes	Yes	NA	NA	0.91	E-Erp < 200
63	2	9	High Hydroxide	35	1.2	0	0	0.4	0	0.02	0.1	0	1	1	No	No	>800	>800	1.45	NA
64	2	10	High Hydroxide	35	1.2	0.6	4.74	0.08	0	0.02	0.1	0	1	1	No	No	>800	>800	1.74	NA
65	2	11	High Hydroxide	35	1.2	0.6	5.32	0.15	0	0	0.1	0	1	1	No	No	>800	>800	1.35	NA
66	2	12	High Hydroxide	35	1.2	0.6	3.31	0.16	0	0.2	0.1	0	1	1	No	No	>800	>800	1.77	NA
67	2	13	High Hydroxide	35	1.2	0.6	2.68	0.24	0	0.05	0.1	0	1	1	No	No	>800	>800	1.59	NA
68	2	14	High Hydroxide	35	1.2	0.6	4.92	0.28	0	0.06	0.1	0	1	3	No	Yes	>800	NA	1.10	NA
69	2	15	High Hydroxide	35	1.2	0.6	1.26	0.32	0	0.01	0.1	0	1	1	No	No	>800	>800	1.61	NA
70	2	16	High Hydroxide	35	1.2	0.6	0.63	0.4	0	0.17	0.1	0	1	1	No	No	>800	>800	1.45	NA

*Test not included in model due low nitrite present in a dilute solution.

Table B-1 (continued)

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
71	2	17	High Hydroxide	35	1.2	0.6	5.32	0.4	0	0.01	0.1	1	3	3	Yes	Yes	NA	NA	0.88	E-Erp < 200
72	2	18	High Hydroxide	35	1.2	1.2	4.01	0.16	0	0.15	0.1	0	1	1	No	No	>800	>800	1.73	NA
73	2	19	High Hydroxide	35	1.2	1.2	4.17	0.21	0	0.01	0.1	0	1	1	No	No	>800	>800	1.50	NA
74	2	20	High Hydroxide	35	1.2	1.2	3.4	0.24	0	0.1	0.1	0	1	1	No	No	>800	>800	1.56	NA
75	2	21	High Hydroxide	35	1.2	1.2	1.99	0.32	0	0.09	0.1	0	1	1	No	No	>800	>800	1.57	NA
76	2	22	High Hydroxide	35	1.2	1.2	4.57	0.32	0	0.13	0.1	0	3	3	Yes	Yes	NA	NA	1.16	620
77	2	23	High Hydroxide	35	1.2	1.2	1.38	0.4	0	0.01	0.1	0	1	1	No	No	>800	>800	1.43	NA
78	2	24	High Hydroxide	35	1.2	1.2	4.17	0.4	0	0.01	0.1	0	1	1	No	No	>800	>800	1.06	NA
79	2	25	High Hydroxide	35	0.3	0.6	2.75	0.2	0	0.15	0.1	1	5	5	Yes	Yes	< 0	< 0	0.55	NA
80	2	26	High Hydroxide	35	0.3	0.6	2.75	0.2	0	0.07	0.1	1	5	5	Yes	Yes	< 0	< 0	0.55	NA
81	2	27	High Hydroxide	35	0.3	0.6	2.75	0.2	0	0.05	0.1	1	5	5	Yes	Yes	< 0	< 0	0.55	NA
82	2	1	NL Interior	35	0.3	1.2	0	0	0	0.2	0.1	0	1	1	No	No	>800	>800	NA	NA
83	2	2	NL Interior	35	0.3	0	0	0	0	0	0.1	0	1	1	No	No	>800	>800	NA	NA
84	2	3	NL Interior	35	0.3	1.2	0	0.4	0	0.2	0.1	1	5	5	Major	Major	< 0	< 0	0.64	NA
85	2	4	NL Interior	35	0.3	1.2	0	0	0	0	0.1	0	1	1	No	No	>800	>800	NA	NA
86	2	5	NL Interior	35	0.3	1.2	5.5	0.4	0	0	0.1	1	5	5	Major	Major	< 0	< 0	0.35	NA
87	2	6	NL Interior	35	1.2	1.2	0	0	0	0.2	0.1	0	1	1	No	No	>800	>800	NA	NA
88	2	7	NL Interior	35	0.3	0	5.5	0.4	0	0.2	0.1	1	5	5	Major	Major	< 0	< 0	0.20	NA
89	2	8	NL Interior	35	0.3	0	5.5	0.4	0	0.2	0.1	1	5	5	Major	Major	< 0	< 0	0.20	NA
90	2	9	NL Interior	35	0.3	0	5.5	0.4	0	0.2	0.1	1	5	5	Major	Major	< 0	< 0	0.20	NA
91	2	10	NL Interior	35	0.3	0	0	0.4	0	0	0.1	1	5	3	Major	Major	< 0	NA	0.36	NA
92	2	11	NL Interior	35	0.0001	1.2	0.8	0	0	0.2	0.1	0	1	1	No	No	>800	>800	2.33	NA
93	2	12	NL Interior	35	0.0001	0.9	0.6	0.025	0	0.16	0.1	0	1	1	No	No	>800	>800	1.37	NA
94	2	13	NL Interior	35	0.0001	0.6	0.4	0.05	0	0.12	0.1	1	3	3	Minor	Minor	NA	NA	0.75	NA
95	2	14	NL Interior	35	0.0001	0.3	0.2	0.075	0	0.08	0.1	1	5	5	Major	Major	< 0	< 0	0.32	NA
96	2	15	NL Interior	35	0.0001	0	0	0.1	0	0.04	0.1	1	5	5	Major	Major	< 0	< 0	0.00	NA
97	3	1	F Testing	35	4	2	0	0.400	0.02	0.2	0.1	0	1	NA	No	NA	>800	NA	5.20	NA
98	3	2	F Testing	35	4	2	0	0.400	0.02	0.2	0.1	0	1	NA	No	NA	>800	NA	5.20	NA
99	3	3	F Testing	35	0.0001	2	4	0.400	0.3	0.2	0.1	1	5	NA	Major	NA	< 0	NA	0.25	NA
100	3	4	F Testing	35	0.0001	2	4	0.400	0.3	0.2	0.1	1	4	NA	Major	NA	74	NA	0.25	NA
101	3	5	F Testing	35	4	0	4	0.400	0	0.2	0.1	0	1	NA	No	NA	>800	NA	3.02	NA
102	3	6	F Testing	35	4	0	4	0.400	0	0.2	0.1	0	1	NA	No	NA	>800	NA	3.02	NA
103	3	7	F Testing	35	4	2	0	0.000	0.3	0.2	0.1	0	1	NA	No	NA	>800	NA	20.67	NA
104	3	8	F Testing	35	4	2	0	0.000	0.26	0.2	0.1	0	1	NA	No	NA	>800	NA	23.85	NA
105	3	9	F Testing	35	4	0	4	0.000	0.14	0.2	0.1	0	1	NA	No	NA	>800	NA	6.72	NA

Table B-1 (continued)

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
106	3	10	F Testing	35	4	2	0	0.000	0	0.2	0.1	0	1	NA	No	NA	>800	NA	NA	NA
107	3	11	F Testing	35	4	0	4	0.400	0	0.2	0.1	0	1	NA	No	NA	>800	NA	3.02	NA
108	3	12	F Testing	35	4	2	4	0.000	0	0.2	0.1	0	1	NA	No	NA	>800	NA	8.84	NA
109	3	13	F Testing	35	0.0001	2	4	0.400	0.3	0.2	0.1	1	4	NA	Major	NA	125	NA	0.25	NA
110	3	14	F Testing	35	0.0001	2	4	0.400	0.3	0.2	0.1	1	4	NA	Major	NA	25	NA	0.25	NA
111	3	15	F Testing	35	4	0	0	0.400	0.22	0.2	0.1	0	1	NA	No	NA	>800	NA	4.06	NA
112	3	1	PF 1-2 & Tank Sim	35	0.0001	0.6	0.3	0.04	0	0.2	0.1	0	3	5	Yes	Yes	NA	< 0	0.96	780
113	3	2	PF 1-2 & Tank Sim	35	0.0001	1.2	0	0.05	0	0.2	0.1	0	5	5	Yes	Yes	< 0	< 0	2.23	511
114	3	3	PF 1-2 & Tank Sim	35	0.0001	1.2	2	0	0	0.2	0.1	0	1	3	No	Yes	>800	NA	0.93	698
115	3	4	PF 1-2 & Tank Sim	35	0.1	0	0.2	0.02	0	0.2	0.1	1	1	4	No	Yes	>800	59	1.51	E-Erp < 200
116	3	5	PF 1-2 & Tank Sim	35	0.1	0.6	0.3	0.06	0	0.2	0.1	0	1	2	No	Yes	>800	615	1.33	761
117	3	6	PF 1-2 & Tank Sim	35	0.1	1.2	0.5	0.05	0	0.2	0.1	0	1	3	No	No	>800	NA	2.00	707
118	3	7	PF 1-2 & Tank Sim	35	0.1	1.2	2.5	0.005	0	0.2	0.1	0	2	3	No	Yes	253	NA	1.03	530
119	3	8	PF 1-2 & Tank Sim	35	0.3	0	0.1	0.08	0	0.2	0.1	0	1	1	No	No	>800	>800	1.68	NA
120	3	9	PF 1-2 & Tank Sim	35	0.3	0.6	0.07	0.1	0	0.2	0.1	0	2	2	Yes	Yes	667	594	1.92	NA
121	3	10	PF 1-2 & Tank Sim	35	0.3	1.2	0.5	0.15	0	0.2	0.1	0	1	1	No	Yes	>800	>800	1.42	589
122	3	11	PF 1-2 & Tank Sim	35	0.3	1.2	2.5	0.05	0	0.2	0.1	0	3	3	No	No	NA	NA	1.28	766
123	3	12	PF 1-2 & Tank Sim	35	0.6	0	0.6	0.05	0	0.2	0.1	0	3	3	Yes	No	NA	NA	3.37	493
124	3	13	PF 1-2 & Tank Sim	35	0.6	0.6	0.001	0.25	0	0.2	0.1	0	2	2	Yes	Yes	480	587	1.38	NA
125	3	14	PF 1-2 & Tank Sim	35	0.6	1.2	0.001	0.3	0	0.2	0.1	0	1	1	No	No	>800	>800	1.34	NA
126	3	15	PF 1-2 & Tank Sim	35	0.6	1.2	5.5	0.01	0	0.2	0.1	0	3	1	Yes	No	NA	>800	1.18	>800
127	3	16	PF 1-2 & Tank Sim	35	0.611	1.99	3.13	0.101	0.001	0.2	0.1	0	1	1	No	No	>800	>800	1.66	NA
128	3	17	PF 1-2 & Tank Sim	35	0.42	1.4	2.99	0.05	0.01	0.2	0.1	0	3	3	No	No	NA	NA	1.43	716
129	3	18	PF 1-2 & Tank Sim	35	1.03	1.37	2.44	0.14	0	0.2	0.1	0	1	1	No	No	>800	>800	2.18	NA
130	3	19	PF 1-2 & Tank Sim	35	1.03	1.37	2.44	0.08	0.06	0.2	0.1	0	1	1	No	No	>800	>800	2.53	NA
131	3	20	PF 1-2 & Tank Sim	35	0.37	1.02	1.25	0.1	0	0.2	0.1	0	1	1	No	No	>800	>800	1.56	NA
132	3	21	PF 1-2 & Tank Sim	35	0.884	0.771	1.578	0.291	0	0.2	0.1	0	1	1	No	No	>800	>800	1.29	NA
133	3	22	PF 1-2 & Tank Sim	35	0.884	0.771	1.578	0.073	0.218	0.2	0.1	0	1	1	No	No	>800	>800	2.06	NA
134	3	23	PF 1-2 & Tank Sim	35	5.76	2.33	2.79	0.19	0.04	0.2	0.1	0	1	1	No	No	>800	>800	8.08	NA
135	4	1	75 C Matrix	75	0.0001	1.2	2.75	0	0	0.2	0.1	1	4	NA	yes	NA	88	NA	0.68	NA
136	4	2	75 C Matrix	75	0.0001	0.48	3.3	0	0.3	0.12	0.1	1	6	NA	yes	NA	< 0	NA	0.15	NA
137	4	3	75 C Matrix	75	0.0001	0	0	0.2	0.3	0.2	0.1	1	5	NA	yes	NA	< 0	NA	0.00	NA
138	4	4	75 C Matrix	75	0.0001	0	5.5	0.4	0	0.1	0.1	1	6	NA	yes	NA	< 0	NA	0.00	NA
139	4	5	75 C Matrix	75	0.0001	1.2	0	0.4	0.15	0	0.1	1	5	NA	yes	NA	< 0	NA	0.25	NA
140	4	6	75 C Matrix	75	0.0001	1.2	5.5	0.4	0.3	0.2	0.1	1	5	NA	yes	NA	< 0	NA	0.13	NA

Table B-1 (continued)

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
141	4	7	75 C Matrix	75	0.24	0.72	2.2	0.16	0	0	0.1	1	5	NA	yes	NA	< 0	NA	0.63	NA
142	4	8	75 C Matrix	75	0.48	0.96	5.5	0.32	0.06	0.2	0.1	1	3	NA	Yes	NA	NA	NA	0.48	E-Erp < 200
143	4	9	75 C Matrix	75	0.6	0	0	0	0	0	0.1	0	1	NA	No	NA	NA	NA	NA	NA
144	4	10	75 C Matrix	75	0.6	0.6	2.75	0.2	0.15	0.1	0.1	1	5	NA	yes	NA	< 0	NA	0.83	NA
145	4	11	75 C Matrix	75	0.6	0.6	2.75	0.2	0.15	0.1	0.1	1	5	NA	yes	NA	< 0	NA	0.83	NA
146	4	12	75 C Matrix	75	0.6	0.6	2.75	0.2	0.15	0.1	0.1	1	4	NA	yes	NA	52	NA	0.83	NA
147	4	13	75 C Matrix	75	0.6	0.6	2.75	0.2	0.15	0.1	0.1	1	5	NA	yes	NA	< 0	NA	0.83	NA
148	4	14	75 C Matrix	75	0.72	0.24	0	0.4	0.12	0.16	0.1	0	2	NA	No	NA	>800	NA	0.84	NA
149	4	15	75 C Matrix	75	0.96	0	4.4	0.24	0.24	0.04	0.1	1	5	NA	yes	NA	< 0	NA	0.79	NA
150	4	16	75 C Matrix	75	1.2	0	5.5	0	0	0.2	0.1	0	2	NA	No	NA	>800	NA	1.76	NA
151	4	17	75 C Matrix	75	1.2	1.2	0	0	0.3	0.1	0.1	0	2	NA	No	NA	>800	NA	6.74	NA
152	4	18	75 C Matrix	75	1.2	1.2	1.1	0.08	0.18	0.08	0.1	0	2	NA	No	NA	>800	NA	3.33	NA
153	4	19	75 C Matrix	75	1.2	1.2	5.5	0.2	0	0	0.1	0	2	NA	No	NA	>800	NA	1.30	NA
154	4	20	75 C Matrix	75	1.2	0.6	0	0.4	0	0.2	0.1	0	2	NA	No	NA	774	NA	1.59	NA
155	4	21	75 C Matrix	75	1.2	0	2.75	0.4	0.3	0	0.1	1	5	NA	yes	NA	< 0	NA	0.87	NA
156	4	1	1.2-6 M OH	75	1.2	0.2	0.2	0	0.2	0.2	0.1	0	1	NA	no	NA	>800	NA	7.45	NA
157	4	2	1.2-6 M OH	50	6	0.2	0.2	0.2	0.2	0.2	0.1	0	1	NA	no	NA	>800	NA	10.40	NA
158	4	3	1.2-6 M OH	75	6	1.2	1.2	0.2	0.2	0.2	0.1	0	1	NA	no	NA	>800	NA	8.84	NA
159	4	4	1.2-6 M OH	75	6	0.2	1.2	0	0	0.2	0.1	0	1	NA	no	NA	>800	NA	40.56	NA
160	4	5	1.2-6 M OH	50	1.2	0.2	1.2	0.2	0	0.2	0.1	0	1	NA	no	NA	>800	NA	2.20	NA
161	4	6	1.2-6 M OH	50	6	1.2	0.2	0	0	0.2	0.1	0	1	NA	no	NA	>800	NA	251.10	NA
162	4	7	1.2-6 M OH	75	1.2	1.2	0.2	0.2	0	0.2	0.1	0	1	NA	no	NA	>800	NA	3.26	NA
163	4	8	1.2-6 M OH	50	1.2	1.2	1.2	0	0.2	0.2	0.1	0	2	NA	no	NA	629	NA	4.93	NA
164	4	9	1.2-6 M OH	55	2.4	1.2	1.2	0	0.1	0.2	0.1	0	1	NA	no	NA	>800	NA	11.98	NA
165	4	10	1.2-6 M OH	65	4.8	0.2	0.7	0.05	0	0.2	0.1	0	1	NA	no	NA	>800	NA	25.41	NA
166	4	11	1.2-6 M OH	70	1.2	0.45	0.45	0.1	0.2	0.2	0.1	0	1	NA	no	NA	>800	NA	3.18	NA
167	4	12	1.2-6 M OH	50	3.6	0.95	0.2	0.15	0.05	0.2	0.1	0	1	NA	no	NA	>800	NA	10.20	NA
168	4	13	1.2-6 M OH	75	6	0.7	0.95	0.2	0.15	0.2	0.1	0	1	NA	no	NA	>800	NA	9.61	NA
169	4	1	pH 12-13, PF 1.2	35	0.040	0.800	0.930	0.020	0.010	0.1	0.20	0	3	NA	no	NA	NA	NA	1.18	738
170	4	2	pH 12-13, PF 1.3	35	0.015	1.060	0.870	0.010	0.070	0.1	0.20	0	1	NA	no	NA	>800	NA	1.23	NA
171	4	3	pH 12-13, PF 1.4	35	0.010	2.180	0.960	0.070	0.180	0.1	0.20	0	1	NA	no	NA	>800	NA	1.10	NA
172	4	4	pH 12-13, PF 1.5	35	0.030	2.250	1.010	0.100	0.090	0.1	0.20	0	1	NA	no	NA	>800	NA	1.17	NA
173	4	5	pH 12-13, PF 1.6	35	0.050	2.090	1.040	0.030	0.100	0.1	0.20	0	1	NA	no	NA	>800	NA	1.73	NA
174	4	6	pH 12-13, PF 1.7	35	0.030	2.820	2.730	0.110	0.010	0.1	0.20	0	1	NA	no	NA	>800	NA	1.00	NA
175	4	7	pH 12-13, PF 1.8	35	0.020	2.200	0.780	0.040	0.110	0.1	0.20	0	1	NA	no	NA	>800	NA	1.72	NA

Table B-1 (continued)

Tests	Reference	Number of Test in respective type	Type of Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Chloride (M)	Fluoride (M)	Sulfate (M)	TIC (M)	Logistic Approach Fail (1) /Pass(0)	Category		Pitting on sample		Erp-Ecorr (mV)		Pitting Factor	G192 Test
													run 1	run 2	run 1	run 2	run 1	run 2		
176	4	8	pH 12-13, PF 1.9	35	0.020	0.75	1.00	0.01	0.01	0.1	0.20	0	1	NA	no	NA	>800	NA	1.08	NA
177	4	9	pH 12-13, PF 1.10	35	0.090	1.00	1.00	0.04	0.04	0.1	0.20	0	1	NA	no	NA	>800	NA	1.20	NA
178	4	10	pH 12-13, PF 1.11	35	0.060	1.00	1.00	0.04	0.06	0.1	0.20	0	1	NA	no	NA	>800	NA	1.01	NA
179	4	11	pH 12-13, PF 1.12	35	0.050	0.70	1.00	0.01	0.04	0.1	0.20	0	1	NA	no	NA	>800	NA	1.07	NA
180	4	12	pH 12-13, PF 1.13	35	0.075	0.50	1.00	0.01	0.01	0.1	0.20	0	1	NA	no	NA	>800	NA	1.13	NA
181	4	13	pH 12-13, PF 1.14	75	0.010	1.060	0.870	0.010	0.070	0.1	0.20	0	1	NA	no	NA	>800	NA	1.20	NA
182	4	14	pH 12-13, PF 1.15	75	0.030	2.250	1.010	0.100	0.090	0.1	0.20	0	3	NA	no	NA	NA	NA	1.17	>800
183	4	15	pH 12-13, PF 1.16	75	0.050	2.090	1.040	0.030	0.100	0.1	0.20	0	1	NA	no	NA	>800	NA	1.73	NA
184	4	16	pH 12-13, PF 1.17	75	0.090	1.00	1.00	0.04	0.04	0.1	0.20	0	1	NA	no	NA	>800	NA	1.20	NA
185	4	17	pH 12-13, PF 1.18	75	0.060	1.00	1.00	0.04	0.06	0.1	0.20	0	1	NA	no	NA	>800	NA	1.01	NA
186	4	18	pH 12-13, PF 1.19	75	0.020	0.75	1.00	0.01	0.01	0.1	0.20	0	1	NA	no	NA	>800	NA	1.08	NA
187	4	19	pH 12-13, PF 1.20	75	0.050	0.70	1.00	0.01	0.04	0.1	0.20	0	2	NA	no	NA	578	NA	1.07	NA
188	4	20	pH 12-13, PF 1.21	75	0.010	2.180	0.960	0.070	0.180	0.1	0.20	0	1	NA	no	NA	>800	NA	1.10	NA
189	4	21	pH 12-13, PF 1.22	75	0.125	1.00	1.25	0.050	0.040	0.1	0.20	0	1	NA	no	NA	>800	NA	1.11	NA
190	4	22	pH 12-13, PF 1.23	75	0.175	1.00	1.25	0.050	0.040	0.1	0.20	0	1	NA	no	NA	>800	NA	1.28	NA
191	4	23	pH 12-13, PF 1.24	75	0.225	0.75	1.00	0.075	0.040	0.1	0.20	0	1	NA	no	NA	>800	NA	1.20	NA
192	4	24	pH 12-13, PF 1.25	75	0.250	0.75	1.25	0.075	0.040	0.1	0.20	0	1	NA	no	NA	>800	NA	1.16	NA
193	4	25	pH 12-13, PF 1.26	75	0.150	1.25	1.00	0.050	0.040	0.1	0.20	0	3	NA	no	NA	NA	NA	1.53	768

References

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3. SRNL-STI-2019-00014, *Hanford Double Shell Waste Tank Corrosion Studies – Final Report FY2018*, R. E. Fuentes and P. K. Shukla, August 2019.
4. SRNL-STI-2019-00xxx, *Hanford Double Shell Waste Tank Corrosion Studies – Final Report FY2019*, R. E. Fuentes and P. K. Shukla, To Be Issued.

Appendix C Historical CPP Results

Table C-1 Historical CPP Results

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
1	25	1.00E-03	0.03	1.04	0.32	0.019	0.003	0.18	1	0.017	4
2	25	0.001	0.03	1.04	0.32	0.019	0.003	0.18	1	0.017	4
3	25	1.00E-03	0.03	1.04	0.32	0.019	0.003	0.18	1	0.017	4
4	25	1.00E-03	0.03	1.04	0.32	0.019	0.003	0.18	1	0.017	4
5	25	1.00E-03	0.14	5.31	0.039	0.065	0.25	0	1	0.034	4
6	25	1.00E-03	0.14	5.31	0.039	0.065	0.25	0	1	0.034	4
7	25	3.98E-03	0.34	1.2	0.023	0.016	0.032	0.56	1	0.350	4
8	25	3.98E-03	0.34	1.2	0.023	0.016	0.032	0.56	1	0.350	4
9	25	0.0001	0.34	0.44	0.023	0.016	0.03	0.56	0	0.630	4
10	25	0.1	2.51	5.11	0.014	0.018	0.19	0.2	0	0.855	4
11	25	0.1	0.15	0.9	0.013	0.026	0.006	0.19	0	0.737	4
12	25	0.1	0.15	0.9	0.013	0.026	0.006	0.19	0	0.737	4
13	25	0.158	0.42	0.31	0.017	0.071	0.018	0.17	0	1.208	4
14	25	0.251	0.42	2.32	0.017	0.071	0.015	0.17	0	0.742	4
15	25	0.251	0.42	2.32	0.017	0.071	0.015	0.17	0	0.742	4
16	25	2.6	0.83	4.32	0.16	0.18	0.25	0.09	0	2.700	4
17	25	2.6	0.83	4.32	0.16	0.18	0.25	0.09	0	2.700	4
18	25	0.501	2.2	4.05	0.008	0.15	0.083	0.79	0	1.128	4
19	25	0.501	2.2	4.05	0.008	0.15	0.083	0.79	0	1.128	4
20	25	0.501	2.2	4.05	0.009	0.15	0.083	0.79	0	1.127	4
21	25	1	2.4	4.21	0.014	0.01	0.48	0.49	0	2.643	4
22	25	1	2.4	4.21	0.014	0.01	0.48	0.49	0	2.643	4
23	25	1	0.04	0.89	0.34	0.016	0.009	0	0	2.624	4
24	25	1	0.04	0.89	0.34	0.016	0.009	0	0	2.624	4
25	25	1	0.03	1.04	0.32	0.019	0.007	0.18	0	2.548	4
26	25	1	0.03	1.04	0.32	0.019	0.007	0.15	0	2.548	4
27	25	1	0	0.31	0.22	0.027	0.05	0	0	4.000	4
28	25	1	0	0.31	0.22	0.027	0.05	0	0	4.000	4
29	25	1	0.07	1.2	0.23	0.027	0	0.02	0	2.758	4
30	25	1	0.07	1.2	0.23	0.027	0	0.02	0	2.758	4
31	25	1	0.14	5.35	0.039	0.065	0.25	0	0	1.243	4
32	25	1	0.14	5.35	0.039	0.065	0.25	0	0	1.243	4
33	25	1	0.19	1.61	0.022	0.031	0.13	0.05	0	3.708	4
34	25	1	0.19	1.61	0.022	0.031	0.13	0.05	0	3.708	4
35	25	1	0.24	3.8	0.009	0.044	0.18	0.1	0	1.839	4
36	25	1	0.24	3.8	0.009	0.044	0.18	0.1	0	1.839	4
37	25	0.00631	0.04	0.18	0.002	0.006	0.002	0.15	0	0.387	7
38	25	0.176	0.27	3.58	0.009	0.031	0.047	0.33	0	0.443	7
39	30	0.072	1.95	3.11	0	0.11	0	0	0	0.728	13
40	30	0.052	2.24	3.77	0	0.11	0	0	0	0.694	13

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
41	30	0.032	1.91	3.06	0	0.11	0	0	0	0.657	13
42	30	0.032	2.13	3.4	0	0.11	0	0	0	0.680	13
43	30	3.16E-04	0.14	5.32	0.039	0.066	0.251	0	1	0.033	5, 6, 7
44	30	7.94E-04	0.05	1.19	0.27	0.025	0.058	1.4	1	0.027	5, 6, 7
45	30	0.158	0.42	2.32	0.017	0.071	0.018	0.17	0	0.534	5, 6, 7
46	30	0.631	2.13	3.97	0.002	0.149	0.082	0.79	0	1.296	5, 6, 7
47	32	0.73	0.91	0.77	0	0	0	0.62	0	9.473	11
48	32	0.694	0.83	0.75	0	0.025	0.036	0.74	0	5.893	11
49	32	0.74	0.81	0.69	0	0.02	0.036	0.8	0	7.051	11
50	35	4.25E-01	0.24	0.74	0.026	0.014	0.026	0.35	0	3.385	9
51	35	1.00E+00	0.15	0.39	0.037	0.009	0.184	0.18	0	11.039	9
52	35	4.25E-01	0.24	0.74	0.026	0.014	0.026	0.35	0	3.385	9
53	35	1.00E+00	0.15	0.39	0.037	0.009	0.184	0.18	0	11.039	9
54	35	4.25E-01	0.24	0.74	0.026	0.014	0.026	0.35	0	3.385	10
55	35	4.25E-01	0.24	0.74	0.026	0.014	0.026	0.35	0	3.385	10
56	35	1.81E-01	0.15	0.39	0.026	0.014	0.026	0.35	0	2.191	10
57	40	2.00E-04	0.5	5	0.05	0.06	0.001	0.02	1	0.124	1
58	40	6.00E-04	0.02	5	0.05	0.01	0.001	0.02	1	0.007	1
59	40	7.00E-04	0.02	0.1	0.003	0.4	0.001	0.02	1	0.005	1
60	40	6.00E-04	0.1	0.1	0.02	0.4	0.001	0.02	1	0.023	1
61	40	7.00E-04	0.02	5	0.05	0.4	0.05	0.2	1	0.003	1
62	40	1.20E-03	0.02	0.1	0.05	0.06	0.001	0.02	1	0.029	1
63	40	2.00E-03	0.5	0.1	0.003	0.4	0.05	0.2	1	0.116	1
64	40	2.30E-03	0.02	5	0.003	0.01	0.001	0.2	1	0.010	1
65	40	2.30E-03	0.02	5	0.003	0.01	0.001	0.2	1	0.010	1
66	40	3.00E-03	0.5	5	0.003	0.4	0.001	0.2	1	0.068	1
67	40	4.80E-03	0.1	0.7	0.05	0.01	0.05	0.2	1	0.168	1
68	40	5.00E-03	0.02	0.7	0.02	0.06	0.05	0.2	1	0.039	1
69	40	1.30E-02	0.5	0.1	0.05	0.4	0.001	0.02	1	0.125	1
70	40	0.0944	0.5	0.1	0.003	0.4	0.001	0.02	1	0.226	1
71	40	0.107	0.5	0.7	0.05	0.4	0.05	0.2	1	0.214	1
72	40	0.0944	0.5	5	0.02	0.4	0.05	0.02	1	0.130	1
73	40	1.22E-01	0.02	5	0.003	0.4	0.05	0.02	1	0.087	1
74	40	1.18E-01	0	5	0.05	0.4	0.001	0.2	1	0.079	1
75	40	1.59E-01	0.02	5	0.05	0.01	0.05	0.2	1	0.241	1
76	40	1.41E-01	0.1	0.1	0.02	0.06	0.05	0.2	1	1.062	1
77	40	1.46E-01	0.02	0.1	0.003	0.4	0.001	0.2	1	0.178	1
78	40	0.0005	0.5	5	0.003	0.01	0.05	0.02	0	0.150	1
79	40	0.0037	0.5	0.1	0.003	0.01	0.001	0.2	0	2.833	1
80	40	0.0028	0.5	0.1	0.05	0.01	0.05	0.2	0	1.445	1

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
81	40	0.0074	0.1	0.1	0.003	0.01	0.05	0.02	0	0.756	1
82	40	0.0186	0.5	5	0.02	0.01	0.001	0.2	0	0.175	1
83	40	0.106	0.5	0.1	0.05	0.01	0.001	0.02	0	2.952	1
84	40	0.114	0.02	0.1	0.02	0.01	0.05	0.02	0	2.493	1
85	40	0.141	0.1	0.7	0.003	0.01	0.001	0.02	0	1.461	1
86	40	0.127	0.5	5	0.003	0.01	0.001	0.02	0	0.347	1
87	40	0.00316	0.86	0.88	0.053	0.014	0.089	0.49	0	0.959	5
88	40	3.00E-04	0.35	3.5	0.007	0.1	0.086	1.4	1	0.105	8
89	40	3.16E-02	0.5	0.1	0.05	0.4	0.005	0.02	1	0.146	10
90	40	3.16E-02	0.5	0.1	0.05	0.4	0.005	0.02	1	0.146	10
91	40	3.16E-02	0.5	0.1	0.05	0.4	0.005	0.02	1	0.146	10
92	40	3.16E-02	0.5	0.1	0.05	0.4	0.005	0.02	1	0.146	10
93	40	3.16E-02	0.5	0.1	0.05	0.4	0.005	0.02	1	0.146	10
94	40	0.005	0.02	0.7	0.02	0.06	0.1	0.2	1	0.039	10
95	40	1.00E-04	0.16	0.03	0	0.2	0	0.28	1	0.074	11
96	40	1.00E-04	0.16	0.03	0	0.4	0	0.28	1	0.037	11
97	40	1.00E-02	0.16	0.03	0	0.2	0	0.28	1	0.098	11
98	40	1.00E-02	0.16	0.03	0	0.4	0	0.28	1	0.049	11
99	40	4.80E-03	0.1	0.7	0.05	0.01	0.05	0.2	1	0.168	12
100	40	5.00E-03	0.02	0.7	0.02	0.06	0.05	0.2	1	0.039	12
101	40	1.30E-02	0.5	0.1	0.05	0.4	0.001	0.02	1	0.125	12
102	40	8.32E-02	0	0.1	0.05	0.4	0.05	0.02	1	0.095	12
103	40	0.01	0.5	3	0	0.11	0	0	1	0.177	12
104	40	0.01	1	3	0	0.11	0	0	0	0.337	12
105	40	0.01	1.5	3	0	0.11	0	0	0	0.497	12
106	40	0.05	0.5	3	0	0.11	0	0	1	0.244	12
107	40	0.05	1	3	0	0.11	0	0	0	0.404	12
108	40	0.05	1.5	3	0	0.11	0	0	0	0.564	12
109	40	0.01	0.5	5.5	0	0.11	0	0	1	0.117	12
110	40	0.0011	0.5	1.1	0	0.11	0	0	1	0.267	12
111	40	0.0013	1	1.1	0	0.11	0	0	0	0.531	12
112	40	0.0011	1.5	1.1	0	0.11	0	0	0	0.795	12
113	40	0.0022	0.5	1.1	0	0.11	0	0	0	0.270	12
114	40	0.0028	1	1.1	0	0.11	0	0	0	0.535	12
115	40	0.0025	1.5	1.1	0	0.11	0	0	0	0.798	12
116	40	0.0022	0.5	5.5	0	0.11	0	0	1	0.108	12
117	40	0.011	0.5	1.1	0	0.11	0	0	0	0.294	12
118	40	0.0117	1	1.1	0	0.11	0	0	0	0.560	12
119	40	0.0102	1.5	1.1	0	0.11	0	0	0	0.820	12
120	40	0.055	0.5	1.1	0	0.11	0	0	0	0.415	12

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
121	40	0.0575	1	1.1	0	0.11	0	0	0	0.686	12
122	40	0.055	1.5	1.1	0	0.11	0	0	0	0.943	12
123	40	0.0102	0.5	3	0	0.11	0	0	1	0.177	12
124	40	0.0102	0.5	5.004	0	0.11	0	0	1	0.125	12
125	40	0.012	1	4.252	0	0.11	0	0	0	0.270	12
126	40	0.0112	1.5	4.089	0	0.11	0	0	0	0.408	12
127	40	0.0513	0.5	5.004	0	0.11	0	0	1	0.174	12
128	40	0.0525	1	4.252	0	0.11	0	0	0	0.324	12
129	40	0.0513	1.5	4.089	0	0.11	0	0	0	0.462	12
130	40	0.127	0.5	5	0.003	0.01	0.001	0.02	0	0.347	12
131	40	0.0005	0.5	5	0.003	0.01	0.05	0.02	0	0.150	12
132	40	0.0074	0.1	0.1	0.003	0.01	0.05	0.02	0	0.756	12
133	40	0.106	0.5	0.1	0.05	0.01	0.001	0.02	0	2.952	12
134	40	0.114	0.02	0.1	0.02	0.01	0.05	0.02	0	2.493	12
135	40	0.141	0.1	0.7	0.003	0.01	0.001	0.02	0	1.461	12
136	40	0.262	1	3	0	0.11	0	0	0	0.757	13
137	40	0.072	1.95	3.11	0	0.11	0	0	0	0.728	13
138	40	0.052	2.24	3.77	0	0.11	0	0	0	0.694	13
139	40	0.032	1.91	3.06	0	0.11	0	0	0	0.657	13
140	40	0.032	2.13	3.4	0	0.11	0	0	0	0.680	13
141	40	0.0316	0.015	0.04	0.000153	0.00032	0.0014	0.0015	0	6.014	13
142	40	0.0316	0.325	0.04	0.000153	0.01	0.0014	0.0015	0	3.649	13
143	40	0.0316	0.12	0.04	0.000153	0.00032	0.1	0.0015	0	9.536	13
144	40	0.0132	0.5	0.1	0.05	0.4	0.005	0.02	1	0.125	13
145	40	0.0316	0.18	0.04	0.000153	0.00032	0.1	0.0015	0	11.548	13
146	40	0.0316	0.04	0.04	0.000153	0.00032	0.02	0.0015	0	6.853	13
147	40	0.0001	0.15	0.2	0	0.0037	0.0451	0.1506	0	0.891	13
148	40	0.0001	0.675	0.9	0	0.0115	0.186	0.674	0	0.959	13
149	40	0.0001	0.225	0.45	0	0.0051	0.0731	0.2259	1	0.653	13
150	40	0.0001	0.9	0.9	0	0.0142	0.3806	0.9018	0	1.227	13
151	40	0.0001	0.425	0.85	0	0.010625	0.0425	0.4261	0	0.642	13
152	40	0.0001	0.113	0.45	0	0.003	0.032	0.1125	1	0.352	13
153	40	0.0001	0.55	0.55	0	0.006875	0.0275	0.551	0	1.284	13
154	40	0.0001	1.8	0.25	0	0.0175	0.0375	1.8046	0	5.147	13
155	40	0.0001	0.1	0.2	0	0.0028	0.0278	0.1001	1	0.631	13
156	40	0.0001	0.5	0.8	0	0.032	0.121	0.5014	0	0.581	13
157	40	0.16	2.5	5	0.007	0.018	0.188	0.2	0	0.967	5, 6, 7
158	45	1.00E-03	0.68	0.91	0.07	0.018	0.076	0.58	1	0.660	5
159	45	3.16E-03	0.68	0.91	0.07	0.018	0.076	0.58	1	0.671	5
160	50	1.00E-04	2.3	2.4	0.015	0.1	0.086	1.4	1	0.858	2

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
161	50	1.00E-04	1.2	3.7	0.015	0.1	0.086	1.4	1	0.341	2
162	50	1.00E-03	1.2	3.7	0.015	0.05	0.086	1.4	1	0.404	2
163	50	1.00E-03	0.75	1.5	0.015	0.1	0.086	1.4	1	0.360	2
164	50	1.00E-03	1.5	1.5	0.015	0.1	0.086	1.4	1	0.717	2
165	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
166	50	1.00E-03	0	3.7	0.015	0.1	0.086	1.4	1	0.001	2
167	50	1.00E-03	0.35	3.7	0.015	0.1	0.086	1.4	1	0.101	2
168	50	1.00E-03	0.88	3.7	0.015	0.1	0.086	1.4	1	0.252	2
169	50	1.00E-03	1.04	3.7	0.015	0.1	0.086	1.4	1	0.297	2
170	50	1.00E-03	3.5	3.7	0.015	0.1	0.086	1.4	1	0.996	2
171	50	1.00E-03	3.5	3.7	0.015	0.1	0.086	1.4	1	0.996	2
172	50	1.00E-03	0	3.7	0.015	0.1	0.086	1.4	1	0.001	2
173	50	1.00E-03	0	3.7	0.015	0.1	0.086	1.4	1	0.001	2
174	50	0.001	0	3.7	0.015	0.1	0.086	1.4	1	0.001	2
175	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
176	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
177	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
178	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
179	50	1.00E-03	1.2	3.7	0.015	0.1	0.086	1.4	1	0.342	2
180	50	1.00E-03	1.2	3.7	0.015	0.2	0.086	1.4	1	0.262	2
181	50	1.00E-02	1.2	3.7	0.015	0.1	0.086	1.4	1	0.356	2
182	50	1.00E-01	1.2	3.7	0.015	0.1	0.086	1.4	1	0.489	2
183	50	3.16E-01	1.2	3.7	0.015	0.1	0.086	1.4	1	0.808	2
184	50	0.001	7	3.7	0.015	0.1	0.086	1.4	0	1.990	2
185	50	1.00E-03	0.86	0.88	0.053	0.014	0.089	0.49	1	0.947	5
186	50	1.00E-03	0.68	0.91	0.07	0.018	0.076	0.58	1	0.660	5
187	50	3.16E-03	0.68	0.91	0.07	0.018	0.076	0.58	1	0.671	5
188	50	1.00E-02	0.68	0.91	0.07	0.018	0.076	0.58	1	0.705	5
189	50	0.00316	0.86	0.88	0.053	0.014	0.089	0.49	0	0.959	5
190	50	0.01	0.86	0.88	0.053	0.014	0.089	0.49	0	0.998	5
191	50	0.00158	1.41	2.93	0	0	0	1.48	0	0.750	6
192	50	0.711	0.21	1.33	0.14	0.018	0.02	0.2	0	2.494	6
193	50	1.24	1.27	1.64	0.084	0.046	0.028	1.12	0	4.144	6
194	50	1.24	1.27	1.64	0.084	0.046	0.028	1.12	0	4.144	6
195	50	2.42	0	1.97	0.084	0.046	0.028	0	0	6.063	6
196	50	2.42	0	1.97	0.084	0.046	0.028	0	0	6.063	6
197	50	2.42	0.94	1.97	0.084	0.046	0.028	0	0	6.516	6
198	50	1.00E-03	0	1.97	0.068	0.011	0.02	1.84	1	0.003	7
199	50	1.00E-03	0	1.97	0.068	0.011	0	1.84	1	0.003	7
200	50	6.31E-03	0.04	0.18	0.002	0.006	0.002	0.15	1	0.387	7

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
201	50	2.00E-02	0.04	0.18	0.002	0.006	0.002	0.15	1	0.765	7
202	50	1.76E-01	0	3.58	0.009	0.031	0.047	0.33	1	0.342	7
203	50	0.001	0.85	0.06	0.068	0.011	0.305	1.84	0	2.100	7
204	50	0.001	0.85	0.06	0.068	0.011	0	1.84	0	2.100	7
205	50	0.001	0	0.06	0.068	0.011	0.305	1.84	0	0.013	7
206	50	0.001	0	0.06	0.068	0.011	0	1.84	0	0.013	7
207	50	0.001	0.85	1.97	0.068	0.011	0.02	1.84	0	0.522	7
208	50	0.0631	0.04	0.18	0.002	0.006	0.002	0.15	0	1.957	7
209	50	0.176	0.27	3.58	0.009	0.031	0.047	0.33	0	0.443	7
210	50	0.176	0.27	3.58	0.009	0.031	0.047	0.33	0	0.443	7
211	50	0.656	0.2	0.93	0.028	0.023	0.02	0.13	0	3.798	7
212	50	0.652	0.28	2.86	0.026	0.039	0.004	0.27	0	1.555	7
213	50	0.771	0.21	1.33	0.014	0.018	0.02	0.2	0	3.824	7
214	50	0.952	0.41	2.86	0.026	0.039	0.004	0.27	0	2.270	7
215	50	4.5	0.12	0.42	0.58	0.01	0.014	0.1	0	9.365	7
216	50	1.00E-04	0.01	0.11	0.007	0.1	0.086	1.4	1	0.009	8
217	50	1.00E-04	0.11	1.11	0.007	0.1	0.086	1.4	1	0.061	8
218	50	1.00E-04	0.35	3.5	0.007	0.1	0.086	1.4	1	0.104	8
219	50	1.00E-04	1	5	0.007	0.1	0.086	1.4	1	0.231	8
220	50	1.00E-04	0.5	5	0	0.15	0.1	0.1	1	0.103	8
221	50	3.00E-04	0.35	3.5	0.007	0.1	0.086	1.4	1	0.105	8
222	50	0.0001	0.91	0.02	0.068	0.011	0.305	1.92	0	2.387	8
223	50	0.348	0.09	0.51	0.006	0.011	0.008	0.17	0	4.045	8
224	50	0.568	0.18	1.05	0.011	0.014	0.016	0.22	0	3.607	8
225	50	2.5	1.75	3.5	0	0.15	0.1	0.1	0	3.807	8
226	50	7.3	1	3.6	0.005	0.1	0.05	0.1	0	11.397	8
227	50	1.00E-03	3	5.5	0	0.145	0.01	0.48	1	0.588	9
228	50	1.00E-03	3	5.5	0	0.145	0.01	0.48	1	0.588	9
229	50	0.0002	3.06	0.12	0.065	0.069	0.286	0.4	0	2.888	9
230	50	0.0004	0.16	0.01	0.004	0.004	0.015	1.61	0	2.522	9
231	50	0.00063	1.81	0.07	0	0.041	0.169	1.81	0	3.724	9
232	50	0.0324	0.16	0.01	0.004	0.004	0.015	0.14	0	5.112	9
233	50	1	3	5.5	0	0.145	0.01	0.48	0	1.604	9
234	50	1	3	5.5	0	0.145	0.01	0.48	0	1.604	9
235	50	1.00E-03	0.66	5.5	0	0	0	0	1	0.187	10
236	50	1.00E-03	0.66	5.5	0	0	0	0	1	0.187	10
237	50	1.00E-03	0.66	5.5	0	0	0	0	1	0.187	10
238	50	1.00E-03	0.66	5.5	0	0	0	0	1	0.187	10
239	50	1.00E-03	0.66	5.5	0	0	0	0	1	0.187	10
240	50	0.00079	1.12	2.26	0.117	0.053	0.049	1.91	0	0.457	10

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
241	50	0.158	0.27	3.56	0.009	0.031	0.047	0.33	0	0.410	10
242	50	0.158	0.27	3.56	0.009	0.031	0.047	0.33	0	0.410	10
243	50	0.158	0.27	3.56	0.009	0.031	0.047	0.33	0	0.410	10
244	50	0.158	0.27	3.56	0.009	0.031	0.047	0.33	0	0.410	10
245	50	0.158	0.27	3.56	0.009	0.031	0.047	0.33	0	0.410	10
246	50	2.51E-04	3.26	5.47	0	0.145	0.01	0.48	1	0.641	11
247	50	0.00132	0.6	1.06	0.009	0.027	0.03	2.1	0	0.602	11
248	50	1.55	0.6	1.06	0.009	0.026	0.03	0.02	0	8.685	11
249	50	1.55	0.6	1.06	0.009	0.026	0.03	0.02	0	8.685	11
250	50	0.262	2	3	0	0.11	0	0	0	1.077	13
251	50	0.262	2.5	3	0	0.11	0	0	0	1.238	13
252	50	0.162	1	3	0	0.11	0	0	0	0.590	13
253	50	0.072	1.95	3.11	0	0.11	0	0	0	0.728	13
254	50	0.062	1.94	2.9	0	0.11	0	0	0	0.740	13
255	50	0.052	2.24	3.77	0	0.11	0	0	0	0.694	13
256	50	0.032	1.91	3.06	0	0.11	0	0	0	0.657	13
257	50	0.032	2.13	3.4	0	0.11	0	0	0	0.680	13
258	50	3.1623	1.27	1.635	0.084	0.046	0.028	1.118	0	9.527	13
259	50	0.0001	0.7	0.388	0.0029	0.0059	0.026	0.36	0	2.158	13
260	55	1.00E-02	0.68	0.91	0.070	0.018	0.076	0.58	0	0.70	5
261	55	3.16E-03	0.68	0.91	0.070	0.018	0.076	0.58	1	0.67	5
262	55	1.00E-03	0.68	0.91	0.070	0.018	0.076	0.58	1	0.66	5
263	55	1.00E-03	0.86	0.88	0.053	0.014	0.089	0.49	1	0.95	5
264	55	3.16E-03	0.86	0.88	0.053	0.014	0.089	0.49	0	0.96	5
265	55	1.00E-02	0.86	0.88	0.053	0.014	0.089	0.49	0	1.00	5
266	60	1.00E-01	0.68	0.91	0.070	0.018	0.076	0.58	0	1.15	5
267	60	3.16E-02	0.68	0.91	0.070	0.018	0.076	0.58	0	0.81	5
268	60	1.00E-02	0.68	0.91	0.070	0.018	0.076	0.58	1	0.70	5
269	60	3.16E-03	0.68	0.91	0.070	0.018	0.076	0.58	1	0.67	5
270	60	1.00E-03	0.68	0.91	0.070	0.018	0.076	0.58	1	0.66	5
271	60	1.00E-04	0.01	0.01	0.000	0.010	0.010	0.01	1	0.09	12
272	60	1.00E-03	0.01	0.01	0.000	0.010	0.010	0.01	1	0.13	12
273	60	1.00E-04	0.001	0.001	0.000	0.001	0.001	0.00	1	0.13	12
274	60	1.00E-03	0.001	0.001	0.000	0.001	0.001	0.00	1	0.54	12
275	60	1.00E-04	0.16	0.03	0.000	0.400	0.000	0.28	1	0.04	12
276	60	1.00E-04	0.16	0.03	0.000	0.200	0.000	0.28	1	0.07	12
277	60	1.00E-02	0.16	0.03	0.000	0.400	0.000	0.28	0	0.05	12
278	60	1.00E-02	0.16	0.03	0.000	0.200	0.000	0.28	0	0.10	12
279	60	3.98E-03	0.05	0.002	0.003	0.004	0.002	0.74	0	1.28	12
280	65	4.27E+00	1.00	1.60	0.000	0.000	0.000	0.40	0	22.45	12

Table C-1 (continued)

Test	Temperature (°C)	Hydroxide (M)	Nitrite (M)	Nitrate (M)	Fluoride (M)	Chloride (M)	Sulfate (M)	TIC (M)	Fail (1) /Pass (0)	PF	Ref.
281	65	3.20E-01	1.99	4.88	0.000	0.000	0.000	0.59	0	1.16	12
282	75	2.50E+00	1.75	3.50	0.000	0.150	0.100	0.10	0	3.80	8
283	77	1.00E-03	0.001	0.002	0.003	0.004	0.018	1.03	0	0.11	3
284	77	2.61E+00	0.98	2.13	0.091	0.050	0.029	0.47	0	6.47	3
285	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	1.02	0	0.02	6
286	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	1.02	0	0.02	6
287	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	1.02	0	0.02	6
288	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	1.02	0	0.02	6
289	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	0.00	1	0.02	6
290	77	1.00E-03	0.001	0.002	0.068	0.011	0.305	0.00	1	0.02	6
291	77	1.00E-03	0.001	1.97	0.068	0.011	0.305	1.02	1	0.00	6
292	77	2.61E+00	0.98	2.13	0.091	0.050	0.029	0.47	0	6.47	6
293	77	2.61E+00	0.49	2.13	0.091	0.050	0.029	0.47	0	6.25	6
294	77	2.61E+00	0.49	2.13	0.091	0.050	0.029	0.47	0	6.25	6
295	77	3.98E-01	0.05	0.21	0.091	0.050	0.029	1.00	0	2.10	6
296	77	1.00E-03	0.00	0.002	0.003	0.004	0.009	0.94	0	0.09	6
297	77	1.00E-03	0.00	0.002	0.003	0.004	0.009	0.94	0	0.09	6
298	77	1.00E-03	0.00	0.002	0.003	0.004	0.009	0.94	0	0.09	6
299	77	1.00E-03	0.00	0.002	0.003	0.004	0.009	0.94	0	0.09	6
300	77	1.00E-03	1.20	1.532	0.000	0.000	0.000	1.24	0	1.22	6
301	77	1.00E-02	0.88	0.11	0.052	0.000	0.186	0.62	0	3.55	7
302	77	2.73E+00	1.08	2.19	0.114	0.051	0.047	0.70	0	6.41	10
303	77	3.24E-02	0.16	0.01	0.004	0.004	0.015	0.14	0	5.11	10
304	77	1.38E+00	0.62	1.10	0.059	0.028	0.031	1.04	0	6.34	10
305	77	7.94E-04	1.12	2.26	0.120	0.053	0.049	1.91	0	0.46	11
306	77	1.00E-03	0.16	0.01	0.004	0.004	0.015	1.61	0	2.57	11
307	77	6.31E-04	0.63	1.11	0.059	0.028	0.032	1.86	0	0.51	11
308	77	7.94E-04	1.12	2.26	0.117	0.053	0.049	1.91	1	0.46	10
309	77	3.98E-04	0.16	0.01	0.004	0.004	0.015	1.61	0	2.52	10
310	77	3.98E-04	0.63	1.11	0.059	0.028	0.014	1.86	0	0.51	10
311	77	5.01E-05	3.12	6.26	0.000	0.148	0.011	0.35	1	0.55	10
312	77	1.58E-04	1.81	0.02	0.000	0.041	0.169	1.81	0	3.98	10
313	77	1.58E-04	3.27	5.76	0.000	0.145	0.010	0.48	1	0.62	10
314	77	1.58E-04	3.27	5.76	0.000	0.145	0.010	0.48	1	0.62	10

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Appendix D Historical SCC Results

Table D-1 Historical SCC Results

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
1	50	1.00E-07	1.20	3.70	0.32	0.50	No	12
2	50	1.00E-07	1.20	3.70	0.32	0.50	No	12
3	50	3.16E-04	1.20	3.70	0.32	0.50	No	12
4	50	1.00E-04	1.20	3.70	0.32	0.50	No	12
5	50	1.00E-03	1.20	3.70	0.32	0.50	No	12
6	50	1.00E-04	2.30	2.40	0.96	1.49	No	12
7	50	1.00E-03	1.20	3.70	0.32	0.50	No	12
8	50	1.00E-03	0.00	0.00	0.50	4.80	No	13
9	77	1.00E-03	0.00	0.00	0.50	4.80	No	13
10	50	2.61E+00	0.98	2.13	0.46	10.58	No	13
11	77	2.61E+00	0.98	2.13	0.46	10.58	No	13
12	40	1.60E-01	2.50	5.00	0.50	1.03	No	14
13	30	3.16E-04	0.14	5.32	0.03	0.04	No	14
14	30	7.94E-04	0.05	1.19	0.04	0.07	No	14
15	30	6.31E-02	1.00	5.70	0.18	0.36	No	14
16	40	1.00E-01	0.83	4.33	0.19	0.48	No	14
17	30	1.00E-06	0.00	0.30	0.00	0.00	No	14
18	30	7.94E-02	0.23	6.10	0.04	0.16	No	14
19	30	1.58E-05	0.23	4.42	0.05	0.08	No	14
20	30	6.31E-01	2.13	3.97	0.54	2.11	No	14
21	30	1.58E-01	0.42	2.32	0.18	0.83	No	14
22	60	1.00E-03	0.68	0.91	0.75	1.17	No	14
23	77	1.00E-03	0.00	0.00	0.50	4.80	No	14
24	77	1.00E-03	0.00	0.00	0.50	4.80	No	14
25	50	7.11E-01	0.21	1.33	0.16	4.55	No	14
26	77	1.00E-03	0.39	1.97	0.20	0.31	No	14
27	77	1.00E-03	0.85	0.06	14.17	22.09	No	14
28	50	1.00E-03	0.85	0.06	14.17	22.09	No	14
29	77	1.00E-03	0.85	0.06	14.17	22.09	No	14
30	50	7.71E-01	0.21	1.33	0.16	4.91	No	14
31	50	2.50E+00	1.75	3.50	0.50	6.53	No	15
32	75	2.50E+00	1.75	3.50	0.50	6.53	No	15
33	50	1.00E-04	0.50	5.00	0.10	0.16	No	15
34	50	7.30E+00	1.00	3.60	0.28	16.75	No	15
35	50	1.00E-04	0.58	5.75	0.10	0.16	No	15
36	50	5.90E+00	2.30	2.74	0.84	18.64	No	15
37	50	1.00E-04	0.35	3.50	0.10	0.16	No	15

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
38	50	1.00E-04	0.11	1.11	0.10	0.15	No	15
39	50	1.00E-04	0.01	0.11	0.09	0.15	No	15
40	50	1.00E-04	1.00	5.00	0.20	0.31	No	15
41	50	1.00E-04	0.91	0.02	45.50	70.57	No	15
42	50	3.00E-04	0.00	0.00	0.00	1.21	No	15
43	50	1.00E-04	0.00	0.00	0.00	0.40	No	15
44	50	3.48E-01	0.09	0.51	0.18	5.77	No	15
45	50	5.68E-01	0.18	1.05	0.17	4.62	No	15
46	50	2.61E+00	0.98	2.13	0.46	10.58	No	15
47	50	2.73E+00	1.08	2.19	0.49	10.80	No	16
48	50	3.24E-02	0.16	0.01	16.00	50.88	No	16
49	50	3.98E-04	0.16	0.01	16.00	25.12	No	16
50	50	3.98E-04	0.63	1.11	0.57	0.88	No	16
51	77	2.73E+00	1.08	2.19	0.49	10.80	No	16
52	77	3.24E-02	0.16	0.01	16.00	50.88	No	16
53	77	1.38E+00	0.62	1.10	0.56	10.97	No	16
54	77	7.94E-04	1.12	2.26	0.50	0.77	No	16
55	77	3.98E-04	0.16	0.01	16.00	25.12	No	16
56	77	3.98E-04	0.63	1.11	0.57	0.88	No	16
57	50	1.26E-03	3.12	6.26	0.50	0.77	No	16
58	50	1.26E-03	3.27	5.75	0.57	0.88	No	16
59	50	3.16E-04	3.12	6.26	0.50	0.77	No	16
60	50	6.31E-04	1.81	0.07	25.86	40.15	No	16
61	50	3.16E-05	3.27	5.76	0.57	0.88	No	16
62	77	5.01E-05	3.12	6.26	0.50	0.77	No	16
63	77	1.58E-04	1.81	0.02	90.50	140.34	No	16
64	50	1.58E-04	3.27	5.76	0.57	0.88	No	16
65	77	1.58E-04	3.27	5.76	0.57	0.88	No	16
66	77	1.58E-04	3.27	5.76	0.57	0.88	No	16
67	50	1.00E+00	3.00	5.50	0.55	2.31	No	16
68	50	1.00E+00	3.00	5.50	0.55	2.31	No	16
69	50	1.00E-03	3.00	5.50	0.55	0.85	No	16
70	50	1.00E-03	3.00	5.50	0.55	0.85	No	16
71	50	5.01E-05	0.20	0.01	20.00	31.04	No	16
72	50	2.00E-04	3.06	0.12	25.50	39.54	No	16
73	50	6.46E-05	1.33	2.66	0.50	0.78	No	16
74	50	3.16E-05	5.68	6.84	0.83	1.29	No	16
75	50	3.16E-05	3.89	7.04	0.55	0.86	No	16
76	96	1.58E-03	0.86	0.06	14.33	22.43	No	16
77	35	4.25E-01	0.24	0.74	0.32	5.13	No	16

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
78	35	1.00E+00	0.15	0.39	0.38	21.24	No	16
79	40	2.30E-03	0.02	5.00	0.00	0.01	No	17
80	40	4.80E-03	0.10	0.70	0.14	0.28	No	17
81	40	5.00E-03	0.02	0.70	0.03	0.10	No	17
82	40	1.30E-02	0.50	0.10	5.00	8.80	No	17
83	96	5.01E-02	0.86	0.06	14.33	28.94	No	16
84	96	1.58E-03	0.86	0.06	14.33	22.43	No	16
85	35	4.25E-01	0.24	0.74	0.32	5.13	No	16
86	35	1.00E+00	0.15	0.39	0.38	21.24	No	16
87	50	2.51E-06	0.00	6.19	0.00	0.00	No	17
88	65	2.51E-06	0.00	6.19	0.00	0.00	No	17
89	86	2.51E-06	0.00	6.19	0.00	0.00	No	17
90	65	2.04E+00	0.00	4.85	0.00	3.39	No	17
91	85	2.04E+00	0.00	4.85	0.00	3.39	No	17
92	105	2.04E+00	0.00	4.85	0.00	3.39	No	17
93	35	4.25E-01	0.24	0.74	0.32	5.13	No	17
94	35	4.25E-01	0.24	0.74	0.32	5.13	No	17
95	35	1.81E-01	0.15	0.39	0.38	4.33	No	17
96	50	1.81E-01	0.15	0.39	0.38	4.33	No	17
97	32	6.94E-01	0.83	0.75	1.11	9.16	No	18
98	32	7.30E-01	0.91	0.77	1.18	9.46	No	18
99	32	7.40E-01	0.81	0.69	1.17	10.45	No	18
100	50	2.51E-04	3.26	5.47	0.60	0.92	No	18
101	50	1.26E-01	5.90	7.64	0.77	1.33	No	18
102	50	2.51E-02	2.80	3.61	0.78	1.26	No	18
103	65	4.27E+00	1.00	1.60	0.63	22.45	No	18
104	65	3.20E-01	1.99	4.88	0.41	1.16	No	18
105	65	1.01E+00	0.00	4.85	0.00	1.68	No	17
106	50	1.58E-01	0.27	3.56	0.08	0.47	No	17
107	50	1.58E-01	0.27	3.56	0.08	0.47	No	17
108	50	1.58E-01	0.27	3.56	0.08	0.47	No	17
109	50	1.58E-01	0.27	3.56	0.08	0.47	No	17
110	50	1.58E-01	0.27	3.56	0.08	0.47	No	17
111	40	1.26E-05	0.43	0.85	0.51	0.78	No	17
112	40	1.26E-05	0.43	0.85	0.51	0.78	No	17
113	40	1.26E-05	0.43	0.85	0.51	0.78	No	17
114	40	1.26E-05	0.43	0.85	0.51	0.78	No	17
115	40	1.26E-05	0.43	0.85	0.51	0.78	No	17
116	40	1.58E-05	0.60	0.40	1.50	2.33	No	17

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
117	40	1.58E-05	0.60	0.40	1.50	2.33	No	17
118	40	1.58E-05	0.60	0.40	1.50	2.33	No	17
119	40	1.58E-05	0.60	0.40	1.50	2.33	No	17
120	40	1.58E-05	0.60	0.40	1.50	2.33	No	17
121	40	2.51E-05	0.13	0.25	0.52	0.81	No	17
122	40	2.51E-05	0.13	0.25	0.52	0.81	No	17
123	40	2.51E-05	0.13	0.25	0.52	0.81	No	17
124	40	2.51E-05	0.13	0.25	0.52	0.81	No	17
125	40	2.51E-05	0.13	0.25	0.52	0.81	No	17
126	40	3.16E-02	0.50	0.10	5.00	10.29	No	17
127	40	3.16E-02	0.50	0.10	5.00	10.29	No	17
128	40	3.16E-02	0.50	0.10	5.00	10.29	No	17
129	40	3.16E-02	0.50	0.10	5.00	10.29	No	17
130	40	3.16E-02	0.50	0.10	5.00	10.29	No	17
131	50	1.00E-03	0.66	5.50	0.12	0.19	No	17
132	50	1.00E-03	0.66	5.50	0.12	0.19	No	17
133	50	1.00E-03	0.66	5.50	0.12	0.19	No	17
134	50	1.00E-03	0.66	5.50	0.12	0.19	No	17
135	50	1.00E-03	0.66	5.50	0.12	0.19	No	17
136	50	3.16E-04	0.00	5.76	0.00	0.00	Yes	16
137	65	6.40E-01	0.00	4.85	0.00	1.06	Yes	17
138	50	4.00E-01	0.10	4.20	0.02	0.80	Yes	17
139	66	4.00E-01	0.10	4.20	0.02	0.80	Yes	17
140	65	6.40E-01	0.00	4.85	0.00	1.06	Yes	18
141	77	2.00E-04	0.63	1.11	0.57	0.88	No	19
142	50	2.51E-04	3.27	5.76	0.57	0.88	No	19
143	32	1.63E-01	1.48	0.90	1.64	4.01	No	19
144	32	3.80E-04	5.15	4.73	1.09	1.69	No	19
145	25	1.00E-04	0.00	5.50	0.00	0.00	No	19
146	50	1.00E-04	0.00	5.50	0.00	0.00	No	19
147	25	5.00E-01	3.50	2.75	1.27	3.44	No	19
148	25	1.00E+00	0.00	0.01	0.00	805	No	19
149	25	1.00E+00	1.75	5.50	0.32	1.96	No	19
150	25	1.00E+00	3.50	0.01	350	1348	No	19
151	40	5.00E-01	3.50	0.01	350	945	No	19
152	50	1.00E+00	3.50	0.01	350	1348	No	19
153	25	6.70E-01	1.20	2.50	0.48	2.90	No	19
154	30	1.00E-01	2.00	1.25	1.60	3.12	No	19
155	30	1.00E+00	1.60	0.60	2.67	17.55	No	19

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
156	35	1.00E-04	3.00	3.75	0.80	1.24	No	19
157	40	2.00E-01	0.80	4.90	0.16	0.58	No	19
158	40	3.00E-01	0.40	4.30	0.09	0.71	No	19
159	45	5.50E-01	0.00	0.01	0.00	443	No	19
160	45	4.50E-01	2.30	3.00	0.77	2.40	No	19
161	50	8.00E-01	2.75	1.80	1.53	5.95	No	19
162	35	1.50E-01	0.00	5.50	0.00	0.22	No	19
163	60	1.00E+00	3.50	5.50	0.64	2.45	No	19
164	60	1.00E-04	3.50	0.01	350.	543	No	19
165	60	1.00E-04	0.00	0.01	0.00	0.08	Yes	19
166	60	1.00E+00	0.00	5.50	0.00	1.46	No	19
167	25	1.00E-04	3.50	5.50	0.64	0.99	No	19
168	60	1.00E-04	3.50	5.50	0.64	0.99	No	19
169	40	1.00E-04	0.16	0.03	5.33	8.29	No	19
170	60	1.00E-04	0.16	0.03	5.33	8.29	No	19
171	40	1.79E-01	0.03	0.49	0.06	3.04	No	19
172	40	1.00E-03	0.03	0.49	0.06	0.11	No	19
173	40	1.79E-01	0.03	0.49	0.06	3.04	No	19
174	40	3.16E-06	0.00	0.29	0.00	0.01	No	19
175	40	3.16E-06	0.00	0.29	0.00	0.01	No	19
176	50	1.00E-06	0.00	6.19	0.00	0.00	No	19
177	65	1.00E-06	0.00	6.19	0.00	0.00	No	19
178	86	1.00E-06	0.00	6.19	0.00	0.00	No	19
179	50	1.00E-06	0.00	6.19	0.00	0.00	Yes	19
180	65	1.00E-06	0.00	6.19	0.00	0.00	Yes	19
181	86	1.00E-06	0.00	6.19	0.00	0.00	Yes	19
182	95	1.25E-03	0.00	0.00	1.00	11.61	No	20
183	95	1.26E-05	1.29	1.00	1.29	2.00	No	20
184	120	1.26E-05	1.29	1.00	1.29	2.00	No	20
185	65	3.98E-05	1.29	1.00	1.29	2.00	No	20
186	50	3.98E-05	1.29	1.00	1.29	2.00	No	20
187	95	1.00E-02	0.64	0.10	6.40	10.73	No	20
188	116	1.00E-02	0.64	0.10	6.40	10.73	No	20
189	95	1.03E+00	0.20	3.79	0.05	2.27	No	20
190	95	1.00E-04	0.54	3.79	0.14	0.22	No	20
191	50	6.00E-01	0.00	2.75	0.00	1.76	No	20
192	50	6.00E-01	0.60	5.50	0.11	1.05	No	20
193	50	1.20E+00	0.00	3.75	0.00	2.58	No	20
194	50	1.20E+00	0.00	4.75	0.00	2.03	No	20

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
195	50	1.20E+00	0.00	3.10	0.00	3.12	No	20
196	50	1.20E+00	0.00	2.42	0.00	3.99	No	20
197	50	1.20E+00	0.00	4.50	0.00	2.15	No	20
198	50	1.20E+00	0.00	0.94	0.00	10.28	No	20
199	50	1.20E+00	0.00	0.26	0.00	37.15	No	20
200	50	1.20E+00	0.60	4.74	0.13	2.23	No	20
201	50	1.20E+00	0.60	5.32	0.11	1.99	No	20
202	50	1.20E+00	0.60	4.92	0.12	2.15	No	20
203	50	1.00E-04	1.20	0.80	1.50	2.33	No	20
204	50	1.00E-04	0.90	0.60	1.50	2.33	No	20
205	50	1.66E-04	0.05	1.00	0.05	0.08	No	20
206	50	1.66E-04	0.10	2.00	0.05	0.08	No	20
207	50	1.74E-04	0.15	3.00	0.05	0.08	No	20
208	50	1.86E-04	0.20	4.00	0.05	0.08	No	20
209	50	1.26E-04	0.20	4.00	0.05	0.08	No	20
210	50	2.29E-04	0.00	4.00	0.00	0.00	No	20
211	50	3.39E-04	0.20	4.00	0.05	0.08	No	20
212	32	7.24E-02	5.15	4.68	1.10	1.83	No	19
213	32	1.34E-06	5.15	4.68	1.10	1.71	No	20
214	50	6.00E-01	1.20	2.75	0.44	2.43	No	20
215	50	1.00E-04	1.20	2.75	0.44	0.68	Yes	20
216	50	6.50E-02	1.20	2.75	0.44	0.87	No	20
217	50	1.20E+00	1.20	2.75	0.44	4.19	No	20
218	50	1.00E-04	1.20	2.75	0.44	0.68	Yes	20
219	55	2.80E-01	0.02	1.55	0.01	1.47	No	20
221	95	2.74E+00	2.57	2.89	0.89	9.01	No	20
222	95	8.90E-01	0.52	1.60	0.33	4.98	No	20
223	55	8.90E-01	0.52	1.60	0.33	4.98	No	20
224	95	2.74E+00	2.57	2.89	0.89	9.01	No	20
225	50	4.00E-01	0.10	4.20	0.02	0.80	No	20
226	50	1.25E-03	0.10	4.20	0.02	0.04	No	20
227	50	1.25E-03	0.10	4.20	0.02	0.04	No	20
228	95	3.20E-01	0.47	0.44	1.07	7.51	No	21
229	95	6.70E-01	0.82	0.74	1.11	9.01	No	21
230	95	3.70E-01	2.07	1.50	1.38	4.12	No	21
231	95	6.80E-01	1.60	0.95	1.68	8.37	No	21
232	95	1.73E+00	1.98	2.59	0.76	6.56	No	21
233	95	1.00E-02	0.88	0.10	8.80	14.45	No	21
234	75	1.00E+01	0.00	0.00	10000	1000	No	21

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
235	75	1.00E+01	0.20	1.50	0.13	53.87	Yes	21
236	80	1.00E+01	0.20	5.00	0.04	16.16	Yes	21
237	50	1.00E+01	0.20	0.01	20.00	8081.00	No	21
238	50	1.00E+01	0.50	0.01	50.00	8127.50	No	21
239	50	1.00E+01	1.50	0.01	150	8282.50	No	21
240	50	1.00E+01	2.50	0.01	250.	8437.50	No	21
241	50	1.00E+01	0.20	0.01	20.00	8081.00	No	21
242	75	3.00E-01	0.30	5.00	0.06	0.58	No	21
243	95	3.00E-01	0.30	5.00	0.06	0.58	Yes	21
244	95	1.10E+00	0.50	1.70	0.29	5.66	No	21
245	95	2.50E+00	1.75	3.50	0.50	6.53	No	21
247	93	7.30E+00	2.90	3.60	0.81	17.57	Yes	1
248	93	7.30E+00	2.90	3.60	0.81	17.57	No	1
249	93	5.50E+00	2.20	2.70	0.81	17.66	No	1
250	93	7.30E+00	2.90	3.60	0.81	17.57	Yes	1
251	93	4.00E+00	2.90	2.40	1.21	15.29	No	1
252	93	6.00E+00	4.40	3.20	1.38	17.23	Yes	1
253	93	7.30E+00	0.00	3.60	0.00	16.32	Yes	1
254	93	7.30E+00	1.00	3.60	0.28	16.75	Yes	1
255	93	1.00E+00	0.00	3.40	0.00	2.37	No	1
256	100	5.00E+00	1.75	3.50	0.50	12.28	No	1
257	100	5.00E-03	3.50	1.50	2.33	3.64	No	2
258	100	5.00E-02	1.75	3.50	0.50	0.89	No	2
259	100	1.50E+00	1.20	3.60	0.33	3.87	No	2
260	50	6.00E+00	3.50	5.50	0.64	9.77	No	2
261	50	5.00E+00	1.75	3.50	0.50	12.28	No	2
262	100	1.40E+00	1.20	3.00	0.40	4.38	No	2
263	50	5.00E-03	0.00	1.50	0.00	0.03	No	2
264	50	5.00E-02	1.75	3.50	0.50	0.89	No	2
265	100	1.40E+00	0.25	3.70	0.07	3.15	No	2
266	75	2.50E+00	3.50	5.50	0.64	4.65	No	2
267	100	2.50E+00	2.00	2.80	0.71	8.29	No	2
268	100	2.50E+00	2.00	2.80	0.71	8.29	Yes	2
269	75	2.50E+00	0.00	5.50	0.00	3.66	No	2
270	75	2.50E+00	3.50	1.50	2.33	17.03	No	2
271	75	2.50E+00	0.00	1.50	0.00	13.42	No	2
272	75	2.50E+00	1.75	3.50	0.50	6.53	Yes	2
273	100	2.50E+00	3.50	3.50	1.00	7.30	No	2
274	100	2.50E+00	1.75	5.50	0.32	4.15	No	2

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
275	100	6.30E+00	2.40	1.60	1.50	34.02	No	2
276	100	6.30E+00	2.40	1.60	1.50	34.02	No	2
277	100	6.00E+00	0.00	5.50	0.00	8.78	Yes	2
278	100	2.50E+00	0.00	3.50	0.00	5.75	No	2
279	50	2.50E+00	3.50	3.50	1.00	7.30	No	2
280	100	8.00E-01	0.00	2.90	0.00	2.22	Yes	2
281	50	3.00E-01	0.00	4.80	0.00	0.50	No	2
282	75	3.00E-01	0.00	4.80	0.00	0.50	Yes	2
283	100	3.00E-01	0.00	4.80	0.00	0.50	Yes	2
284	50	2.50E+00	0.00	3.50	0.00	5.75	No	2
285	75	5.00E+00	1.75	5.50	0.32	7.81	No	2
286	75	5.00E-02	1.75	5.50	0.32	0.57	No	2
287	75	5.00E+00	1.75	1.50	1.17	28.64	No	2
288	75	5.00E-02	1.75	1.50	1.17	2.08	No	2
289	75	2.50E+00	1.75	3.50	0.50	6.53	Yes	2
290	100	3.00E-01	0.00	4.80	0.00	0.50	Yes	2
291	100	8.00E-01	0.00	2.90	0.00	2.22	Yes	2
292	100	2.50E+00	1.75	1.50	1.17	15.23	No	2
293	100	6.00E+00	3.50	1.50	2.33	35.82	No	2
294	100	1.60E+00	0.00	6.00	0.00	2.15	Yes	2
295	100	1.50E+00	0.70	3.30	0.21	3.99	No	2
296	100	1.50E+00	0.70	3.30	0.21	3.99	No	2
297	50	2.50E+00	1.75	5.50	0.32	4.15	No	2
298	50	5.00E-03	3.50	5.50	0.64	0.99	No	2
299	50	2.50E+00	1.75	1.50	1.17	15.23	No	2
300	100	5.00E-03	3.50	5.50	0.64	0.99	Yes	2
301	75	5.00E+00	3.50	3.50	1.00	13.05	No	2
302	100	5.00E-03	0.00	5.50	0.00	0.01	Yes	2
303	75	5.00E-02	3.50	3.50	1.00	1.67	No	2
303	75	5.00E-02	3.50	3.50	1.00	1.67	No	2
304	100	6.00E+00	0.05	1.50	0.03	32.25	No	2
305	75	5.00E+00	0.00	3.50	0.00	11.50	No	2
306	50	5.00E-03	0.00	1.50	0.00	0.03	No	2
307	75	5.00E-02	0.00	3.50	0.00	0.12	No	2
308	100	1.10E+00	0.50	1.70	0.29	5.66	No	2
309	100	1.10E+00	0.50	1.70	0.29	5.66	Yes	2
310	50	6.00E+00	3.50	1.50	2.33	35.82	No	2
311	75	2.50E+00	1.75	3.50	0.50	6.53	Yes	2
312	100	2.80E+00	3.20	1.90	1.68	14.47	No	2

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
313	100	2.80E+00	3.20	1.90	1.68	14.47	Yes	2
314	50	6.00E+00	0.00	5.50	0.00	8.78	No	2
315	100	5.00E-01	0.00	7.40	0.00	0.54	Yes	2
316	35	1.50E-01	0.00	5.50	0.00	0.22	Yes	2
317	55	1.00E-06	0.00	5.50	0.00	0.00	Yes	2
318	55	5.00E-01	0.00	5.50	0.00	0.73	Yes	2
319	55	1.50E-01	0.25	5.50	0.05	0.29	Yes	2
320	55	1.00E+00	0.25	5.50	0.05	1.53	No	2
321	55	5.00E-01	0.50	5.50	0.09	0.87	No	2
322	55	1.50E-01	0.00	6.40	0.00	0.19	Yes	2
323	55	1.00E+00	0.00	6.40	0.00	1.26	No	2
324	55	5.00E-01	0.25	6.40	0.04	0.69	No	2
325	55	1.50E-01	0.50	6.40	0.08	0.31	Yes	2
326	55	1.00E+00	0.50	6.40	0.08	1.38	No	2
327	35	5.00E-01	0.25	5.50	0.05	0.80	No	2
328	55	1.50E-01	0.00	7.25	0.00	0.17	Yes	2
329	55	5.00E-01	0.00	7.25	0.00	0.56	No	2
330	55	1.50E-01	0.25	7.25	0.03	0.22	Yes	2
331	55	1.00E+00	0.25	7.25	0.03	1.16	No	2
332	55	5.00E-01	0.50	7.25	0.07	0.66	No	2
333	75	1.50E-01	0.00	5.50	0.00	0.22	Yes	2
334	75	5.00E-01	0.25	5.50	0.05	0.80	No	2
335	75	1.50E-01	0.00	6.40	0.00	0.19	Yes	2
336	75	5.00E-01	0.00	6.40	0.00	0.63	Yes	2
337	75	1.50E-01	0.25	6.40	0.04	0.25	Yes	2
338	35	5.00E-01	0.00	6.40	0.00	0.63	Yes	2
339	75	1.00E+00	0.25	6.40	0.04	1.32	No	2
340	75	5.00E-01	0.50	6.40	0.08	0.75	No	2
341	75	1.50E-01	0.00	7.25	0.00	0.17	Yes	2
342	75	5.00E-01	0.25	7.25	0.03	0.61	No	2
343	35	1.00E+00	0.25	6.40	0.04	1.32	No	2
344	35	1.50E-01	0.25	6.40	0.04	0.25	Yes	2
345	35	5.00E-01	0.50	6.40	0.08	0.75	No	2
346	35	5.00E-01	0.25	7.25	0.03	0.61	No	2
347	35	6.00E-01	0.30	8.00	0.04	0.66	No	2
348	35	6.00E-01	0.30	8.00	0.04	0.66	No	2
349	60	8.00E+00	0.50	0.02	25.00	3258.75	No	2
350	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
351	80	5.50E+00	0.50	0.20	2.50	225.25	No	2

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
352	100	8.00E+00	0.50	2.00	0.25	32.59	No	2
353	60	5.50E+00	0.05	0.20	0.25	221.76	No	2
354	100	8.00E+00	0.01	2.00	0.00	32.21	No	2
355	100	8.00E+00	0.50	0.02	25.00	3258.75	No	2
356	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
357	60	3.00E+00	0.01	0.02	0.25	1208.28	No	2
358	100	8.00E+00	0.01	0.02	0.25	3220.78	No	2
359	100	3.00E+00	0.01	0.02	0.25	1208.28	No	2
360	80	8.00E+00	0.05	0.20	0.25	322.39	No	2
361	60	8.00E+00	0.50	2.00	0.25	32.59	No	2
362	60	8.00E+00	0.01	2.00	0.00	32.21	No	2
363	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
364	100	5.50E+00	0.05	0.20	0.25	221.76	No	2
365	60	8.00E+00	0.01	0.02	0.25	3220.78	No	2
366	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
367	80	5.50E+00	0.05	0.02	2.50	2217.63	No	2
368	100	3.00E+00	0.01	2.00	0.00	12.08	No	2
369	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
370	60	3.00E+00	0.50	0.02	25.00	1246.25	No	2
371	80	5.50E+00	0.05	0.20	0.25	221.76	No	2
372	100	3.00E+00	0.50	0.02	25.00	1246.25	No	2
373	60	3.00E+00	0.50	2.00	0.25	12.46	No	2
374	80	3.00E+00	0.05	0.20	0.25	121.14	No	2
375	80	3.00E+00	0.05	2.00	0.03	12.11	No	2
376	60	3.00E+00	0.01	2.00	0.00	12.08	No	2
377	97	6.00E-01	0.00	5.00	0.00	0.97	Yes	2
378	97	1.00E+00	0.00	5.00	0.00	1.61	Yes	2
379	97	1.50E+00	0.00	5.00	0.00	2.42	No	2
380	100	1.50E+00	1.20	3.60	0.33	3.87	No	2
381	97	1.30E+00	0.00	5.00	0.00	2.09	No	2
382	100	1.40E+00	1.20	3.00	0.40	4.38	No	2
383	97	8.00E-01	0.50	5.00	0.10	1.44	No	2
384	100	1.40E+00	0.25	3.70	0.07	3.15	No	2
385	97	5.00E-01	0.50	5.00	0.10	0.96	No	2
386	97	3.00E-01	0.75	5.00	0.15	0.72	No	2
387	97	2.00E-01	1.00	5.00	0.20	0.63	No	2
388	97	1.00E-01	1.00	5.00	0.20	0.47	No	2
389	97	5.00E-01	1.50	5.00	0.30	1.27	No	2
390	97	4.00E-02	1.80	5.00	0.36	0.62	No	2

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
391	97	5.00E-01	0.00	5.00	0.00	0.81	Yes	2
392	97	4.00E-02	2.30	5.00	0.46	0.78	No	2
393	100	8.00E-01	0.00	2.90	0.00	2.22	Yes	2
394	100	3.00E-01	0.00	4.80	0.00	0.50	Yes	2
395	97	4.00E-02	0.00	5.00	0.00	0.06	Yes	2
396	100	1.50E+00	0.70	3.30	0.21	3.99	No	2
397	97	7.50E-01	0.15	5.00	0.03	1.25	Yes	2
398	97	5.00E-01	0.25	5.00	0.05	0.88	Yes	2
399	97	2.00E-01	0.25	5.00	0.05	0.40	Yes	2
400	97	1.00E-01	0.50	5.00	0.10	0.32	Yes	2
401	97	4.00E-02	0.50	5.00	0.10	0.22	Yes	2
402	97	4.00E-02	1.50	5.00	0.30	0.53	Yes	2
403	100	2.80E+00	3.20	1.90	1.68	14.47	No	2
404	100	4.00E-02	0.00	8.00	0.00	0.04	Yes	2
405	100	5.00E-01	0.00	7.40	0.00	0.54	Yes	2
406	95	1.00E-06	0.00	5.00	0.00	0.00	Yes	3
407	95	1.00E-06	0.00	5.00	0.00	0.00	Yes	3
408	50	1.00E-06	0.00	5.00	0.00	0.00	Yes	3
409	40	1.00E-06	0.00	5.00	0.00	0.00	No	3
410	50	1.00E-06	0.00	5.00	0.00	0.00	Yes	3
411	95	1.00E-06	0.00	5.00	0.00	0.00	Yes	3
412	40	1.00E-06	0.00	5.00	0.00	0.00	No	3
413	95	1.00E-05	0.50	5.00	0.10	0.16	Yes	3
414	95	1.00E-05	0.50	5.00	0.10	0.16	Yes	3
415	95	1.00E-05	0.50	5.00	0.10	0.16	Yes	3
416	95	1.00E-05	0.50	5.00	0.10	0.16	Yes	3
417	95	5.00E-01	0.00	5.00	0.00	0.81	No	3
418	95	5.00E-01	0.00	5.00	0.00	0.81	No	3
419	95	5.00E-01	0.00	5.00	0.00	0.81	No	3
420	95	5.00E-01	0.00	5.00	0.00	0.81	No	3
421	95	5.00E-01	0.00	5.00	0.00	0.81	No	3
422	95	5.00E-01	0.20	5.00	0.04	0.87	Yes	3
423	95	5.00E-01	0.20	5.00	0.04	0.87	No	3
424	95	5.00E-01	0.20	5.00	0.04	0.87	Yes	3
425	95	3.00E-01	0.30	5.00	0.06	0.58	Yes	3
426	95	3.00E-01	0.30	5.00	0.06	0.58	No	3
427	95	3.00E-01	0.30	5.00	0.06	0.58	No	3
428	50	5.00E-01	0.50	5.00	0.10	0.96	No	3
429	95	1.00E+00	0.00	5.00	0.00	1.61	No	3

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
430	50	1.00E+00	0.00	5.00	0.00	1.61	No	3
431	50	1.00E-05	1.00	5.00	0.20	0.31	Yes	3
432	140	5.00E-01	0.01	3.00	0.00	1.35	Yes	4
433	99	2.00E-01	0.01	2.00	0.01	0.81	Yes	4
434	99	2.00E-01	0.01	5.00	0.00	0.33	Yes	4
435	140	5.00E+00	0.20	0.30	0.67	135.20	Yes	4
436	140	9.00E+00	0.01	0.20	0.05	362.33	Yes	4
437	99	2.00E-01	0.10	5.00	0.02	0.35	Yes	4
438	99	2.00E-01	0.10	5.00	0.02	0.35	Yes	5
439	93	3.00E-02	0.03	0.39	0.06	0.74	Yes	5
440	93	3.00E-02	0.39	0.39	1.00	2.17	No	5
441	93	3.90E-01	0.39	0.39	1.00	9.60	No	5
442	93	1.00E-02	0.10	0.10	1.00	2.36	No	5
443	93	3.90E-01	0.03	0.39	0.06	8.17	No	5
444	93	3.00E-02	0.39	0.03	15.72	28.20	No	5
445	93	1.00E-01	0.10	0.10	1.00	9.60	No	5
446	93	3.00E-02	0.03	0.03	1.00	9.60	No	5
447	93	1.00E-01	0.10	1.00	0.10	0.96	Yes	5
448	93	1.00E-01	0.10	0.10	1.00	9.60	No	5
449	93	1.00E-01	0.10	0.01	10.00	96.00	No	5
450	93	1.00E+00	0.10	0.10	1.00	82.05	No	5
451	93	1.00E-01	1.00	0.10	10.00	23.55	No	5
452	93	3.90E-01	0.39	0.03	15.72	124.80	No	5
453	93	1.00E-01	0.01	0.10	0.10	8.21	No	5
454	93	3.90E-01	0.03	0.03	1.00	106.20	No	5
455	75	1.00E+00	0.50	8.70	0.06	1.01	No	6
456	75	1.00E+00	0.50	8.70	0.06	1.01	No	6
457	95	6.00E-01	0.50	5.50	0.09	1.02	No	6
458	95	3.00E-01	0.30	5.50	0.05	0.52	No	6
459	95	6.00E-01	0.50	8.00	0.06	0.70	No	6
460	95	1.00E+00	0.00	8.00	0.00	1.01	No	6
461	95	6.00E-01	0.50	9.70	0.05	0.58	No	6
462	95	6.00E-01	0.50	5.50	0.09	1.02	No	6
463	95	6.00E-01	0.50	8.00	0.06	0.70	No	6
464	95	1.00E+00	0.00	8.00	0.00	1.01	No	6
465	95	6.00E-01	0.50	9.70	0.05	0.58	No	6
466	95	3.00E-01	0.30	5.50	0.05	0.52	Yes	6
467	25	6.00E-02	0.00	2.00	0.00	0.24	No	7
468	25	2.00E-01	0.30	6.00	0.05	0.35	No	7

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
469	50	6.00E-02	0.30	2.00	0.15	0.47	No	7
470	50	2.00E-01	0.30	6.00	0.05	0.35	No	7
471	25	8.00E-01	0.30	2.00	0.15	3.45	No	7
472	25	8.00E-01	0.30	6.00	0.05	1.15	No	7
473	50	8.00E-01	0.30	2.00	0.15	3.45	No	7
474	50	8.00E-01	0.30	6.00	0.05	1.15	No	7
475	25	2.00E-01	0.00	6.00	0.00	0.27	No	7
476	50	2.00E-01	0.00	2.00	0.00	0.81	No	7
477	50	6.00E-02	0.00	6.00	0.00	0.08	No	7
478	50	5.00E-01	0.00	6.00	0.00	0.67	No	7
479	25	8.00E-01	0.00	2.00	0.00	3.22	No	7
480	25	8.00E-01	0.00	6.00	0.00	1.07	No	7
481	50	8.00E-01	0.00	2.00	0.00	3.22	No	7
482	50	8.00E-01	0.00	6.00	0.00	1.07	No	7
483	25	6.00E-02	0.30	2.00	0.15	0.47	No	7
484	40	3.70E-03	0.50	0.10	5.00	8.05	No	8
485	40	2.00E-03	0.02	5.00	0.00	0.01	No	8
486	40	5.00E-04	0.50	5.00	0.10	0.16	No	8
487	40	2.80E-03	0.50	0.10	5.00	7.98	No	8
488	40	6.00E-04	0.02	5.00	0.00	0.01	No	8
489	40	1.20E-03	0.02	0.10	0.20	0.41	No	8
490	40	2.00E-04	0.50	5.00	0.10	0.16	No	8
491	40	7.00E-04	0.02	0.10	0.20	0.37	No	8
492	40	2.00E-03	0.50	0.10	5.00	7.91	No	8
493	40	3.00E-03	0.50	5.00	0.10	0.16	No	8
494	40	6.00E-04	0.10	0.10	1.00	1.60	No	8
495	40	7.00E-04	0.02	5.00	0.00	0.01	No	8
496	40	7.40E-03	0.10	0.10	1.00	2.15	No	8
497	40	1.86E-02	0.50	5.00	0.10	0.18	No	8
498	40	4.80E-03	0.10	0.70	0.14	0.28	No	8
499	40	5.00E-03	0.02	0.70	0.03	0.10	No	8
500	40	1.30E-02	0.50	0.10	5.00	8.80	No	8
501	40	1.41E-01	0.10	0.70	0.14	1.85	No	8
502	40	1.27E-01	0.50	5.00	0.10	0.36	No	8
503	40	1.14E-01	0.02	0.10	0.20	9.45	No	8
504	40	1.06E-01	0.50	0.10	5.00	16.27	No	8
505	40	1.59E-01	0.02	5.00	0.00	0.26	No	8
506	40	1.41E-01	0.10	0.10	1.00	12.92	No	8
507	40	1.46E-01	0.02	0.10	0.20	12.08	No	8

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
508	40	9.44E-02	0.50	0.10	5.00	15.35	No	8
509	40	1.22E-01	0.02	5.00	0.00	0.20	No	8
510	40	9.44E-02	0.50	5.00	0.10	0.31	No	8
511	40	8.32E-02	0.02	0.10	0.20	7.01	No	8
512	40	1.07E-01	0.50	0.70	0.71	2.34	No	8
513	40	1.18E-01	0.02	5.00	0.00	0.20	No	8
514	50	1.00E-04	2.30	2.40	0.96	1.49	No	9
515	50	1.00E-07	1.20	3.70	0.32	0.50	No	9
516	50	1.00E-07	1.20	3.70	0.32	0.50	No	9
517	50	1.00E-07	1.20	3.70	0.32	0.50	No	9
518	50	3.16E-05	1.20	3.70	0.32	0.50	No	9
519	50	3.16E-05	1.20	3.70	0.32	0.50	No	9
520	50	1.00E-04	1.20	3.70	0.32	0.50	No	9
521	50	1.00E-04	1.20	3.70	0.32	0.50	No	9
522	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
523	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
524	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
525	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
526	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
527	50	1.00E-03	0.00	3.70	0.00	0.00	No	9
528	50	1.00E-03	1.20	3.70	0.32	0.50	No	9
529	50	7.10E-01	0.21	1.33	0.15	4.54	No	9
530	50	2.42E+00	0.94	1.97	0.48	10.63	No	9
531	50	2.42E+00	0.94	1.97	0.48	10.63	No	9
532	77	2.60E-01	0.05	0.21	0.23	10.33	No	9
533	77	2.60E-01	0.05	0.21	0.23	10.33	No	9
534	77	2.60E-01	0.05	0.21	0.23	10.33	No	9
535	77	1.00E-03	0.85	0.06	14.12	22.02	No	9
536	77	1.00E-03	0.00	1.97	0.00	0.00	No	9
537	77	1.00E-03	0.00	1.97	0.00	0.00	No	9
538	77	1.00E-03	0.00	1.97	0.00	0.00	No	9
539	77	2.46E+00	0.98	2.13	0.46	10.01	No	9
540	77	2.46E+00	0.49	2.13	0.23	9.65	No	9
541	77	2.46E+00	1.96	2.13	0.92	10.72	No	9
542	77	2.46E+00	0.49	2.13	0.23	9.65	No	9
543	50	2.63E-01	0.03	0.44	0.07	4.92	No	9
544	50	7.00E-03	0.04	0.18	0.20	0.66	No	9
545	50	2.63E-01	0.06	0.44	0.15	5.02	No	9
546	50	2.63E-01	0.06	0.44	0.15	5.02	No	9

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
547	50	2.63E-01	0.06	0.44	0.15	5.02	No	9
548	50	4.50E-01	0.12	0.42	0.29	9.07	No	9
549	50	6.56E-01	0.20	0.93	0.22	6.01	No	9
550	50	2.43E+00	2.91	1.97	1.48	12.22	No	9
551	50	2.63E-01	0.19	2.64	0.07	0.91	No	9
552	50	9.38E-01	0.28	2.86	0.10	2.79	No	9
553	50	9.38E-01	0.41	2.86	0.14	2.86	No	9
554	50	1.76E-01	0.27	3.58	0.08	0.51	No	9
555	50	1.76E-01	0.27	3.58	0.08	0.51	No	9
556	50	1.76E-01	0.27	3.58	0.08	0.51	No	9
557	50	1.00E-03	1.23	3.70	0.33	0.52	No	9
558	50	1.00E-03	1.23	3.70	0.33	0.52	No	9
559	50	1.00E-03	1.23	3.70	0.33	0.52	No	9
560	50	1.67E+00	0.74	5.09	0.14	2.87	No	9
561	50	1.67E+00	0.51	5.09	0.10	2.80	No	9
562	77	1.00E-02	0.88	0.11	8.41	13.13	No	9
563	50	1.76E-01	0.27	3.58	0.08	0.51	Yes	9
564	50	2.50E+00	1.75	3.50	0.50	6.53	No	9
565	50	1.00E-04	0.35	3.50	0.10	0.16	No	9
566	50	1.00E-04	0.91	0.02	53.65	70.57	No	9
567	50	3.16E-04	0.00	0.00	0.50	1000	No	9
568	50	1.00E-04	0.58	5.75	0.10	0.16	No	9
569	50	1.00E-04	0.00	0.00	0.50	1000	No	9
570	50	2.50E-01	3.50	5.75	0.61	1.29	No	9
571	50	7.30E+00	1.00	3.50	0.29	17.23	No	9
572	50	5.68E-01	0.18	1.05	0.17	4.62	No	9
573	50	3.48E-01	0.09	0.51	0.18	5.77	No	9
574	50	2.50E+00	1.75	3.50	0.50	6.53	No	9
575	50	5.90E+00	2.30	2.74	0.84	18.64	No	9
576	50	1.00E-04	0.11	1.11	0.10	0.15	No	9
577	50	1.00E-04	0.01	0.11	0.10	0.15	No	9
578	50	1.00E-04	1.00	5.00	0.20	0.31	No	9
579	50	2.50E-01	0.50	5.00	0.10	0.56	No	9
580	50	1.00E-03	0.85	0.06	14.12	22.09	No	9
581	50	1.00E-03	0.85	0.06	14.12	22.09	No	9
582	50	7.00E-01	0.21	1.33	0.15	4.48	No	9
583	77	1.00E-03	0.85	0.06	14.12	22.09	No	9
584	50	1.00E-03	0.66	5.50	0.12	0.19	No	10
585	50	1.00E-03	0.40	1.00	0.40	0.63	No	10

Test	Temp	[OH]	[NO2]	[NO3]	Ratio	PF (Max)	Crack	Ref
	°C	M	M	M				
586	30	1.00E-03	1.00	1.00	1.00	1.56	No	10
587	40	1.00E-02	0.01	0.10	0.12	0.99	No	10
588	30	1.00E-02	0.12	1.00	0.12	0.27	No	10
589	30	1.00E-02	5.50	5.50	1.00	1.56	No	10
590	30	1.00E-02	0.04	0.10	0.40	1.43	No	10
591	40	1.00E-02	1.00	1.00	1.00	1.63	No	10
592	50	1.00E-03	0.10	0.10	1.00	1.63	No	10
593	50	1.00E-02	5.50	5.50	1.00	1.56	No	10
594	50	1.00E-02	0.04	0.10	0.40	1.43	No	10
595	50	1.00E-02	0.12	1.00	0.12	0.27	No	10
596	30	1.00E-03	0.01	0.10	0.12	0.27	No	10
597	30	1.00E-03	2.20	5.50	0.40	0.62	No	10
598	40	1.00E-03	0.10	0.10	1.00	1.63	No	10
599	40	1.00E-03	0.40	1.00	0.40	0.63	No	10
600	40	1.00E-02	2.20	5.50	0.40	0.63	No	10
601	40	1.00E-03	0.66	5.50	0.12	0.19	No	10
602	50	1.00E-02	0.01	7.00	0.00	0.01	Yes	11
603	50	1.00E-01	0.10	7.00	0.01	0.14	Yes	11
604	50	3.00E-01	0.10	7.00	0.01	0.37	Yes	11
605	50	6.00E-01	0.20	7.00	0.03	0.73	Yes	11

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Appendix E Critical cracking potential for temperatures less than 50 °C

Table E-1 Critical Cracking Potentials [1]

Source	Temp °C	Hydroxide M	Hydroxide pH	Nitrite M	Nitrate M	Ratio	PF	SCC Observations: Cracking (Yes = 1, No = 0) at test potential in mV(SCE)												
								OCP	-250	-200	-100	-50	0	50	100	150	200	250	300	350
SR[1]	50	1.00E-02	12	0.01	7	0	0.014	-150	1											
SR	50	1.00E-01	13	0.1	7	0.01	0.137	-200		1			1		1					
SR	50	3.00E-01	13.5	0.1	7	0.01	0.367	-250		1										
SR	50	6.00E-01	13.8	0.2	7	0.03	0.734	-300			1									
Matrix 1[2,3]	50	1.00E-03	11	0.66	5.5	0.12	0.187	-75				0	1, 1	1						
Matrix 2	50	1.00E-03	11	0.4	1	0.4	0.628	-75			0	0	1							
Matrix 3	50	1.00E-03	11	0.1	0.1	1	1.631	-75				0	0	1						
Matrix 4	40	1.00E-03	11	0.66	5.5	0.12	0.187	-75			0	0	0, 0		1					
Matrix 5	40	1.00E-03	11	0.4	1	0.4	0.628	-75										0		0
Matrix 6	40	1.00E-03	11	0.1	0.1	1	1.631	-75										0		0
Matrix 7	30	1.00E-03	11	2.2	5.5	0.4	0.621	-75							0		0		0	
Matrix 8	30	1.00E-03	11	1	1	1	1.558	-75						0		0		0		
Matrix 9	30	1.00E-03	11	0.01	0.1	0.12	0.236	-75				0	1	1		1				
Matrix 10	50	1.00E-02	12	5.5	5.5	1	1.565	-150				0		0		0				
Matrix 11	50	1.00E-02	12	0.12	1	0.12	0.267	-150					0	1, 1	1					
Matrix 12	50	1.00E-02	12	0.04	0.1	0.4	1.425	-150								0	0	1, 1		
Matrix 13	40	1.00E-02	12	2.2	5.5	0.4	0.635	-150					0		0	0	1			
Matrix 14	40	1.00E-02	12	1	1	1	1.631	-150						0		0		0		
Matrix 15	40	1.00E-02	12	0.01	0.1	0.12	0.960	-150			0	1, 0,0	1, 0		1					
Matrix 16	30	1.00E-02	12	5.5	5.5	1	1.565	-150					0		0		0			
Matrix 17	30	1.00E-02	12	0.12	1	0.12	0.267	-150					0		0		0			
Matrix 18	30	1.00E-02	12	0.04	0.1	0.4	1.425	-150						0		0		0		

Table E-1 (Continued)

Source	Temp °C	Hydroxide M	Hydroxide pH	Nitrite M	Nitrate M	Ratio	PF	SCC Observations: Cracking (Yes = 1, No = 0) at test potential in mV(SCE)												
								OCP	-250	-200	-100	-50	0	50	100	150	200	250	300	350
DNV3	50	1.00E-03	11	0	3.7	0	0.002	-75			1	1								
DNV	50	1.00E-07	7	1.2	3.7	0.32	0.503	NA			0									
DNV	50	3.16E-05	9.5	1.2	3.7	0.32	0.503	50			0									
DNV	50	1.00E-04	10	1.2	3.7	0.32	0.503	0			0									
DNV	50	1.00E-03	11	1.2	3.7	0.32	0.505	-75		0	0, 0	1								
DNV	50	1.00E-03	11	3.5	3.7	0.95	1.468	-75					0							
DNV	50	1.00E-03	11	7	3.7	1.89	2.935	-75					0							
DNV	50	2.63E-01	13.4	0.19	2.64	0.07	0.914	-250			0	1								
DNV	50	1.00E-04	10	2.3	2.4	0.96	1.486	0				0								
DNV	50	2.63E-01	13.4	0.03	0.44	0.07	4.917	-250			0									
DNV	50	2.63E-01	13.4	0.06	0.44	0.14	5.023	-250			0	0								
DNV	50	1.00E-03	11	1.2	3.7	0.32	0.505	-75				0	0	1						
DNV	30	5.20E-01	13.7	1.82	3.19	0.57	2.197	-300							0		0			
DNV	50	5.20E-01	13.7	1.82	3.19	0.57	2.197	-300							0		0			
DNV	30	5.20E-01	13.7	1.82	3.19	0.57	2.197	-300							0		0			
DNV	50	5.20E-01	13.7	1.82	3.19	0.57	2.197	-300							0		0			

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