



Commitments made in this letter:

During the fall 2012 refueling outage (2R21), DNC will install a safety-related cover plate to cover the entire sump strainer.

Attachment:

Millstone Power Station Unit 2, Response to Request for Additional Information Regarding Generic Letter 2004-02.

cc: U. S. Nuclear Regulatory Commission  
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**ATTACHMENT**

**MILLSTONE POWER STATION UNIT 2**  
**RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING**  
**GENERIC LETTER 2004-02**

**DOMINION NUCLEAR CONNECTICUT, INC.**  
**MILLSTONE POWER STATION UNIT 2**

## **Millstone Power Station Unit 2 (MPS2), RAI 3**

*DNC's response is unclear as to how likely it is that the stream of break flow will be broken-up. Based on the MPS2 audit, the NRC staff believes that a significant portion of one of the strainer arrays is located in a loop compartment beneath piping subject to breaking. Without a cover plate, it is difficult to conclude that liquid falling from the break would not fall into the containment pool above the strainer array with sufficient kinetic energy to result in air entrainment. Also, the NRC staff notes that page 7 of Attachment 1, to the December 18, 2008, DNC letter states that "... many of the possible break locations are above a portion of the strainer and break flow in these areas would keep the portion of the strainer below the break clear of debris." It is not clear to the NRC staff why air entrainment would not occur if many of the breaks result in water falling from the break onto the strainer such that the affected portion of the strainer is continually cleared off. Also, the flow-controlling baffles inside the strainer may encourage uniform flow, but when energetic water is splashing down onto a strainer array from above, it is not clear how the baffle can limit the air entrainment to a negligible quantity. It is not clear that the strainer baffles were designed to compensate for such a non-uniform external flow. Please clarify these points.*

*The basis for the claim that air will escape from the strainer fins is not clear. Based on the description in the responses for MPS2, it is not clear why the 1-1/2 inch opening in the top of the strainer would perform differently than the rest of the strainer, or would not be covered with debris, just like any other strainer surface. Please clarify these points.*

*Regarding the Froude number discussion, the basis for the determination that air could not reach the suction pipes based on the Froude value was not clear. One particular point that was unclear concerned the assumed size of the air bubbles and whether the Froude number limit referred to was associated with vortexing or bubble ingestion. Please provide the basis or reference used for this assumption. MPS2 cites the head loss tests performed by Atomic Energy of Canada, Ltd (AECL). Some of the AECL head loss tests experienced air in the pump suction line. Please address how this impacts MPS2's evaluation of sump performance. Please address whether the Froude number was excessive for these tests (e.g., greater than 0.31). If there is direct testing evidence that could help resolve the question, please provide such documentation.*

*Based on the NRC staff's understanding, any air ingested by the strainer would seemingly remain trapped inside, accumulating until it was able to exit through the perforated plate or into the suction lines. Air ingestion is complex and it is unclear to the NRC staff which way the air would eventually go and how much would accumulate in the strainer before steady-state conditions are reached. The installation of a cover plate would prevent water from splashing down onto and entraining air into the strainer, removing some of complex issues associated with air ingestion.*

*Please address the above air ingestion concerns because excessive air ingestion can degrade operation of the pumps, which takes suction from the sump.*

### **Response to MPS2, RAI 3**

To minimize the likelihood for air ingestion DNC will install a safety-related cover plate during the fall 2012 refueling outage (2R21). The proposed cover plate will cover the entire strainer. This will prevent water from splashing down onto and entraining air into the strainer. The cover plate design uses 3/16-inch thick stainless steel diamond plate. Below the diamond plate is 1 3/4-inch stainless steel grating. The bottom surface of the cover plate is at least 9 inches above the strainer fins to avoid encapsulation. Testing with the full debris load and the cover plate was done with the bottom of the cover plate 9 inches above the tops of the fins to avoid strainer encapsulation by debris. The cover plate does not overhang the strainer. The initial design established the load bearing capacity of the cover plate as 60 lb/ft<sup>2</sup>. Evaluations of the final design loading for the cover plate will take into account the waterfall from the postulated break.

### **MPS2, Head Loss and Vortexing, RAI 6**

*This RAI identified some differences in non-chemical head losses between the two test facilities. The December 18, 2008, DNC letter provided the first docketed information providing significant information on the MPS2 Rig-89 testing. The NRC staff has reviewed this and determined that the following information is needed to complete the review:*

- a. *Please provide information that justifies that the Rig-89 head loss test was conducted with a fibrous debris load that maximized non-chemical debris head loss.*
- b. *Please provide information regarding whether the debris bed contained adequate fiber to ensure that a maximum head loss was attained without bed disturbances limiting the head loss.*

### **Response to MPS2, Head Loss and Vortexing, RAI 6, Issue 'a'**

For the MPS2 Rig 89 chemical effects test, the thin-bed debris addition methodology was used to maximize the non-chemical debris bed head loss. The full particulate debris load was added at the start of the test, and then additions of fibrous debris were made in 1/16 inch (1.6 mm) theoretical bed thickness increments. Note that the theoretical bed thickness is defined as the uncompressed fiber volume divided by the test module surface area. The first fiber addition (1/16 inch (1.6 mm)) was made 30 minutes (enough time for debris preparation) after the addition of the particulate debris. The second fiber addition (an additional 1/16 inch (1.6 mm)) was made 30 minutes after the first addition. Previous thin bed tests conducted in Rig 33 (reduced-scale) [1] and Rig 42 (large-scale) [2] had determined a thin bed thickness of 1/8 inch. Rig 33 test results were used to establish a thin-bed. In both of the reported Rig 33 thin-bed tests, three fiber additions were made to verify that the third fiber addition did not result in any significant head loss change. Since the third fiber addition in both of these tests resulted in no significant additional head loss, the thin-bed was determined to be 1/8 inch. The debris to strainer surface area ratios in Table 1 below reflect three fiber additions in the Rig 33 tests and two fiber additions in the Rig 89 test. A third fiber addition in the Rig 89 test was unnecessary since the thin-bed thickness of 1/8 inch was established in Rig 33. The fiber density was 2.4 lb/ft<sup>3</sup>.

The particulate debris load in the reduced-scale thin bed tests (Tests M2-22 and M2-27) was greater than in the Rig 89 test. In the Rig 89 test, an updated debris load was used based on Dominion Engineering Transmittal 25203-ER-07-0029 Rev 0 [3]. Table 1 lists the different test debris quantities per unit test strainer surface area for Rigs 89 and 33. The particulate debris quantity was almost two times greater in Rig 33 tests than in the Rig 89 test.

At the time of MPS2 Rig 89 testing, it was believed that the test strainer area was 5.74 ft<sup>2</sup>. After testing, however, it was found that the Rig 89 fin area had been miscalculated [4]. The true Rig 89 fin area was recalculated to be 5.08 ft<sup>2</sup>. Therefore, the tested fibrous debris amount was almost 13% more than intended. It is considered the extra fibrous debris might settle on the test tank floor or attach to the debris bed loosely.

**Table 1: MPS2 Test Debris Load Comparisons between Rigs 89 and 33**

Rig	Walnut Shell [lbm/ft <sup>2</sup> ]	Nukon [lbm/ft <sup>2</sup> ]	Knauf [lbm/ft <sup>2</sup> ]	Mineral Wool [lbm/ft <sup>2</sup> ]
89	0.38	0.018	0.028	0.016
33	0.69	0.024	0.037	0.020

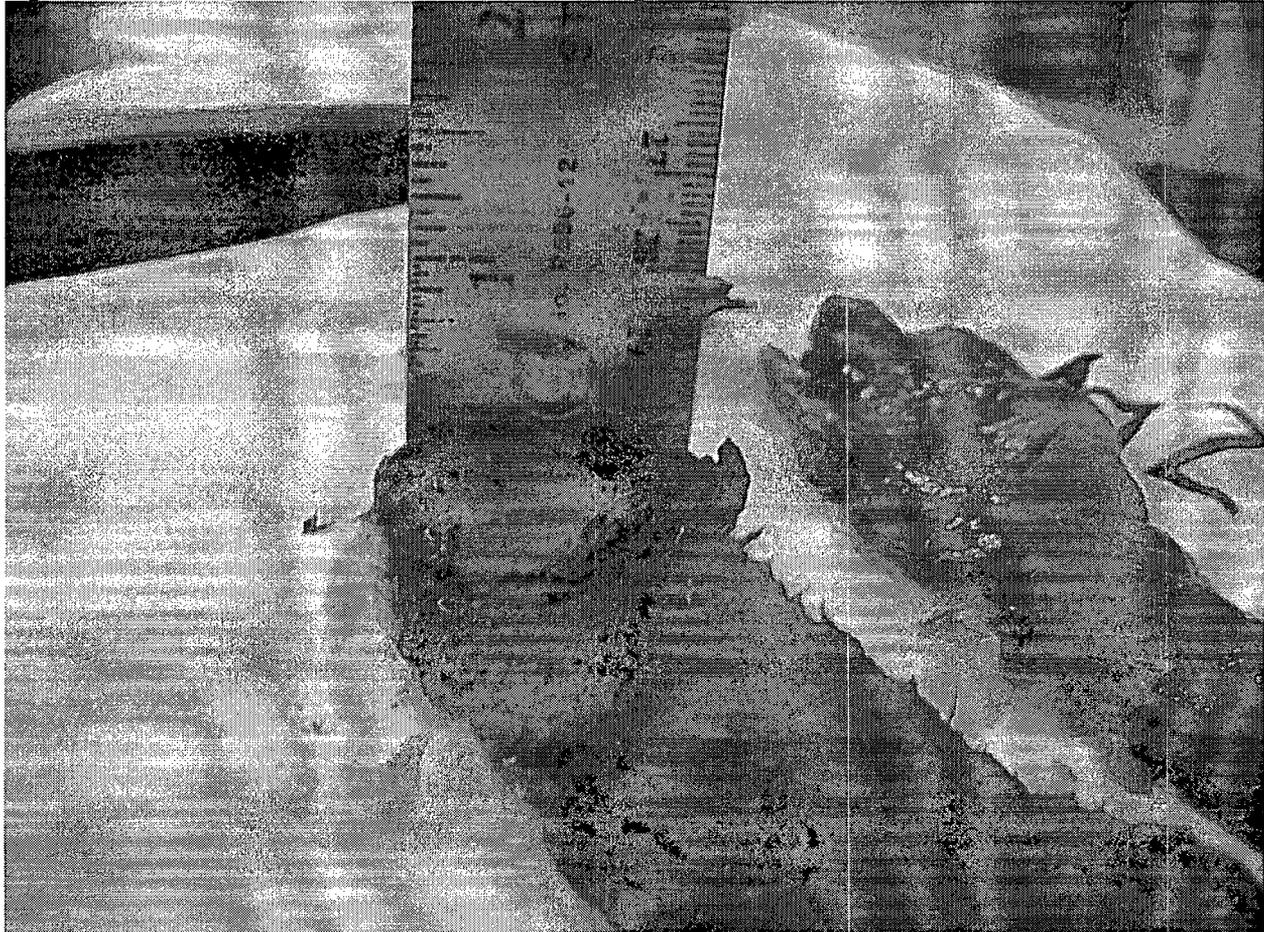
At the end of the Rig 89 test, it was found that the amount of debris attached to the fin surface was ~56%, which is comparable to the debris on the fin for Rig 33 tests (~58% and 66%). In Rig 33 tests it was demonstrated that the change in head loss after 1/8 inch fiber addition was insignificant. Since Rig 89 test had about the same amount of fiber on the fins with nearly half of the particulate quantity per unit area of the fins, the amount of fiber in the debris bed should be equal or more than the required quantity of fiber to form a thin bed.

Figure 1 shows the debris bed after the test. It can be seen that a uniform debris bed was formed across the whole surface of the test strainer. Figure 2 shows a portion of the debris bed removed from the strainer surface after the test.

**Figure 1: Debris Bed after the Test M2-C1**



**Figure 2: Close up of Debris Bed after Removing from Fin**



**Response to MPS2, Head Loss and Vortexing, RAI 6, Issue 'b'**

As explained above, the fibrous debris additions in the Rig 89 MPS2 test were sufficient to form a thin bed and to have maximized the non-chemical head loss. If more fiber were added, the extra fiber added to the test would either loosely attach to the thin-bed surface, forming a porous layer, or settle between and in front of the fins on the tank floor.

Figure 1 and Figure 2 also show the debris bed was firm and uniform across the entire surface of the fin with no crack or hole or other degradations; also the final thickness of the bed was measured to be nearly  $\frac{1}{4}$  inch, which was more than the theoretical thin bed thickness. The fully developed thin-bed thickness thus ensured debris bed structural integrity for the subsequent chemical additions.

Flow sweeps were performed at the end of the test. The changes in head loss during the flow sweeps showed no signs of hysteresis, and head loss changes were reversible. After-test debris bed examination did not find any sign of degradations, such as large holes, dislocations or fractures. Thus, 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.

## **MPS2 Chemical Effects Questions**

*Following review of the chemical effects evaluation details in the DNC December 18, 2008, letter, the NRC staff identified that the following additional information was needed in order to determine if the testing was performed in an acceptable manner:*

*12. The MPS2 calcium dissolution test at a pH of 7.0 resulted in a 30-day calcium concentration of 126 mg/L. DNC's December 18, 2008, letter states that the pH 7.0 case (without tri-sodium phosphate present) was used to determine the concentration of calcium in the Rig-89 test. However, the calcium concentration used for Rig-89 testing was 40.4 mg/L. Please justify why 40.4 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 126 mg/L.*

*13. In Attachment 1, Table 0-2, of DNC's December 18, 2008, letter, the calcium concentration for time infinity is shown as 117 mg/L for pH 7.0. Please explain why this concentration for time infinity is appropriate, given the 30-day bench test calcium concentration at pH 7.0 was 126 mg/L.*

*14. 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.*

*15. 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 MPS2, Chemical Effects Question 12**

The value of 40.4 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 MPS2 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 MPS2 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 (126 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 3 times greater than the current calculated SA/V ratio using data from ERC 25203-ER-06-0007 Rev. 3 [5] 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 that document [6] 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 MPS2 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 [5].

**Table 2: Comparison of Dissolution Test Concrete SA/V Ratio to MPS2 Values**

Source	ERC 25203-ER-06-0007, Rev. 1 [6]	Dissolution Test	ERC 25203-ER-06-0007, Rev. 3 [5]
Date	2007/08	2008/02 – 2008/03	2008/04
Submerged Concrete	3700 ft <sup>2</sup> [3.44×10 <sup>6</sup> cm <sup>2</sup> ]	1.1×3.4×0.5 cm coupons [11.98 cm <sup>2</sup> ]	400 ft <sup>2</sup> [3.7×10 <sup>5</sup> cm <sup>2</sup> ]
Exposed Concrete	2600 ft <sup>2</sup> [2.42×10 <sup>6</sup> cm <sup>2</sup> ]	-	925 ft <sup>2</sup> [8.6×10 <sup>5</sup> cm <sup>2</sup> ]
Volume	41,000 ft <sup>3</sup> [1.16×10 <sup>6</sup> L]	4 L	41,800 ft <sup>3</sup> [1.18×10 <sup>6</sup> L]
SA/V Ratio (Submerged)	2.97 cm <sup>2</sup> /L	3.0 cm <sup>2</sup> /L	0.31 cm <sup>2</sup> /L
SA/V Ratio (Total)	5.05 cm <sup>2</sup> /L	-	1.04 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 (3.0 cm<sup>2</sup>/L), as indicated by the right-hand vertical axis in Figure 3. 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.

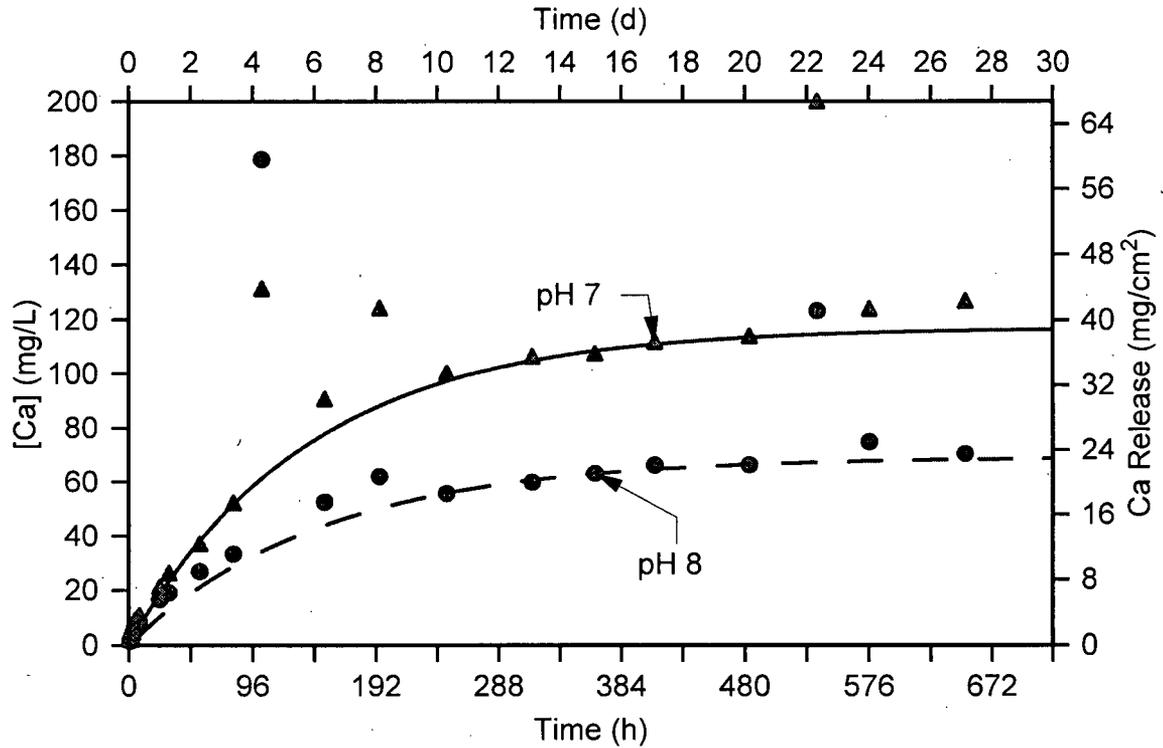
Figure 3 also shows first-order curve fits to the data represented by Equations 1 and 2. These were determined using robust fitting procedures within TableCurve 2D<sup>†</sup> that reduce the fitting errors caused by data outliers. The constants found within Equation 1 were reported in Table 2-5 of the bench-top Test Report [7] and Table O-2 of DNC's December 18, 2008 letter. Equation 2 may be calculated from Equation 1 by dividing the initial constant by the tested surface area-to-volume ratio, 3.0 cm<sup>2</sup>/L.

$$Ca \left[ \frac{mg}{L} \right] = 117 \left[ \frac{mg}{L} \right] (1 - \exp(-0.0072h^{-1} \cdot t)) \quad \text{Equation 1}$$

$$Ca \text{ Release} \left[ \frac{mg}{cm^2} \right] = 39.1 \left[ \frac{mg}{cm^2} \right] (1 - \exp(-0.0072h^{-1} \cdot t)) \quad \text{Equation 2}$$

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

**Figure 3: Calcium Release Data from MPS2 pH 7 and pH 8 Dissolution Tests without Tri-Sodium Phosphate at 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 (Inductively Coupled Plasma Optical Emission Spectroscopy), may alter the measured concentration.

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

$$Ca \text{ Release } \left[ \frac{mg}{cm^2} \right] = 39.1 \left[ \frac{mg}{cm^2} \right] (1 - \exp(-0.0072h^{-1} \cdot 720h)) = 38.9 \left[ \frac{mg}{cm^2} \right]$$

Using the total SA/V ratio from the 4th column of Table 2, 1.04 cm<sup>2</sup>/L, the expected calcium concentration is

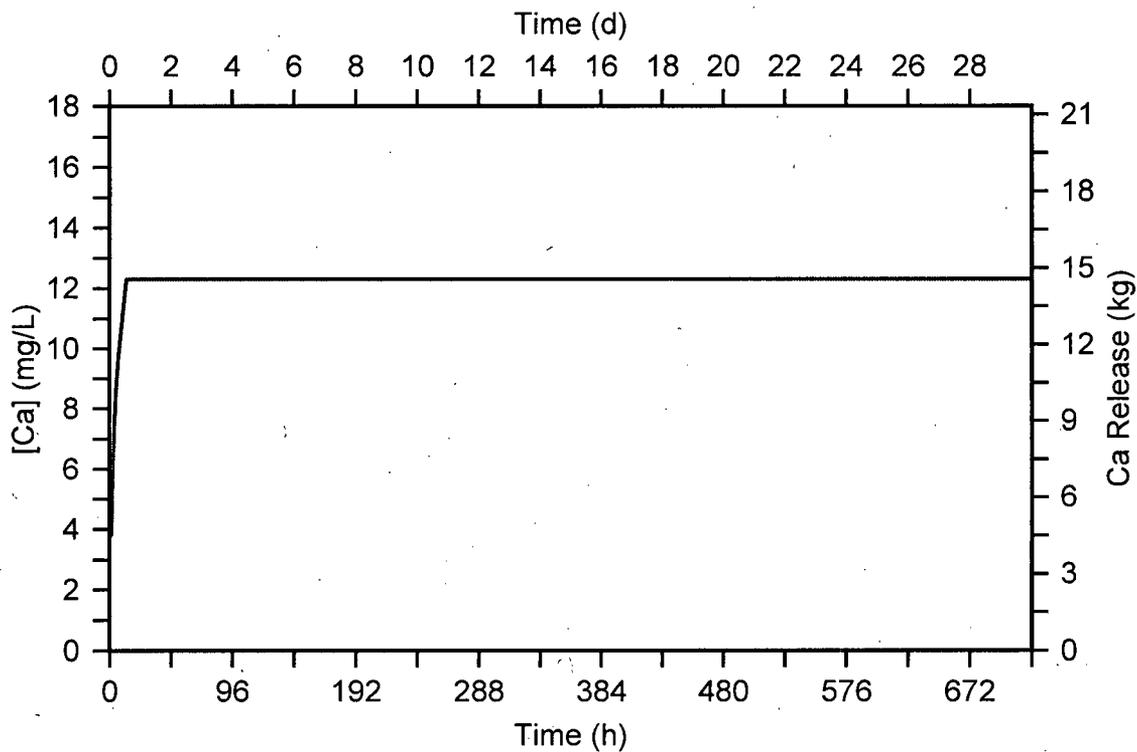
$$Ca \text{ Expected } \left[ \frac{mg}{L} \right] = 38.9 \left[ \frac{mg}{cm^2} \right] 1.04 \left[ \frac{cm^2}{L} \right] = 40.4 \left[ \frac{mg}{L} \right]$$

For comparison, the expected calcium concentration at pH 8 is 23.7 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. [8]. 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 NuKon and Mineral Wool (around pH 8.3) 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>1</sup>; most of the calcium released comes from fibrous debris. The calcium concentration is predicted to plateau at 12.3 mg/L (Figure 4), the "saturation limit" of calcium released from NuKon at pH 8.3 and 189°F (87.2°C). Therefore, the calcium concentration obtained by scaling the AECL pH 7 dissolution test results is conservative with respect to the WCAP result.

**Figure 4: Calcium release from MPS2 fibrous debris and concrete as calculated by the WCAP method [8]**



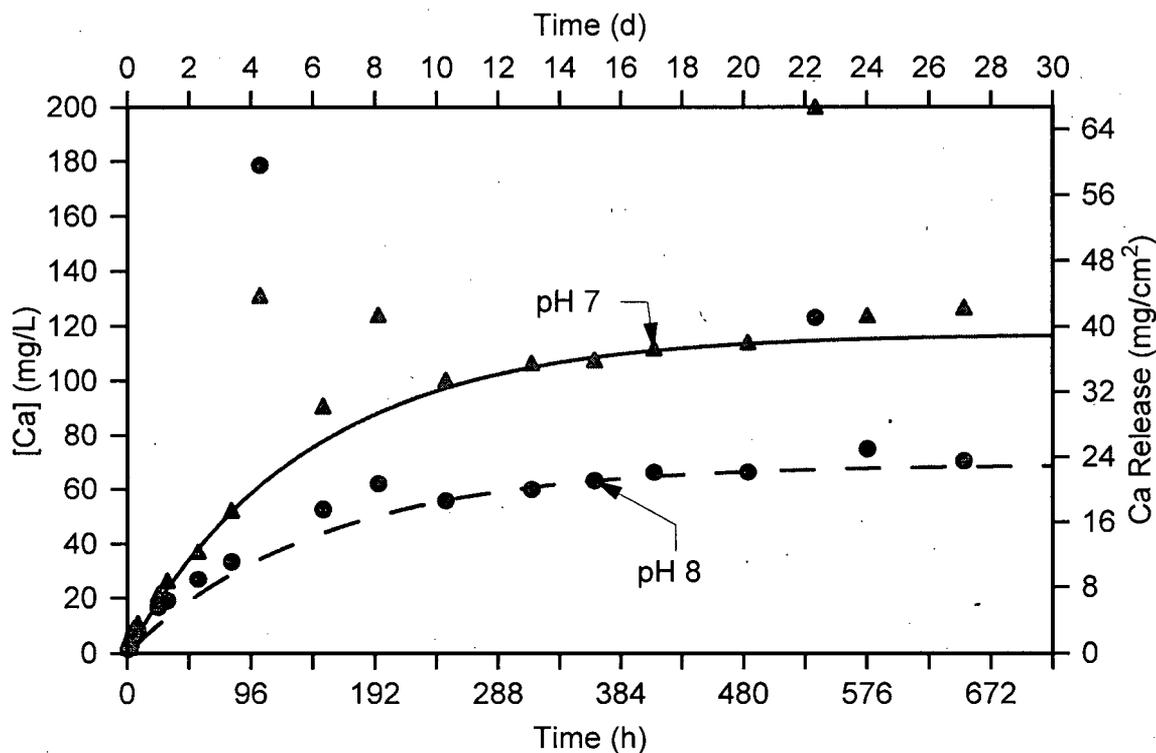
### Response to MPS2, Chemical Effects Question 13

As with any datum, the measured calcium concentration for the day 30 sample was subject to sampling and statistical errors, with the magnitude of the statistical error alone being about  $\pm 8$  mg/L. When the data are evaluated as a whole, the data fit produced by TableCurve 2D calculated a calcium concentration of 117 mg/L for time infinity; it should be noted that this value is arguably identical to 126 mg/L within the experimental error. Sources of error are further discussed below.

<sup>1</sup> When Nukon and Mineral Wool contributions to calcium release are neglected, the calculated calcium release from concrete using the WCAP method is less than 7 g. By contrast, when NuKon and Mineral Wool contributions are included, the calculated calcium release is nearly 15 kg.

The dissolution test data and the first-order fit to them are re-presented in Figure 5.

**Figure 5: Calcium Release Data from MPS2 pH 7 and pH 8 Dissolution Tests (without TSP)**



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

It is immediately apparent that the data contain a few outliers. It is important to consider that each datum suffers to some degree from experimental errors (position in the solution at which the tube was placed, contamination of sample vials, insufficient filtering of samples before analysis, pH drift, etc.). For example, if the sample had been taken from a location in the flask near a source of calcium (concrete or fibrous debris), the result could have been biased high. There is also uncertainty (statistical error) associated with the analysis technique, ICP-OES; this uncertainty was approximately  $\pm 8$  mg/L for the 117 mg/L measurement. Therefore, considering all sources of error and uncertainty, there is no statistically significant difference between 117 mg/L and 126 mg/L.

**Response to MPS2, Chemical Effects Question 14**

Potentially decreased calcium phosphate solubility at higher temperatures does not significantly impact the MPS2 test results due to significant conservatism built into the testing program.

1. There is no significant source of calcium in the MPS2 containment. The only potential calcium sources for the MPS2 containment are uncoated concrete and dislodged fibrous insulation. By design, there is no uncoated concrete in the MPS2 containment. For the Rig 89 testing, a total of 1325 ft<sup>2</sup> of concrete is assumed to be uncoated in containment. Of that total, 825 ft<sup>2</sup> is considered uncoated due to the break jet impacting coated walls. The remaining 500 ft<sup>2</sup> is margin for damaged concrete coating in containment. No calcium silicate insulation exists within the loop rooms and calcium silicate insulation is not a part of any debris load since the small amount of calcium silicate insulation outside the loop rooms is steel-jacketed and not subject to dissolution. 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.
2. In the bench-top testing, Trisodium Phosphate (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 40.4 mg/L based on tests without TSP present. In the presence of TSP, the 30-day calcium concentration in bench-top testing was < 10 mg/L. In the absence of TSP, the concrete coupons in the test showed significant dissolution. In the tests 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 (chemical effects) 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 MPS2 containment water is expected to be above 8.0 following the LOCA resulting in much less calcium release. Concrete dissolution is much lower at higher pH as seen in the answer to question 12 above. Expected long-term calcium concentration at pH 8 (without TSP) is 23.7 mg/L as compared to the expected (and tested) calcium concentration at pH 7 (without TSP) of 40.4 mg/L. Thus, the calcium concentration in containment is likely to be as much as 40% lower than the tested value due only to the pH in containment.
5. A total of 15 calcium additions were made to the MPS2 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 0.26 to 0.66 psig. The second calcium addition was made following a power loss in the test Rig and that addition increased the head loss from 0.60 to 0.67 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.

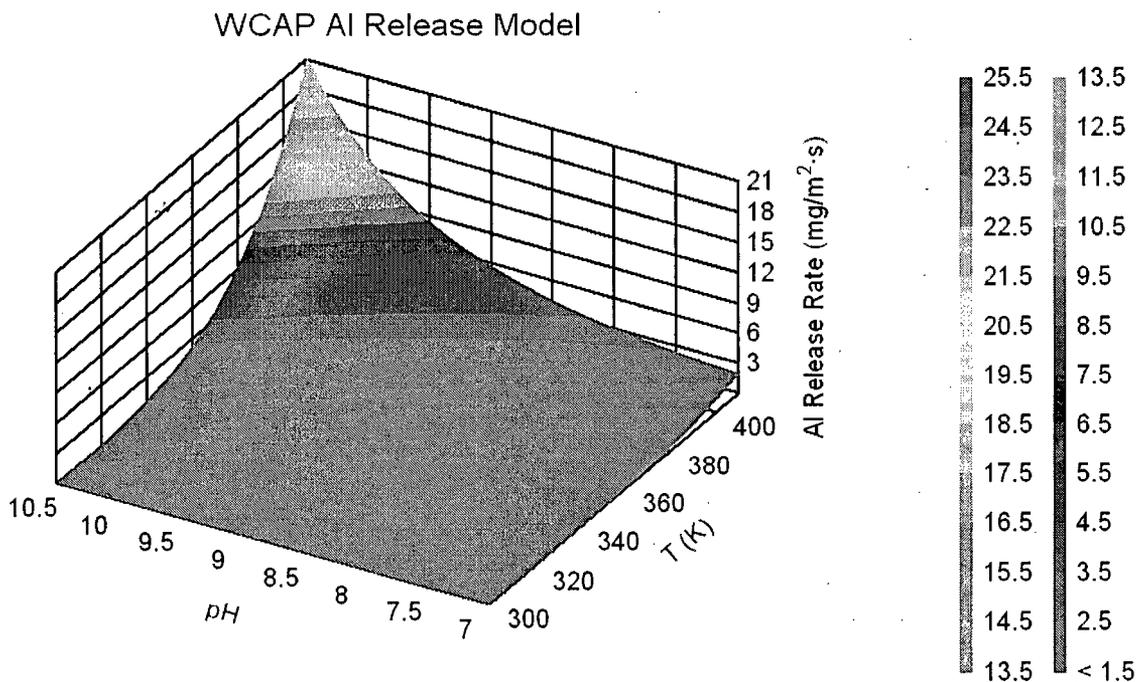
### Response to MPS2, Chemical Effects Question 15

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. [8], which included data from ICET 1, CR-6873, WCAP-7153A and WCAP-16530. The WCAP model is described by Equation 3 and the results are shown in Figure 6.

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

Equation 3

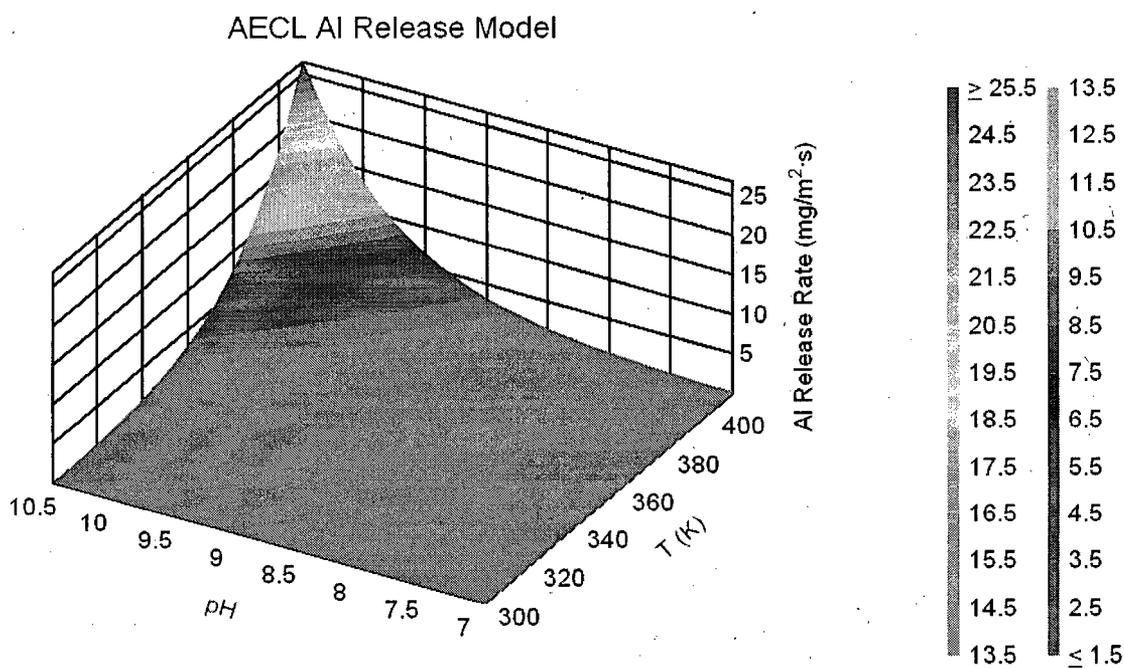
Figure 6: 3D Illustration of the WCAP Aluminum Release Model



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 [9] and was very similar to that used for the WCAP-16530 model. The AECL model is described by Equation 4 and the results are shown in Figure 7.

$$RR \left[ \frac{mg}{m^2 \cdot s} \right] = 55.2 \exp \left( 1.3947 \cdot pH - \frac{6301.1}{T[K]} \right) \quad \text{Equation 4}$$

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 8. At more moderate temperatures, the two models predict very similar release rates. For example, ICET Test 5 [9] 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 release from sprayed aluminum with high-pH spray is included (Figure 9).

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

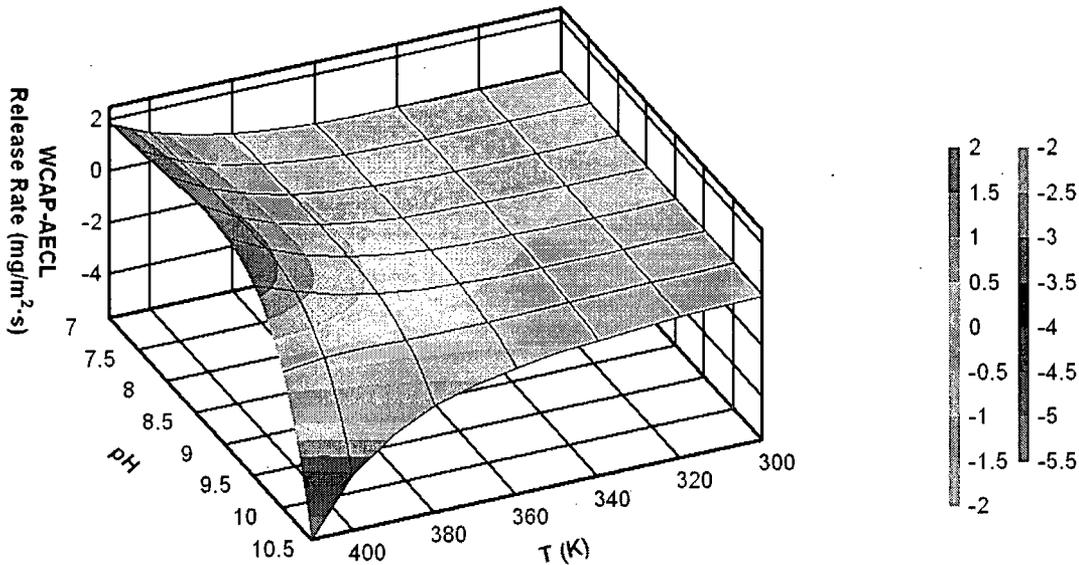
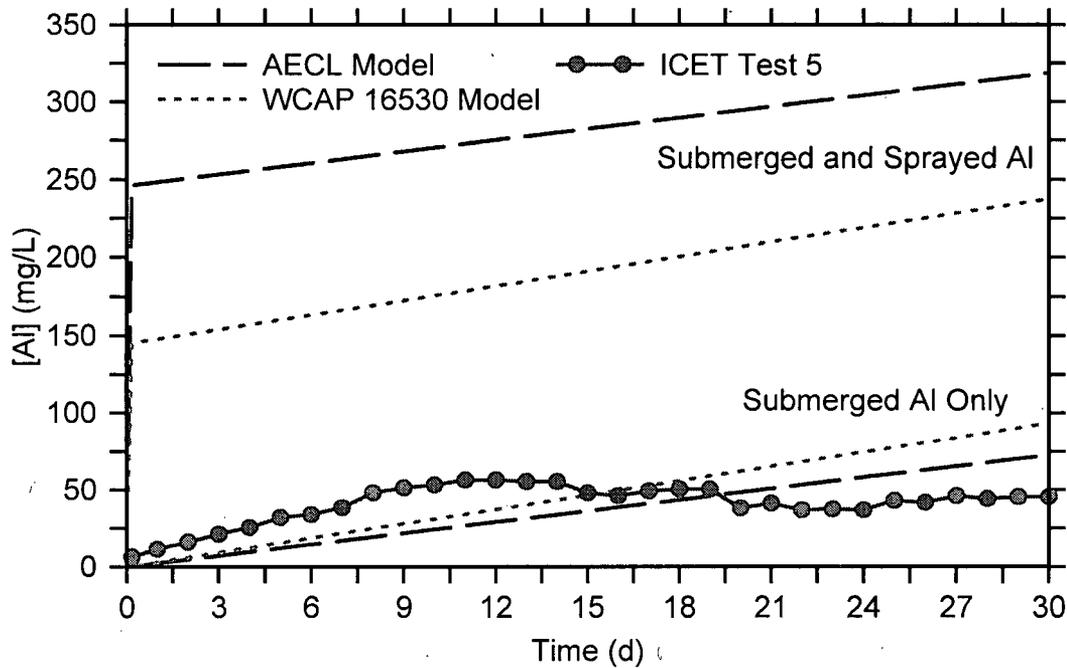


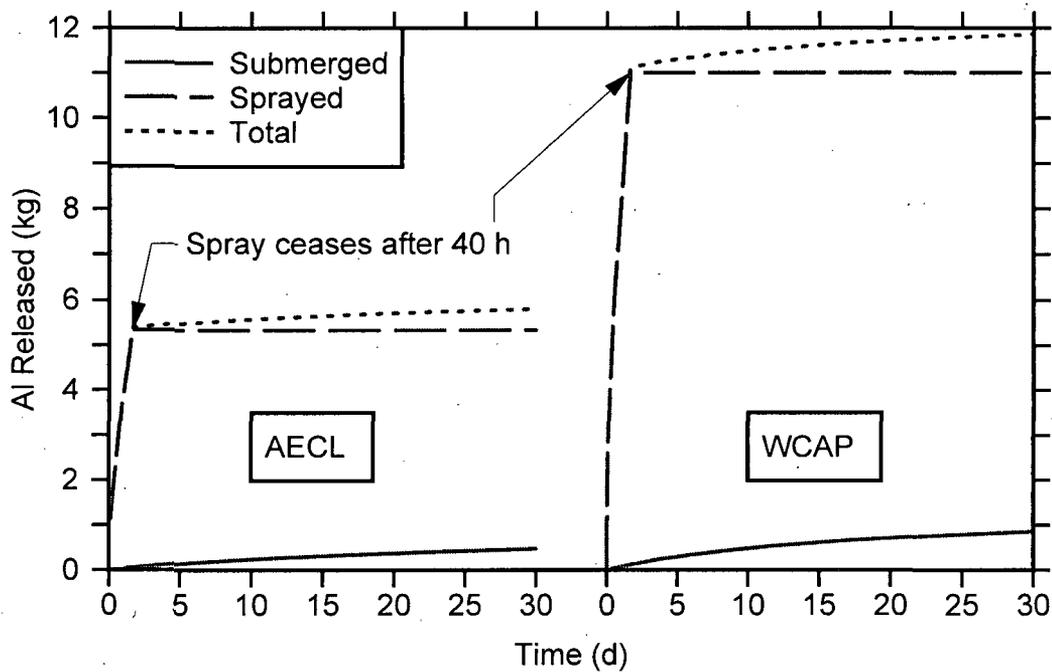
Figure 9: WCAP and AECL Aluminum Release Models' Predictions of ICET Test 5 Aluminum Concentration



Note ICET Test 5 concentration data adapted from [9]. Spray pH, reported as < 12, was taken to be 11 for calculations.

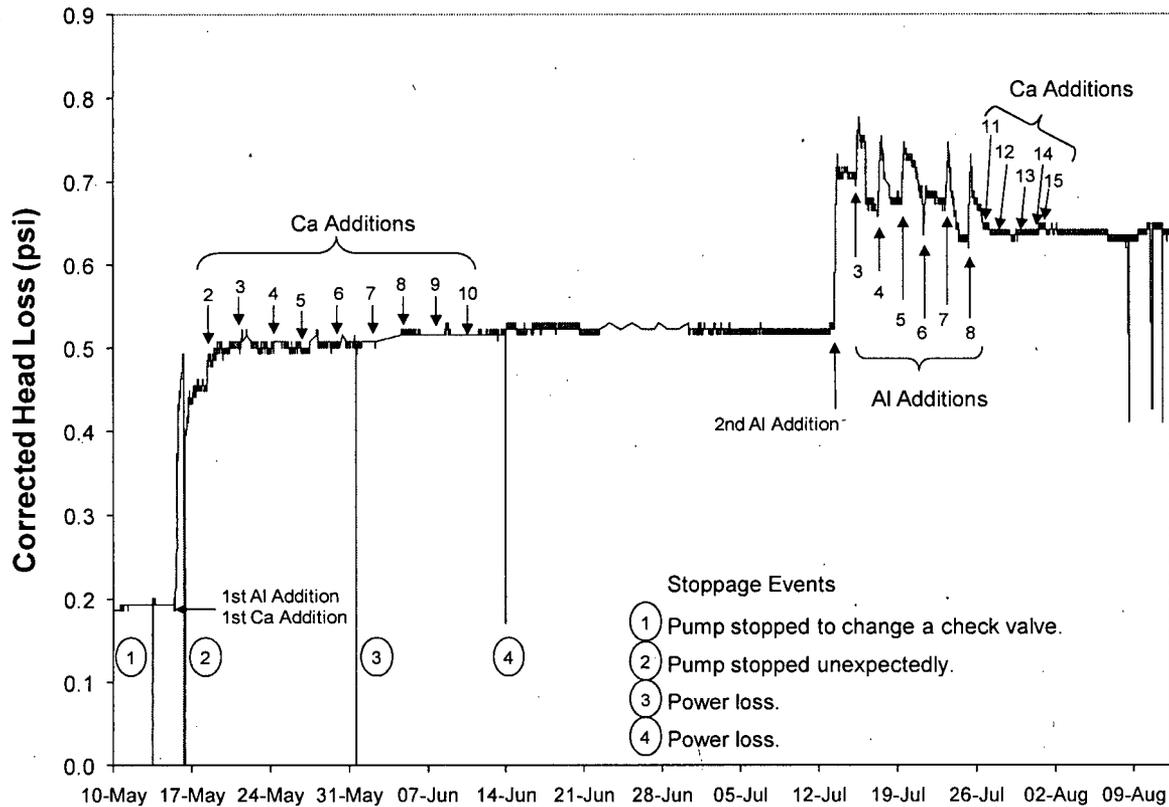
The MPS2 post-LOCA sump and spray operates mainly in the range of pH 8.0-8.3, where the WCAP model predicts a greater aluminum release rate at high temperatures than the AECL model (Figure 8). For the 1876 ft<sup>2</sup> of sprayed and 24 ft<sup>2</sup> of submerged aluminum reported to be present at MPS2 [3], the WCAP model predicts 11.9 kg Al whereas the AECL model predicts 5.8 kg Al (Figure 10). It should be noted that the scaled equivalent of 6.6 kg Al was added during the Rig 89 test<sup>2</sup> and that the last 5 aluminum additions (Figure 11), representing over 60% of the aluminum added, did not produce increases in head loss, suggesting a head loss plateau.

**Figure 10: Comparison of AECL/WCAP Aluminum Release Models' Predictions of Submerged, Sprayed and Total (Combined) Aluminum Release for MPS2 Post-LOCA Containment**



<sup>2</sup> Although the scaled equivalent of 6.6 kg Al was added during the test, only 6.52 kg can be said to have precipitated with certainty (i.e., the aluminum load on the strainer), as it must be conservatively assumed that the aluminum concentration is not zero but the method detection limit for ICP-OES for aluminum (0.4 mg/L).

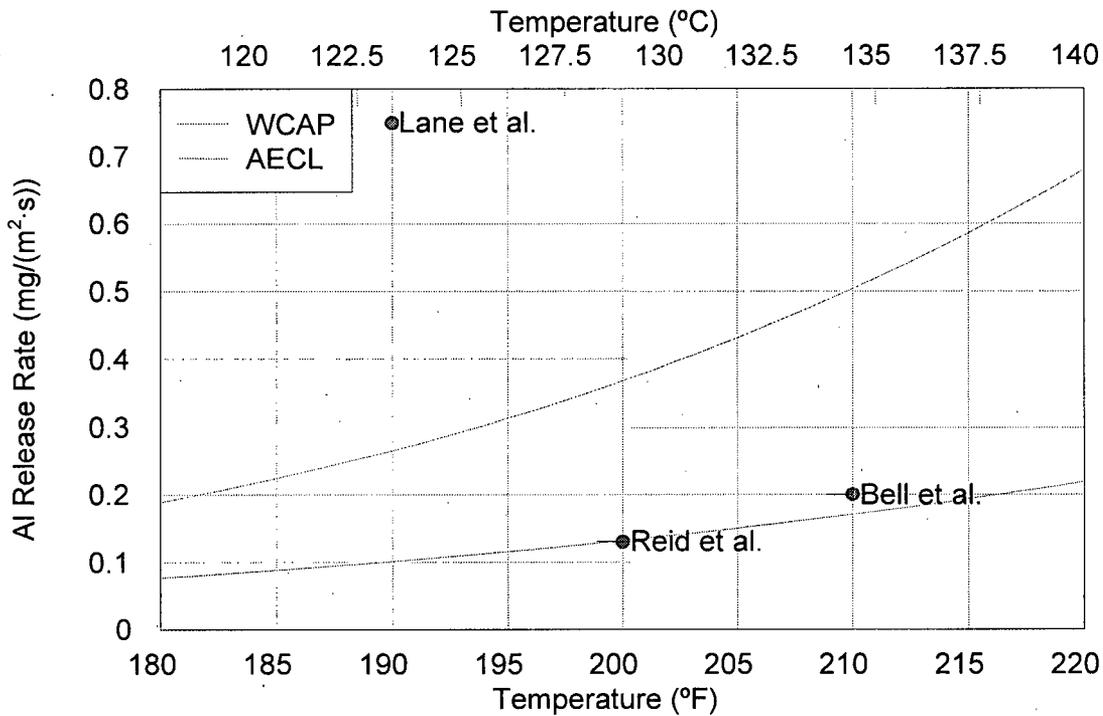
**Figure 11: Rig 89 Head Loss Trace Corrected to Match the Approach Velocity of MPS2**



Without 30-day aluminum corrosion tests where temperatures (and pressures) of the MPS2 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. [8]; 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. [8] 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. [10] measured 0.13 mg/(m<sup>2</sup>·s) at pH 8 and 200°F (93°C), Bell et al. [11] measured 0.20 mg/(m<sup>2</sup>·s) at pH 8 and 210°F (99°C), Jain et al. [12] 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 do 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 [13, 14].

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<sup>1</sup> Fisher NJ, Bartlett MM, Cheng Q. Reduced-scale testing for Millstone 2 replacement containment sump strainers. AECL Test Report MIL2-34325-TR-001, Rev. 0; 2006 September.

<sup>2</sup> Fisher NJ, Bartlett MM, Cheng Q. Large-scale testing for Millstone 2 replacement containment sump strainers. AECL Test Report MIL2-34325-TR-002, Rev. 0; 2006 October.

<sup>3</sup> Legg M. Millstone Unit 2 inputs for GSI-191 strainer head loss testing. Dominion ERC No.: 25203-ER-07-0029, Rev. 0; 2007 December 20.

<sup>4</sup> Guzonas D, Edwards MK, Cheng Q, Haque Z, Deadman J. Final report on strainer debris bed head loss arising from prototypical chemical addition: Dominion: Millstone 2. AECL Report No.: MIL2-34325-TR-004 Rev. 1; 2009 October.

<sup>5</sup> Legg M. Millstone Unit 2 inputs for GSI-191 chemical effects testing. Dominion ERC No.: 25203-ER-06-0007, Rev. 3; 2008 Apr 15.

<sup>6</sup> Legg M. Millstone Unit 2 inputs for GSI-191 chemical effects testing. Dominion ERC No.: 25203-ER-06-0007, Rev. 1; 2007 Aug 21.

<sup>7</sup> Guzonas D, Qiu L, Edwards M. Results of bench-top chemical effects tests: Dominion – Surry 1 and 2, North Anna 1 and 2, Millstone 2 and 3. AECL Report No.: DOM 34325-TR-001 Rev. 0; 2008 July.

<sup>8</sup> Lane AE, Byers WA, Jacko RJ, Lahoda EJ, Reid RD. Evaluation of post-accident chemical effects in containment sump fluids to support GSI-191. Westinghouse Report No.: WCAP-16530-NP-A; 2008 March.

<sup>9</sup> Dallman J, Letellier B, Garcia J, Madrid J, Roesch W, Chen D, Howe K, Archuleta L, Sciacca F, Jain BP. Integrated chemical effects test project: Consolidated data report. NUREG/CR-6914; 2006 August.

<sup>10</sup> Reid RD, Crytzer KR, Lane AE. Evaluation of additional inputs to the WCAP-16530-NP chemical model. Westinghouse Report No.: WCAP-16785-NP; 2007 May.

<sup>11</sup> Bell MJ, Bulkowski JE, Picone LF. Investigation of chemical additives for reactor containment sprays. Westinghouse Report No.: WCAP-7153A; 1975 April.

<sup>12</sup> Jain V, He X, Pan YM. Corrosion rate measurements and chemical speciation of corrosion products using thermodynamic modeling of debris components to support GSI-191. U.S. NRC Report NUREG/CR-6873; 2005 April.

<sup>13</sup> 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.

<sup>14</sup> Troutner VH. Uniform aqueous corrosion of aluminum—effects of various ions. Hanford Atomic Products Operation Report No.: HW-50133; 1957 June 10.