



September 16, 2010

U.S. Nuclear Regulatory Commission  
Attention: Document Control Desk  
Washington, DC 20555

Serial No. 10-509  
NSSL/WEB R0  
Docket No. 50-423  
License No. NPF-49

**DOMINION NUCLEAR CONNECTICUT, INC.**  
**MILLSTONE POWER STATION UNIT 3**  
**RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING**  
**GENERIC LETTER (GL) 2004-02**

In letters dated March 4, September 1 and November 29, 2005, November 15, 2007, February 29 and December 18, 2008, and July 8, 2010, Dominion Nuclear Connecticut, Inc. (DNC) submitted information in response to GL 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," for Millstone Power Station Units 2 and 3 (MPS2 and MPS3).

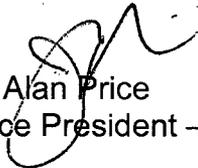
In a letter dated December 17, 2008, the Nuclear Regulatory Commission (NRC) transmitted a request for additional information (RAI) regarding GL 2004-02. Responses to RAI questions for both units were provided to the NRC in letter dated March 13, 2009.

On February 4, 2010, the NRC issued a second RAI to DNC. Based on review of the RAI responses from the March 13, 2009 letter, the NRC concluded that additional information was needed to assess whether there is reasonable assurance that GL 2004-02 has been satisfactorily addressed at MPS2 and MPS3. The DNC response for MPS2 was provided to the NRC in letter dated July 8, 2010. The following attachment contains DNC's response for MPS3 with the exception of the response for MPS3 RAI 6, (specifically items 3, 4, and 6), which will be submitted under a separate cover.

A116  
WRR

Should you have any questions in regard to this submittal, please contact Wanda Craft at 804-273-4687.

Sincerely,

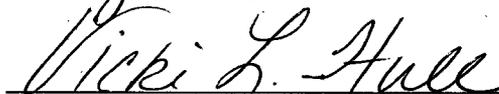
  
J. Alan Price  
Vice President – Nuclear Engineering

COMMONWEALTH OF VIRGINIA     )  
  )  
COUNTY OF HENRICO            )

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by J. Alan Price, who is Vice President – Nuclear Engineering of Dominion Nuclear Connecticut, Inc. He has affirmed before me that he is duly authorized to execute and file the foregoing document in behalf of that company, and that the statements in the document are true to the best of his knowledge and belief.

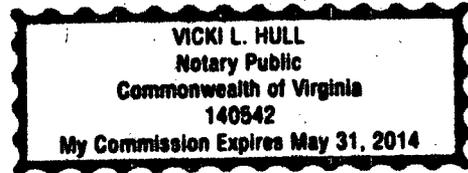
Acknowledged before me this 16<sup>TH</sup> day of September, 2010.

My Commission Expires: May 31, 2014

  
Notary Public

Commitments made in this letter:   None

Attachment:



Millstone Power Station Unit 3, Response to Request for Additional Information Regarding Generic Letter 2004-02.

cc: U. S. Nuclear Regulatory Commission  
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Millstone Power Station

**ATTACHMENT**

**MILLSTONE POWER STATION UNIT 3**  
**RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING**  
**GENERIC LETTER 2004-02**

**DOMINION NUCLEAR CONNECTICUT, INC.**  
**MILLSTONE POWER STATION UNIT 3**

**Millstone Power Station Unit 3 (MPS3) Head Loss and Vortexing RAI 6**

*Please provide the following additional information to document that the MPS3 strainer evaluation provides adequate assurance that it will perform as required under accident conditions:*

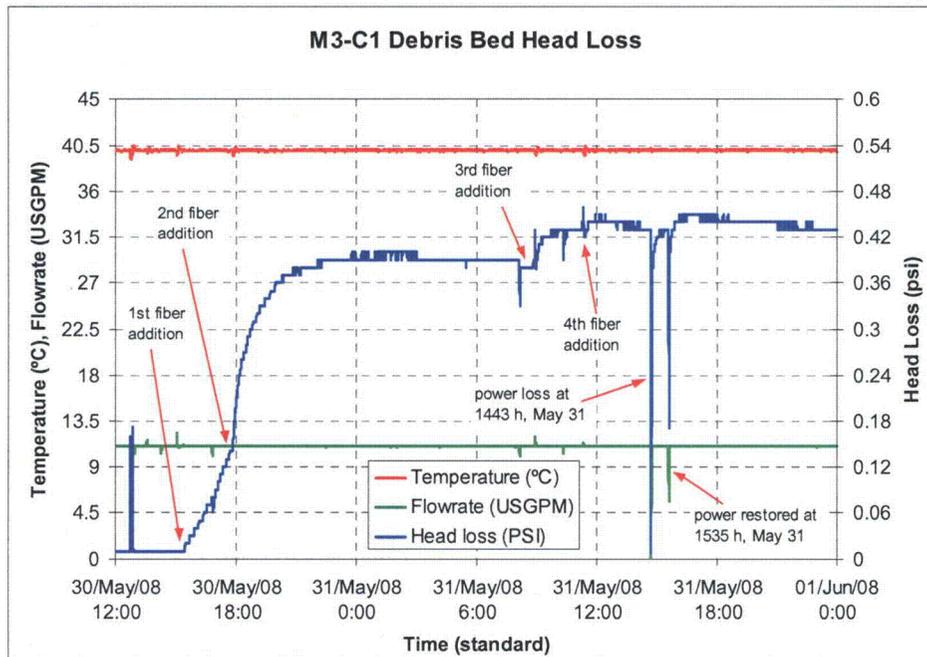
**MPS3 Head Loss and Vortexing RAI 6, Item 1**

*The December 18, 2008, DNC letter provides contradictory information on the amount of fibrous debris added during the test. On page 8, Attachment 2, it is stated that the limiting bed was determined to be 1/4 inch during earlier testing. Yet the same paragraph states that only two increments, containing fibrous debris to form 1/16 inch bed each, were added to the test and that no further fiber was added. Page 16 states that two 1/16 inch additions were made and implies that two further additions were made later. In addition, the graph on page 19 shows 4 fibrous additions. Describe, in detail, the initial fibrous debris conditions of the test and the amount of any additions that were made during the test.*

**Response to MPS3, Head Loss and Vortexing, RAI 6, Item 1**

For the MPS3 Rig 89 chemical effects test M3-C1, four fibrous debris additions were made to the test loop to achieve a thin bed thickness of 1/4 inch as determined by previous thin bed tests. The first fiber addition (1/16 in. (1.6 mm)) was made at 1504 h, May 30, 2008, after the addition of the particulate debris. The second fiber addition (an additional 1/16 in. (1.6 mm)) was made at 1750 h, May 30, 2008. The third and the fourth fiber additions (1/16 in. (1.6 mm)) were made at 0856 h and 1120 h, May 31, 2008, respectively. The detailed debris addition information is also indicated in the head loss vs. time curve as shown in Figure 1.

Figure 1: Debris Bed Head Loss vs. Time for Test M3-C1



**MPS3 Head Loss and Vortexing RAI 6, Item 2**

The December 18, 2008, DNC letter states that the limiting thin bed for MPS3 is 1/4 inch as determined by previous testing. However, the head loss plot on page 19, Attachment 2, indicates that the third and fourth 1/16 inch fiber additions had little effect on head loss. Please evaluate the thin bed thickness for MPS3 in consideration of these points. Also, if the thin bed for the Rig-89 test is different from that of other tests that were used to provide Rig-89 test inputs, please provide an evaluation of how the final qualification test could have been affected by the use of such inputs. The licensee's assertion that 55% of the debris attached to the strainer for the Rig-89 test, and 72% and 84% attached to the strainer for the reduced scale test should also be considered in this evaluation.

**Response to MPS3 Head Loss and Vortexing RAI 6, Item 2**

As shown in Figure 1 (response to RAI 6 Item 1), the debris bed head loss increased from 0.38 psi to 0.43 psi after the third fiber addition, indicating that the thin bed thickness was at least equivalent to three additions. After the fourth fiber addition, the head loss peaked at 0.45 psi and stabilized at 0.43 psi before the first chemical addition. This indicates that the fourth addition made little difference and the thin bed could be considered to be less than 1/4 inch.

The particulate debris load was 10% lower in Rig 89 test than in Rig 33 tests. Thus, the thin bed thickness would be slightly lower than that of Rig 33 tests, even though it took the same four fiber additions to form a thin bed. Also, periodic floor sweeping and continuous stirring in Rig 33 maintained the fiber in suspension resulting in eventual attachment to the debris bed. These two factors resulted in a higher percentage of debris to attach to the strainer surface. The Rig 89 test head loss versus time curve conclusively shows that a thin bed was formed by the fourth fiber addition. Extra fiber

addition will not increase or decrease the head loss because any extra fiber lies on top of the already established thin-bed. The lower percentage of debris attached to the strainer surface as compared to that of the Rig 33 tests had no negative effect on the stabilized head loss.

**MPS3 Head Loss and Vortexing RAI 6, Item 5**

*Figure 0-4 on page 22, Attachment 2, of the December 18, 2008, letter showed that following chemical debris additions head loss would increase, and then decrease back to the pre-addition value. Please evaluate this behavior considering that it may have been caused by bed degradation. Consider whether higher head losses may have occurred had additional fibrous debris been present to provide structural support to the debris bed.*

**Response to MPS3 Head Loss and Vortexing RAI 6, Item 5**

The head loss behavior after the chemical debris additions was explained in Atomic Energy of Canada Limited (AECL) test report MIL3-34325-TR-004 Rev 1 [1] as:

*Aluminum additions invariably resulted in head loss peaks, followed quickly by decreases in head loss. This phenomenon seems to have been the result of the addition method and may have been caused by the transiently high (and non-prototypical) concentration of dissolved aluminum. As the aluminum precipitates formed and settled, the head loss returned to lower values.*

The head loss versus time curve shown in Figure 1 demonstrated that the thin bed thickness was 1/4 inch or less. As long as a thin bed was formed, further fiber addition would not increase the non-chemical debris bed head loss. Extra fiber would either loosely attach to the strainer surface forming a porous layer, or settle on the tank floor. A flow sweep at the end of the test demonstrated that the head loss responded quickly to changes in flow rate and head loss changes were found to be reversible. Post-test examination (as shown in Figure 2) also confirmed that the debris bed was not degraded during the test and head loss was not limited by holes in, or dislocation of, portions of the debris bed.

Figure 2: A Piece of Debris Bed after the Rig 89 Testing



**MPS3 Head Loss and Vortexing RAI 6, Item 7**

*Please provide information that justifies that air evolution will not affect pump NPSH margins or strainer head loss in the plant. Provide the key assumptions used in the evaluation and the bases for these assumptions.*

**Response to MPS3 Head Loss and Vortexing RAI 6, Item 7**

Assumptions/Design Inputs:

- The Refueling Water Storage Tank (RWST) will be emptied in about three hours from the start of the accident.
- The minimum containment water level above the top of the strainer is 4.7 feet for a Small Break Loss of Coolant Accident (SBLOCA) and 5.3 feet for a Large Break Loss of Coolant Accident (LBLOCA).
- The maximum temperature of the containment water is less than 185°F three hours after the accident. Water density at 185°F is 60.46 lb/ft<sup>3</sup>.

The generation of air in the debris bed is dependent on the static head of water above the strainer fin. If the debris bed head loss is less than the static head of water, no air evolution is expected. The submerged depth for the reduced-scale tests was set at 8 inches whereas the minimum water level in MPS3 containment continues to rise for three hours following the accident to a minimum height of 4.7 ft above the top of the strainer.

Both the maximum static head and the increase in static head with time in containment must be compared to the head loss results to determine if air could be generated in the debris bed in MPS3 containment.

At minimum submergence (4.7 ft), the static head at the tops of the fins in containment is 2.0 psi with 185°F water. The maximum measured debris bed pressure drop was 2.17 psi in Rig 89 testing. This maximum head loss value was later corrected by calculation to be 1.67 psi since the surface area of the test module was actually 5.08 ft<sup>2</sup> vice the 5.74 ft<sup>2</sup> erroneously used in calculations at the time of testing. In addition, the maximum

debris bed head loss includes the addition of aluminum precipitates to the debris bed (from aluminum corrosion) which provides a conservative result. Aluminum corrosion is a long-term phenomenon which will only add particulate to the debris bed long after the water has cooled, resulting in significant additional static head due to subcooling. Thus, DNC concludes that the debris bed head loss will remain below the static head on the strainer preventing air evolution in the debris bed or strainer.

Within the first three hours after the accident, the static water head will increase to at least 2.0 psi. The sump water turnover time just after the start of the Recirculation Spray System (RSS) pumps (at minimum water level), would be about 48 minutes (sump water volume: 398,908 gal., flow rate: 8220 USGPM [2]). It takes three turnovers for the static water head to reach at least 2.0 psi. The Rig 89 test turnover time was about five minutes. In Rig 89, three turnovers (15 minutes) after the first fiber addition, the debris bed head loss barely reached 0.1 psi. As observed in the strainer testing, it usually took days to build a thin bed. Thus, DNC concludes that air evolution will not occur in the plant strainers.

#### **MPS3 Net Positive Suction Head RAI 9**

*It is not clear how water drains from the refueling cavity into the reactor cavity, and whether this drainage path is large enough to ensure that debris blockage would not occur. While the plant Final Safety Analysis Report (FSAR) documents that a significant amount of venting surface is available, there is also a significant quantity of debris available. The potential for blockage of the vent covers is also considered in the FSAR.*

*The RAI intended to ask about the entire refueling cavity: did your response account for the entire refueling cavity or only the cavity saddle? If your RAI response did not account for the entire refueling cavity, please update your response.*

*To ensure that the evaluation has accounted for the worst-case minimum containment water level, please clarify the drainage path from the refueling cavity to the reactor cavity, the minimum flow restrictions, and provide a basis for why blockage would not occur there.*

#### **Response to MPS3 Net Positive Suction Head RAI 9**

The previous RAI response (see Attachment 2 to DNC letter dated March 13, 2009, Serial Number 09-175, ADAMS Accession Number ML 090750436) considered the maximum potential holdup volume of the refueling cavity. The minimum water level calculation conservatively determines the minimum containment water level which exists at the earliest RSS pump start time. The total possible holdup in the refueling cavity is limited to 49,202 gallons since any water beyond this volume spills into the reactor cavity and instrumentation tunnel which in turn spills over to the containment floor. The instrumentation tunnel is assumed to be full and the refueling cavity is considered to be 99% full (48,823 gallons) in determining the minimum sump water level.

Water spills from the refueling cavity into the reactor cavity through open seal ring hatches. Spillover through the eight (8) seal ring hatches (each about 24-inch diameter) directly enters the reactor cavity and spills into the instrument tunnel prior to reaching the containment floor. Seal ring hatch protective covers are installed over the open Seal Ring Hatches (raised 8.5-inch above the opening). These covers allow unimpeded air and water flow. The open seal ring hatches with protective covers installed do not present credible locations for debris blockage due to the large size of the openings. No other minimum flow restrictions between the refueling and reactor cavities exist.

### **MPS3 Chemical Effects RAIs**

*AECL performed dissolution tests both with and without tri-sodium phosphate (TSP) in the beakers. The testing showed that the tests that included TSP showed an inhibition of the calcium dissolution. However, for the head loss testing the licensee stated that they applied the calcium quantity determined by the uninhibited (non-TSP) bench testing. Data from the lowest allowable pH (7.0) was used when determining the amount of calcium to be added to the head loss test. The calcium concentration used for head loss testing was 14.7 mg/L. This value is significantly lower than the measured value for the 30-day bench scale dissolution testing, which used scaled amounts of concrete to represent the MPS3 condition. Please provide the following additional information in order to determine that the testing was performed in an acceptable manner:*

### **MPS3 Chemical Effects RAI 14**

*The solubility data for calcium shows increased dissolution at lower pH ranges. In table 0-2, Attachment 2, to the December 18, 2008 letter, the calcium concentrations for pH 5.0 and 6.0 are lower than the concentration for pH 7.0. In addition, page 11 of 30 states that the concrete samples in the beaker tests fully dissolved in the pH 5.0 and 6.0 tests but were not fully dissolved in the pH 7.0 and 8.0 tests. Please explain why the bench tests at lower pH ranges, in which the concrete fully dissolved, resulted in lower concentrations of dissolved calcium than the bench tests at higher pH ranges, in which the concrete did not fully dissolve.*

### **Response to MPS3 Chemical Effects RAI 14**

The coupons used in these tests were small and subject to variability of rock and mortar content; thus, it must be argued that the coupons used in the pH 5 and 6 tests contained less mortar (the primary source of calcium) than those used in the pH 7 and 8 tests. The slightly lower concentrations attained in the pH 5 and 6 tests represented the limit of the calcium source (mortar) while slightly higher concentrations were attained in the pH 7 and 8 tests, despite the coupons remaining structurally intact. A more detailed explanation of the apparent conflict between the results of these tests and calcium solubility data is included below.

Concrete is inherently basic. In general, concrete dissolution rates increase as the exposed medium becomes more acidic. In the AECL test report [3] of bench top tests conducted for DNC, the results of dissolution tests simulating the MPS3 concrete

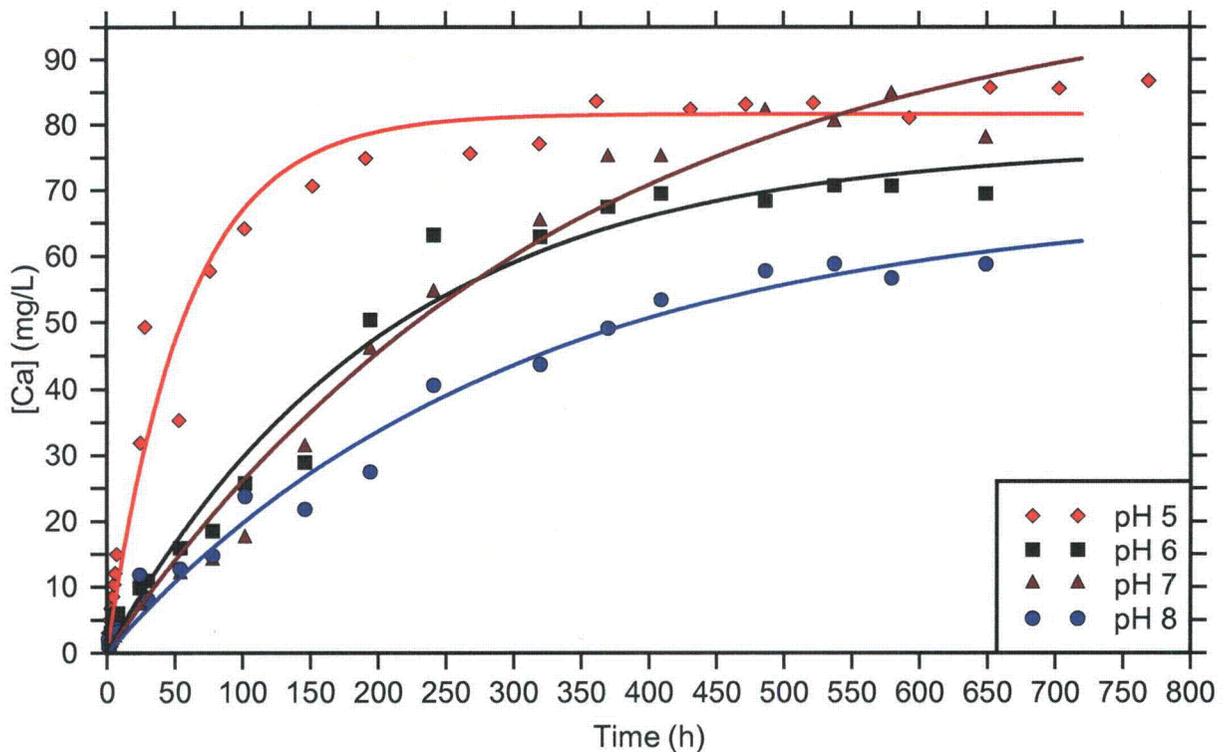
surface area-to-volume ratio<sup>i</sup> do show higher dissolution rates at lower pH ranges, but the ultimate concentrations reached were lower in the tests at pH 5 and 6 than in those at pH 7 and 8 (Figure 3). This apparent contradiction can be explained by the small size of the coupons used: (each coupon measured approximately 0.4×1.2×0.5 cm, and were small in comparison to similar tests performed for MPS2). As a result of their limited size, two of the coupons completely dissolved in the pH 5 and 6 tests. Additionally, their small size made them more prone to containing non-uniform proportions of rock and mortar. Consequently, the calcium concentrations measured toward the end of the pH 5 and 6 tests represent the natural limit when all of the concrete had dissolved. The data from all of the tests were fit to Equation 1. The early plateau seen in Figure 3 for the pH 5 and 6 tests biased their extrapolated concentrations at t=∞ shown in Table 1 (Table O-2 of the above-mentioned report).

$$Ca \text{ Release } (t) = C_{\infty}(1 - \exp(-kt)) \quad \text{Equation 1}$$

Table 1: Calcium Concentration Fitting Parameters of Equation 1 from MPS3 Dissolution Tests

Parameter	pH 5	pH 6	pH 7	pH 8
C <sub>∞</sub> [mg/L]	82	77	103	68
k [h <sup>-1</sup> ]	0.017	0.0049	0.0029	0.0034

Figure 3: Calcium Release Data from MPS3 Dissolution Tests without TSP at 90°C



<sup>i</sup> As estimated at the time; the ratio has since changed.

*Note: The lines are fits of the data sets to a first-order release equation.*

The recovery of coupons from the pH 7 and 8 tests, and the lack of any obvious plateau in Figure 3, strongly implies that the results of these more important tests were not biased by a limited calcium source. The results of the pH 7 test, in particular, were used in the design of the reduced-scale test, as pH 7 is the minimum allowed sump water pH. However, it should be noted that this remains a conservative estimate of calcium release since the MPS3 sump pool is likely to remain mainly above pH 8.

### **MPS3 Chemical Effects RAI 15**

*For MPS3, the calcium dissolution test at pH of 7.0 resulted in a 30-day calcium concentration of 78 mg/L. The December 18, 2008, letter states that the pH 7.0 case (without TSP present) was used to determine the concentration of calcium in the Rig-B9 test. However, the calcium concentration used for Rig-89 testing was 14.7 mg/L. Please justify why 14.7 mg/L is a representative value in the Rig-89 testing when the dissolution testing conducted with scaled quantities of concrete resulted in a calcium concentration of 78 mg/L.*

### **Response to MPS3 Chemical Effects RAI 15**

The value of 14.7 mg/L used in the Rig 89 testing was calculated by appropriately scaling the results of the dissolution tests to match updated estimates of the MPS3 concrete surface area. This response will show:

1. The concrete surface area-to-volume ratio used in the bench-top dissolution tests was based on estimates of the concrete surface area that were later updated;
2. The results of the dissolution tests may be normalized to units of calcium release per unit area, which may then be used to calculate the expected calcium release and calcium concentration in MPS3 based on the updated concrete surface area;
3. It is appropriate to use the fit to the entire data set to determine the scaled calcium concentration rather than to scale the analysis result obtained on day 30 (78 mg/L), which is more subject to sampling and statistical errors.

The concrete surface area-to-volume (SA/V) ratio used in the bench-top dissolution tests was roughly six times greater than the current calculated SA/V ratio using data from ERC 25212-ER-06-0013 Rev. 2 [2] and leads to the apparent discrepancy. The dissolution tests conducted from February to March, 2008, used coupons sized to meet the SA/V ratio calculated from Rev. 1 of ERC 25212-ER-06-0013 [4] and included scaled quantities of fibrous debris. Table 2 compares the SA/V ratio used in the dissolution tests to those calculated from the source references. It is important to note that, by design, there is no uncoated concrete within the MPS3 containment and that all values quoted are conservative estimates of bare areas exposed either by chipping and wear or by impact of the break jet [2].

Table 2: Comparison of Dissolution Test Concrete SA/V Ratio to MPS3 Values

Source	ERC 25212-ER-06-0013 Rev. 1	Dissolution Test	ERC 25212-ER-06-0013 Rev. 2
Date	2007/09	2008/02 – 2008/03	2008/04
Submerged Concrete	1000 ft <sup>2</sup> (9.29×10 <sup>5</sup> cm <sup>2</sup> )	0.4×1.2×0.5 cm coupons (2.56 cm <sup>2</sup> )	100 ft <sup>2</sup> (9.29×10 <sup>4</sup> cm <sup>2</sup> )
Exposed Concrete	1932 ft <sup>2</sup> (1.795×10 <sup>6</sup> cm <sup>2</sup> )	-	408 ft <sup>2</sup> (3.79×10 <sup>5</sup> cm <sup>2</sup> )
Volume	3,819,002 lb <sub>m</sub> @61.55 lb <sub>m</sub> /ft <sup>3</sup> (1.757×10 <sup>6</sup> L)	4 L	160,000 ft <sup>3</sup> (4.53×10 <sup>6</sup> L)
SA/V Ratio (Submerged)	0.529 cm <sup>2</sup> /L	0.64 cm <sup>2</sup> /L	0.0205 cm <sup>2</sup> /L
SA/V Ratio (Total)	1.55 cm <sup>2</sup> /L	-	0.104 cm <sup>2</sup> /L

Because the concrete SA/V ratio for containment differs from that tested, the results obtained are non-representative but may be appropriately scaled. Normalization of the dissolution test data may be performed by dividing the results (in mg/L) by the SA/V ratio (0.64 cm<sup>2</sup>/L), as indicated by the right-hand vertical axis in Figure 4. Similarly, the fit to the calcium concentration data described below, may also be normalized to produce a calcium release equation. Thus, the 30-day calcium release per unit area of concrete can be read from the figure or calculated from the fit and used to calculate the calcium release from a known surface area of concrete.

Figure 4 also shows the curve fits to the data represented by Equations 2 and 3. These were determined using robust fitting procedures within TableCurve 2D<sup>†</sup> that reduce the fitting errors caused by data outliers. The constants found within Equation 2 were reported in Table 2-5 of the bench-top test report [3] and Table O-2 of DNC's December 18, 2008 letter. Equation 3 may be calculated from Equation 2 by dividing the initial constant<sup>ii</sup> by the tested surface area-to-volume ratio, 0.64 cm<sup>2</sup>/L.

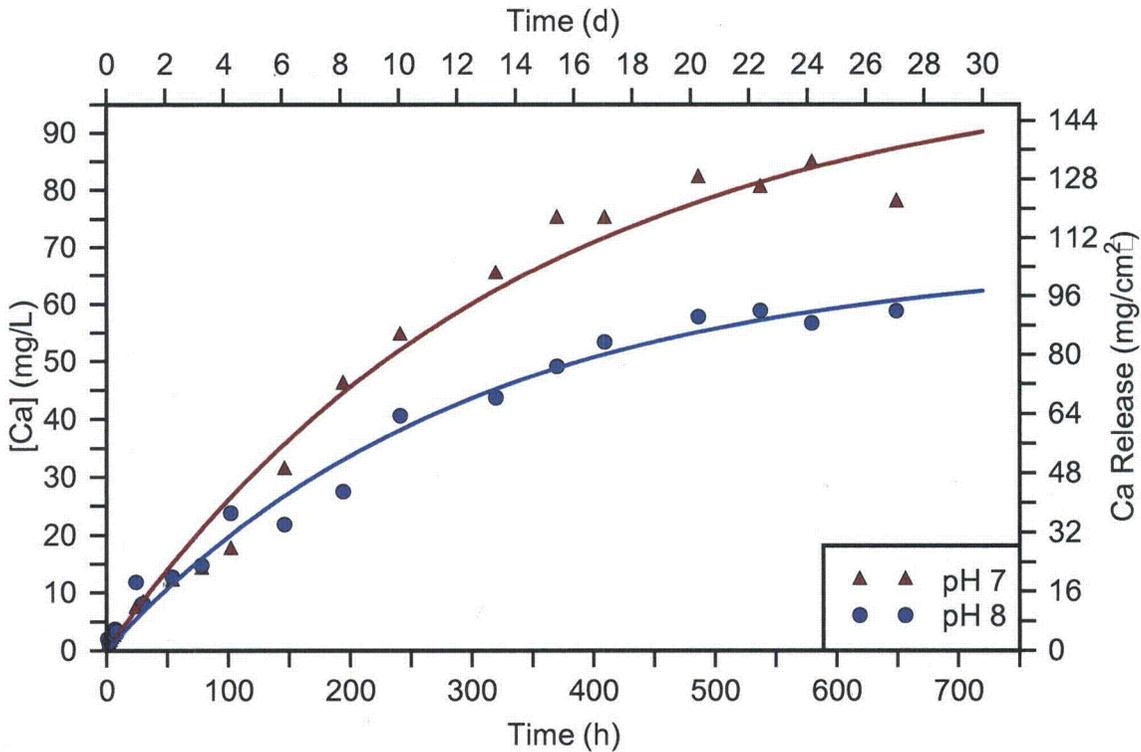
$$Ca \left[ \frac{mg}{l} \right] = 103 \left[ \frac{mg}{L} \right] \left( 1 - \exp(-0.0029h^{-1}t) \right) \quad \text{Equation 2}$$

$$Ca \text{ Release} \left[ \frac{mg}{cm^2} \right] = 160 \left[ \frac{mg}{cm^2} \right] \left( 1 - \exp(-0.0029h^{-1}t) \right) \quad \text{Equation 3}$$

<sup>†</sup> TableCurve 2D is produced and distributed by Systat Software Inc.

<sup>ii</sup> The initial constant, C<sub>o</sub>, was determined to be 102.5 mg/L, where the tenths decimal place should not be considered significant.

Figure 4: Calcium Release Data from MPS3 pH 7 and pH 8 Dissolution Tests  
(without Tri-Sodium Phosphate (TSP)) @ 90°C



Note the lines are fits of the data sets to a first-order release equation.

It is appropriate to use the fit rather than the raw data to determine the 30-day calcium concentration, as drifts in pH, sampling errors, and statistical error associated with the analysis technique, ICP-OES, may alter the measured concentration.

After 30 days, the expected calcium release at pH 7 and 90°C:

$$Ca \text{ Release } \left[ \frac{mg}{cm^2} \right] = 160 \left[ \frac{mg}{cm^2} \right] (1 - \exp(-0.0029h^{-1} \cdot 720h)) = 140 \left[ \frac{mg}{cm^2} \right]$$

Using the SA/V ratio from the last column of Table 2, 0.104 cm<sup>2</sup>/L, the expected calcium concentration is:

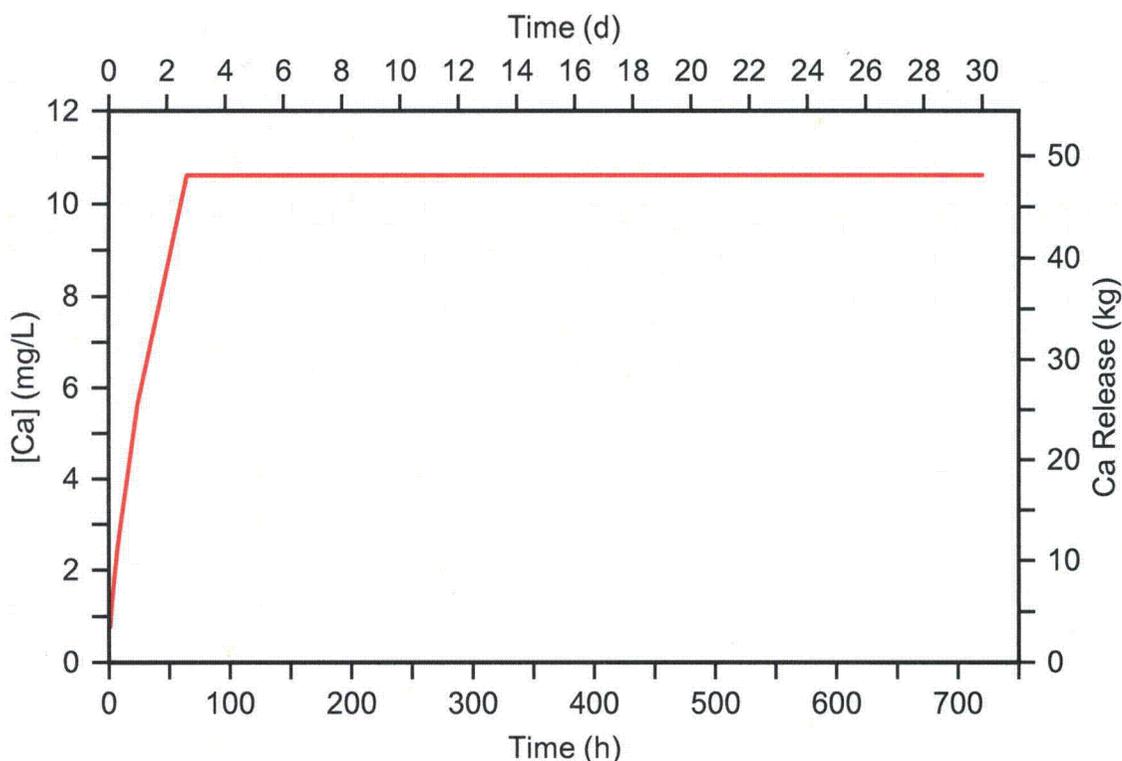
$$Ca \text{ Expected } \left[ \frac{mg}{L} \right] = 140 \left[ \frac{mg}{cm^2} \right] \cdot 0.104 \left[ \frac{cm^2}{L} \right] = 14.6 \left[ \frac{mg}{L} \right]$$

Within the error of this analysis, there is no significant difference between this result and the previously reported value of 14.7 mg/L. For comparison, the expected calcium concentration at pH 8 is 10.1 mg/L by similar analysis.

This result may be compared to the WCAP-16530 method of calculating calcium release, as described by Lane et al [5]. In utilizing this method, the calculated pH has been used; in order to maximize the release rate, the maximum pH was used to

calculate the release from Transco Thermal Wrap (around pH 8.1) and the minimum pH was used to calculate the release from concrete (around pH 8.0). By this method, the calculated calcium release from concrete is miniscule<sup>iii</sup> with most of the calcium released coming from fibrous debris. The calcium concentration is predicted to plateau at 10.6 mg/L (Figure 5), the "saturation limit" of calcium released from Transco Thermal Wrap at pH 8.1 and 165.34°F (74.08°C). Therefore, the calcium concentration obtained by scaling the AECL pH 7 dissolution test results is conservative with respect to the WCAP result.

Figure 5: Calcium Release from MPS3 Fibrous Debris/Concrete IAW WCAP Method



**MPS3 Chemical Effects RAI 16**

*DNC's testing was performed at 104°F, which is well below early post-loss-of-coolant accident pool temperatures. The solubility of calcium phosphate (hydroxyapatite) decreases as the temperature increases. Please discuss whether more calcium phosphate precipitate would have formed in the Rig-89 tests if this test would have been performed at higher temperature. If more calcium phosphate precipitate would be expected at a higher temperature, when the short-term NPSH margin is applicable, please justify why the overall Rig-89 test results provide for an adequate evaluation of chemical effects.*

<sup>iii</sup> When the Transco Thermal Wrap contribution to calcium release is neglected, the calculated calcium release from concrete using the WCAP method is less than 5 g. By contrast, when the Transco Thermal Wrap contribution is included; the calculated calcium release is nearly 50 kg.

### **Response to MPS3 Chemical Effects RAI 16**

Potentially decreased calcium phosphate solubility at higher temperatures does not significantly impact the MPS3 test results due to significant conservatism built into the testing program.

1. There is no significant source of calcium in the MPS3 containment. The only potential calcium sources for MPS3 containment are uncoated concrete and dislodged fibrous insulation. By design, there is no uncoated concrete in the MPS3 containment. For the Rig 89 testing, a total of 508 ft<sup>2</sup> of concrete is assumed to be uncoated in containment. Of that total, 308 ft<sup>2</sup> is considered uncoated due to the break jet impacting coated walls. The remaining 200 ft<sup>2</sup> is margin for damaged concrete coating in containment. No calcium silicate insulation exists in containment at MPS3. Calcium releases due to degradation of other dislodged insulation are included in the total calcium release used in the testing. Based on the conservative estimates of existing uncoated concrete, there will be significantly less calcium released into the containment sump water than was tested in Rig 89.
2. In the bench-top testing, TSP inhibited calcium release from uncoated concrete. Identical tests were run in the bench-top testing to determine the effect of TSP on calcium concentration. Both sets of tests were conducted with scaled amounts of concrete and fibrous insulation. In one set of tests, no TSP was used. In an identical set of tests, a representative concentration of TSP was established in the test water. At pH 7, the expected calcium concentration in containment in the absence of TSP is 14.6 mg/L. In the presence of TSP, the 30-day calcium concentration during the bench-top testing was 2.2 mg/L. In the absence of TSP, the concrete coupons in the test showed significant dissolution. When the tests were repeated with TSP present, concrete coupons in the test showed no evidence of dissolution and experienced less than a 1% loss in mass. For conservatism, the results from calcium dissolution tests without TSP present were used to determine the amount of calcium to add to the Rig 89 test tank.
3. Concrete used in testing was not safety-related concrete and thus was more likely to degrade in the bench-top testing than is the safety-related concrete installed in containment.
4. Concrete dissolution data for pH 7 was used in the testing to determine the amount of calcium released and the amount of calcium used in chemical effects testing. The pH in the MPS3 containment water is expected to be above 8.0 following the LOCA resulting in much less calcium release. Concrete dissolution is lower at higher pH. Expected long-term calcium concentration at pH 8 (without TSP) is 10.1 mg/L as compared to the expected (and tested) calcium

concentration at pH 7 (without TSP) of 14.6 mg/L. Thus, the calcium concentration in containment is likely to be as much as 30% lower than the tested value due to the pH in containment.

5. A total of 14 calcium additions were made to the MPS3 Rig 89 test. These additions had a minimal impact on head loss though TSP was present in the test tank at the expected concentration in containment. This TSP concentration far exceeded the amount needed to precipitate all of the available calcium in the test. The first calcium addition was made together with an aluminum addition and the head loss increased from 0.43 to 0.73 psig. The remaining 13 calcium additions (all made separately from aluminum additions) had no significant impact on head loss.

The above information demonstrates that sufficient conservatism exists in the determination of post-LOCA sump water calcium concentration to offset the potential lower solubility of calcium at the higher post-LOCA sump temperatures expected early in the accident.

#### **MPS3 Chemical Effects RAI 17**

*Please compare the total amount of aluminum that is predicted to be released by the AECL model with that predicted by the WCAP-16530 base model (i.e., no refinements for silicate or phosphate inhibition). Discuss any significant differences between the plant-specific predictions for the two methods, including the acceptability of these differences.*

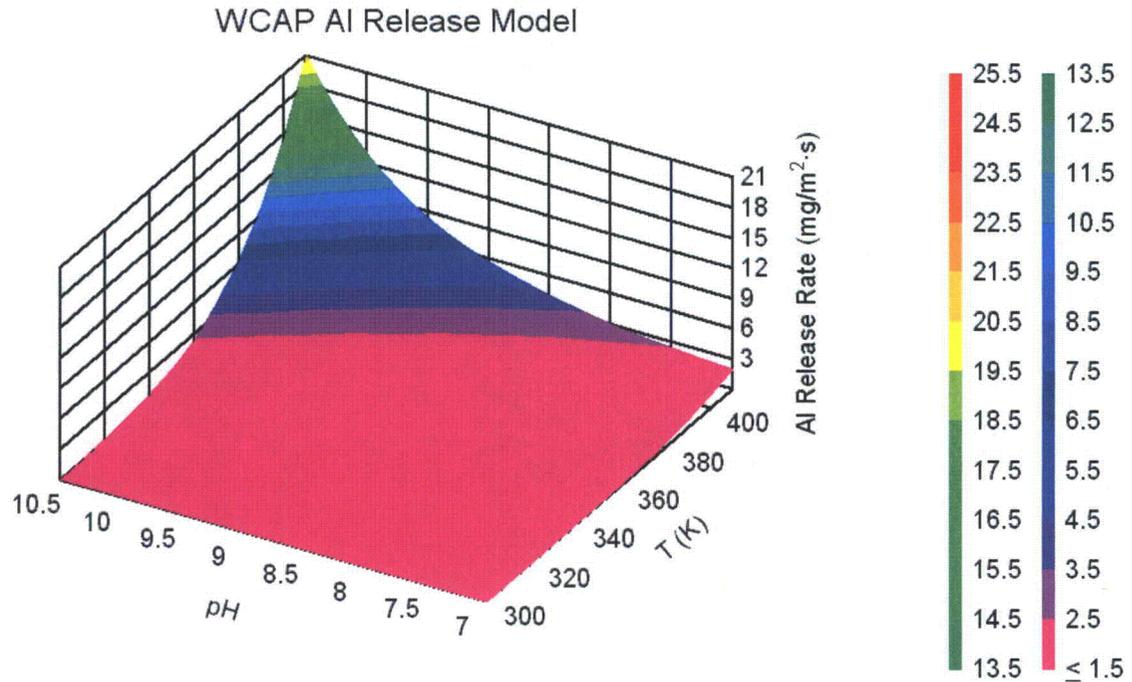
#### **Response to MPS3 Chemical Effects RAI 17**

The WCAP-16530 base model is an empirical model of the aluminum release rate (RR) based on the data set described by Lane et al [5], which included data from ICET 1, CR-6873, WCAP-7153A and WCAP-16530. The WCAP model is described by Equation 4 and the results are shown in Figure 6.

$$RR \left[ \frac{mg}{m^2 \cdot min} \right] = 10^{14.69039 - 4.64537 \left( \frac{1000}{T(K)} \right) + 0.044554 (pH_a)^2 - \frac{1.20131 pH_a T}{1000}}$$

Equation 4

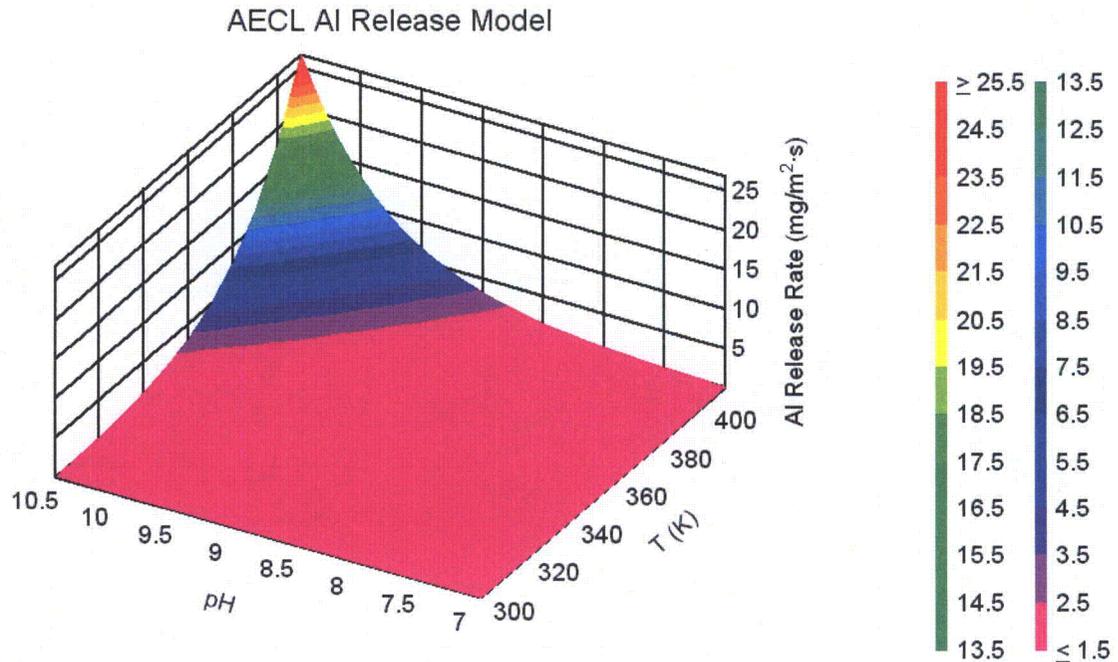
Figure 6: 3D Illustration of the WCAP Aluminum Release Model



The AECL model is a semi-empirical model of the aluminum release rate, in that the equation form was developed from first principles but the parameters were fit to literature data. The release equation takes an Arrhenius form with temperature and, since the corrosion reaction involves hydroxide, the release rate is likewise related to the exponential of the pH. The data set used to fit the model was described by Guzonas and Qiu [6] and was very similar to that used for the WCAP-16530 model. The AECL model is described by Equation 5 and the results are shown in Figure 7.

$$RR \left[ \frac{mg}{m^2 \cdot s} \right] = 55.2 \exp \left( 1.3947pH - \frac{6301.1}{T(K)} \right) \quad \text{Equation 5}$$

Figure 7: 3D Illustration of the AECL Aluminum Release Model



Both models ignore any time dependence of the Al release rate. As one might expect, the two models give similar predictions. Mathematical comparison of the two models shows that they differ mainly at temperatures above the normal boiling point of water. The WCAP model predicts higher release at moderate pH values (between pH 7-9.5) and lower release at high pH values, as shown in Figure 7. At more moderate temperatures, the two models predict very similar release rates. For example, ICET Test 5 [7] was conducted at 60°C at pH 8.0-8.5, and both models are observed to conservatively predict the long-term aluminum release, especially when the release of aluminum is through a high-pH spray (Figure 8).

Figure 8: 3D Differential of WCAP and AECL Aluminum Release Models

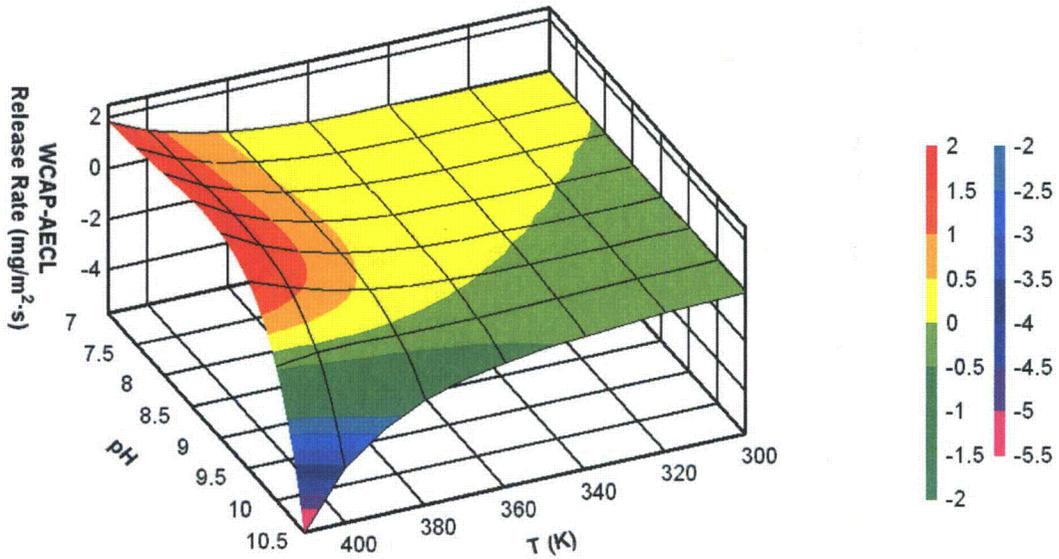
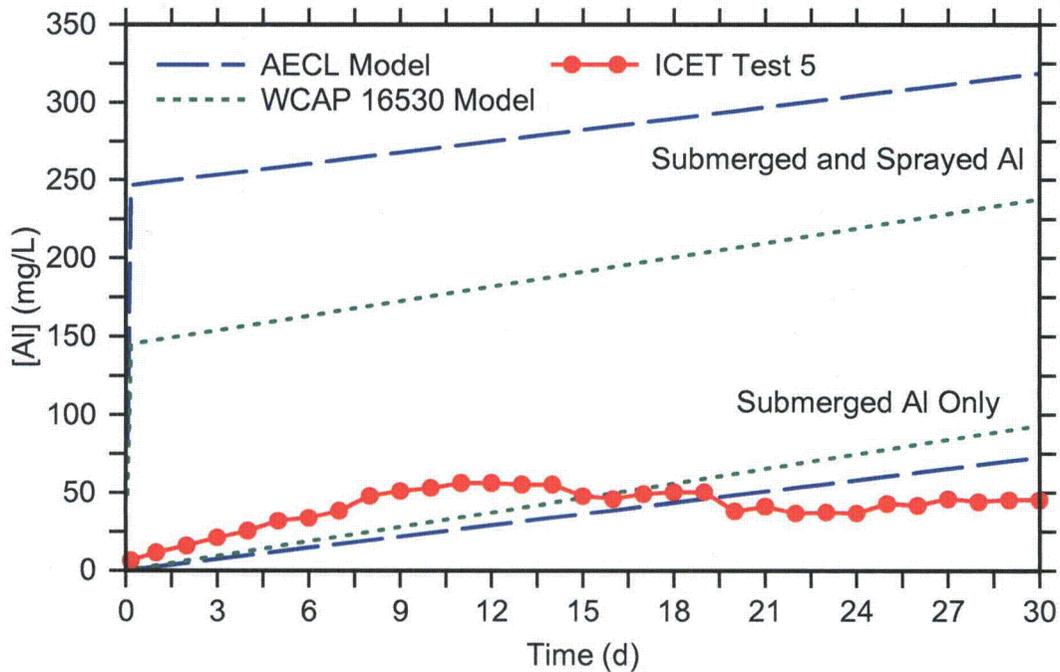


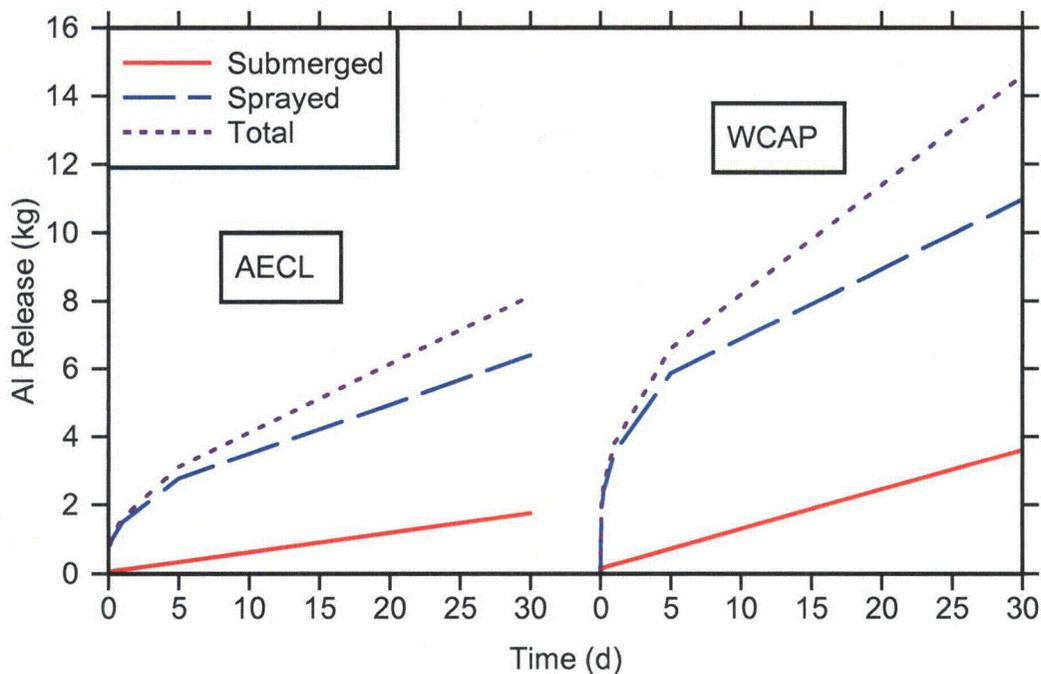
Figure 9: WCAP/AECL Aluminum Release Model of ICET Test 5 Aluminum Concentration



Note ICET Test 5 concentration data adapted from [7]. Spray pH, reported as < 12, was taken to be 11 for calculations.

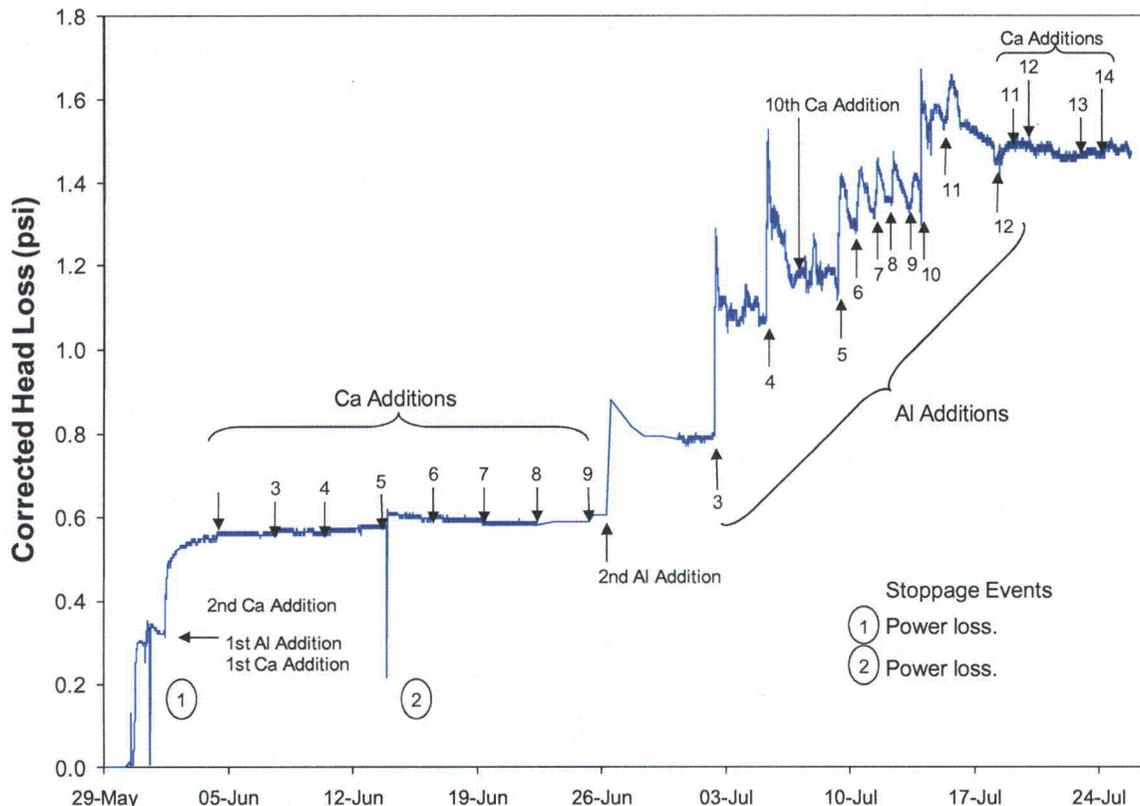
The MPS3 post-LOCA sump and spray operates mainly in the range of pH 8.0-8.5, where the WCAP model predicts a greater aluminum release rate at high temperatures than the AECL model (Figure 10). For the 1080 ft<sup>2</sup> of sprayed and 120 ft<sup>2</sup> of submerged aluminum reported to be present in MPS3 containment [2], the WCAP model predicts 14.6 kg aluminum whereas the AECL model predicts 8.15 kg aluminum (Figure 10). Note that the scaled equivalent of 7.6 kg aluminum was added during the Rig 89 test<sup>iv</sup> and that the last two aluminum additions (i.e., additions 11 and 12, Figure 11), representing over 30% of the aluminum added, did not produce increases in head loss, suggesting a head loss plateau. Although slightly more aluminum was needed to meet the predicted aluminum release, the observed head loss plateau allows confident prediction of the head loss for the predicted aluminum release.

Figure 10: Comparison of AECL/WCAP Aluminum Release Model of the Submerged, Sprayed and Total (Combined) Aluminum Release for MPS3 Post-LOCA Containment



<sup>iv</sup> Although the scaled equivalent of 7.6 kg of Al was added during the test, only 7.45 kg can be said to have precipitated with certainty due to the error uncertainty resulting from the method detection limit for ICP-OES for aluminum (0.4 mg/L)

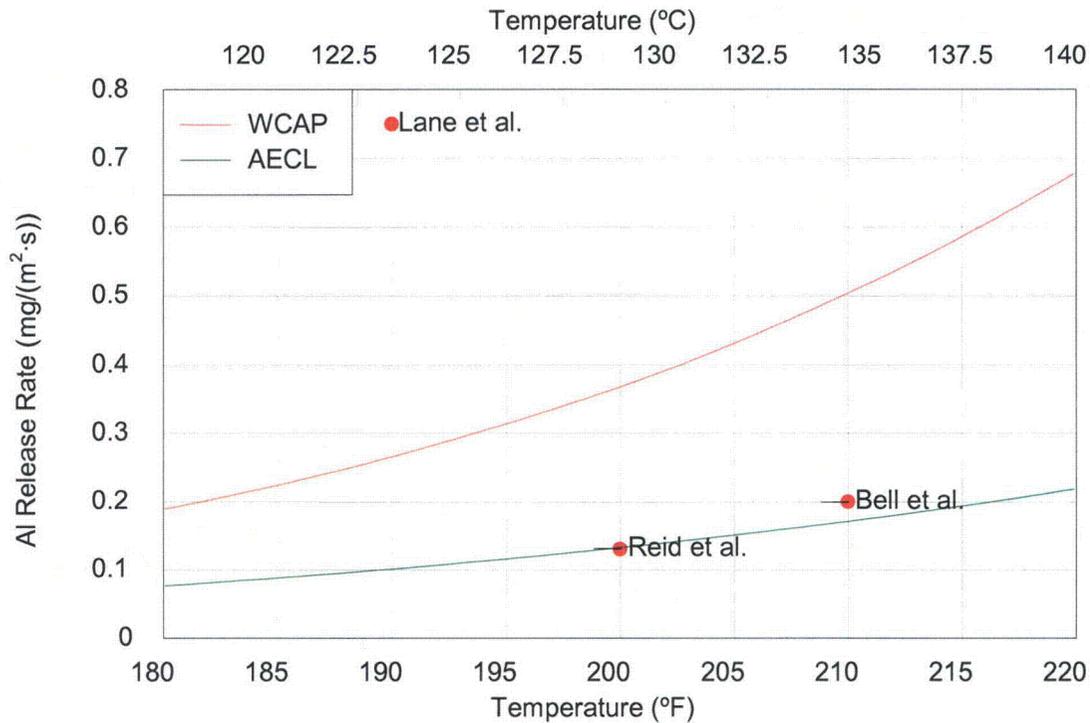
Figure 11: Rig 89 Head Loss Trace Corrected to Match Approach Velocity of MPS3



Without 30-day aluminum corrosion tests, where temperatures (and pressures) of the MPS3 sump are simulated, it is difficult to speculate on the significance of the difference between predictions of the WCAP and AECL models. The only available data for aluminum release at pH 8, for temperatures exceeding the normal boiling point of water, was reported for a 90-minute test at 265°F (129°C) by Lane et al [5]; the reported release rate of 6.6 mg/(m<sup>2</sup>·s) was many times greater than that predicted by either model (the WCAP model predicts 2.7 mg/(m<sup>2</sup>·s), and the AECL model predicts 1.0 mg/(m<sup>2</sup>·s)). While this comparison may seem to highlight apparent deficiencies in both models, the deficiencies of the data set are more apparent, as it cannot be said with any certainty that the value of 6.6 mg/(m<sup>2</sup>·s) is either accurate or repeatable. There are many variables to control in corrosion tests, and it is difficult to get consistent results; hence, Lane et al [5] could measure a release rate of 0.75 mg/(m<sup>2</sup>·s) at pH 8 and 190°F (88°C) while others could measure lower rates at more severe conditions: Reid et al [8] measured 0.13 mg/(m<sup>2</sup>·s) at pH 8 and 200°F (93°C), Bell et al [9] measured 0.20 mg/(m<sup>2</sup>·s) at pH 8 and 210°F (99°C), and Jain et al [10] measured 0.53 mg/(m<sup>2</sup>·s) at pH 10 and 194°F (90°C). These values are compared to WCAP and AECL model predictions at pH 8 in Figure 12. It is clear there is a large scatter in the test data, with two data points clustered closely together and one very much higher. This may reflect differences in test methodology or conditions; AECL has found experimental uncertainties of about 30% in nominally identical tests. Both models predict release rates within the scatter of the plotted data; the AECL model better fits most of the data, but the WCAP model more closely models the average value and is the more conservative. However, the limited experimental data available does not

provide a basis for selecting one model over the other, and no significance can be ascribed to the differences in the predicted aluminum release.

Figure 12: Comparison of AECL and WCAP Aluminum Release Model Predictions and Measured Values at pH 8



It should also be noted that neither model was developed to predict short-term release rates. Although short-term release rates may be higher than predicted by the models, long-term release rates are likely to be lower than predicted, as indicated by the results of ICET Test 5 (Figure 9) and other tests showing a plateau in release rates, including the classic aluminum corrosion tests described by Troutner [11, 12].

## References

1. AECL Report No. MIL3-34325-TR-004, Rev 1, October 2009, Final Report on Strainer Debris Bed Head Loss Arising from Prototypical Chemical Addition, Millstone 3
2. Dominion ERC No. 25212-ER-06-0013, Rev 2, April 16, 2008, Millstone Unit 3 Inputs for GSI-191 Chemical Effects Tests
3. AECL Report No. DOM 34325-TR-001, Rev 0, July 2008, Results of Bench-Top Chemical Effects Tests for Surry 1 and 2, North Anna 1 and 2, and Millstone 2 and 3
4. Dominion ERC No. 25212-ER-06-0013, Rev 1, September 24, 2007, Millstone Unit 3 Inputs for GSI-191 Chemical Effects Tests
5. WCAP-16530-NP, Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191
6. AECL Report No. MIL3-34325-401-000; August 18, 2008; Chemical Effects Testing for Millstone Unit 3
7. NUREG/CR-6914, Integrated Chemical Effects Test Project: Consolidated Data Report
8. WCAP-16785-NP, Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model
9. WCAP-7153A, Investigation of Chemical Additives for Reactor Containment Sprays
10. NUREG/CR-6873, Corrosion Rate Measurements and Chemical Speciation of Corrosion Products Using Thermodynamic Modeling of Debris Components to Support GSI-191
11. Troutner, VH; Observations on the Mechanisms and Kinetics of Aqueous Aluminum Corrosion: Part 1—Role of the Corrosion Product Film in the Uniform Aqueous Corrosion of Aluminum; Corrosion 1959; 15(1):9t-15t
12. Troutner, VH; Uniform Aqueous Corrosion of Aluminum—Effects of Various Ions; Hanford Atomic Products Operation Report No. HW-50133; June 10, 1957