

November 29, 2009 RC-09-0134

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

Dear Sir / Madam:

Subject: VIRGIL C. SUMMER NUCLEAR STATION (VCSNS) UNIT 1 DOCKET NO. 50/395 OPERATING LICENSE NO. NPF-12 RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION FOR GENERIC LETTER 2004-02

Reference: 1. NRC Letter (ADAMS Accession No. ML090270927) to Mr. Jeffrey B. Archie dated February 3, 2009, "V. C. Summer Nuclear Station - Request for Additional Information for Generic Letter 2004-02 (TAC NO. MC4721)"

- SCE&G Letter (ADAMS Accession No. ML080640545) from Mr. Jeffrey B. Archie to USNRC Document Control Desk dated February 29, 2008, "Supplemental Response to NRC Generic Letter 2004-02: Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors"
- 3. SCE&G Letter (ADAMS Accession No. ML091270196) from Mr. Jeffrey B. Archie to USNRC Document Control Desk dated May 1, 2009, "Request for Additional Information for Generic Letter 2004-02 Response Due Date Extension"

South Carolina Electric & Gas Company (SCE&G) hereby submits a response to the Request for Additional Information (RAI) items identified in the referenced NRC letter (Ref. 1). These RAIs resulted from NRC review of the supplemental response (Ref. 2) provided by SCE&G to Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors". The referenced NRC letter requested that a response be provided in 90 days to all the RAIs except No. 23 and that only one response letter be provided. It was also identified that if the licensee concludes that more than 90 days is needed to respond to the RAIs, the licensee should request additional time, including a basis for why such time is needed. Additional time was requested and a basis was provided by a subsequent SCE&G letter (Ref. 3). On September 14, 2009 and November 18, 2009 conference calls were held with the NRC staff concerning the SCE&G draft RAIs. The issues discussed during the conference calls are included in this response.

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Attachment I to this letter provides a response to all of the RAIs, except No. 23. As identified in RAI No. 23, the SCE&G supplemental response refers to WCAP-16406-P to address in-vessel downstream effects. This WCAP is not recognized by the NRC. SCE&G plans to demonstrate that the in-vessel downstream effects are addressed by the application of WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in Recirculating Fluid" after the final version is accepted and the NRC Safety Evaluation (SE) is issued. Therefore, within 90 days of issuance of the final NRC staff SE on WCAP-16793-NP, SCE&G will respond to RAI No. 23 to demonstrate that the in-vessel downstream effects are bounded by this WCAP and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE.

Attachment II lists the commitments made in this letter.

Should you have questions, please call Bruce Thompson at (803) 931-5042.

I certify under penalty of perjury that the foregoing is true and correct.

11/29/09

Executed on

Jeffrey B. Archie

Vice President, Nuclear Operations

GAR/JBA/jg

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  - S. A. Byrne N. S. Carns J. H. Hamilton R. J. White W. M. Cherry L. A. Reves (with Attachments) R. E. Martin (with Attachments) NRC Resident Inspector K. M. Sutton NSRC RTS (CR-04-02911) File (815.14) PRSF (RC-09-0134)

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## NRC RAI #1

Identify which reactor coolant loop was used to evaluate the postulated crossover leg break and describe how it was ensured that the break selection maximized the generation of Temp-Mat debris.

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## SCE&G Response:

Break selection consists of determining the size and location of the High Energy Line Breaks (HELBs) that produce debris and potentially challenge the performance of the sump strainer. The break selection methodology for determining the worst case maximum generation of TempMat debris is outlined in the V.C. Summer Debris Generation Analysis. Since the limiting break location was not known prior to the evaluation, the break selection process evaluated a number of break locations to identify the location that produces the largest quantity of debris and/or the combination of debris types likely to present the greatest challenge to post-accident sump performance. The debris inventory and the transport path were considered when making this determination.

Sections 3.3.4.1 and 4.2.1 of the SER recommend that a sufficient number of breaks bounding variations in debris size, quantity, and type be identified. Per the guidance of the SER, the following break locations were considered:

- Breaks in the RCS with the largest potential for debris
- Large breaks with two or more different types of debris
- Breaks in the most direct path to the sump
- Large breaks with the largest potential particulate debris to fibrous insulation ratio by weight
- Breaks that generate a "thin bed" high particulate with 1/8" fiber bed

A comprehensive approach was taken at V.C. Summer for break selection which accounted for the overall placement and target density of TempMat insulation. Specific break locations were selected by modeling the various Zones of Influence (ZOIs) along the RCS piping and maximizing the debris generated by those ZOIs. LBLOCAs were postulated at multiple RCS locations to ensure the most limiting break was evaluated.

All three reactor coolant loops were evaluated and considered in the debris generation process. Then all three reactor coolant loops were evaluated in the Debris Transport Analysis. Subsequently, the combination of debris generation and debris transport for each reactor coolant loop was then evaluated and the design basis loads were based on the worst case results.

The Loop "A" reactor coolant loop was used to evaluate the postulated crossover leg break as this loop resulted in the greatest amount of destroyed TempMat (15.49 ft<sup>3</sup>). The Loop "C" break does result in some smaller amount of destroyed TempMat (11.38 ft<sup>3</sup>), but is bounded by the Loop "A" quantity. The total volume of TempMat destroyed for each loop was determined by volume analysis of a CAD model as shown in Figure 1-1. The Debris Generation Analysis also determined that the Loop "B" reactor coolant loop crossover line break does not result in any destroyed TempMat.

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# NRC RAI #1 (Cont.)

The SBLOCAs that involve piping located inside the bio-shield walls were evaluated in the Debris Generation Analysis and the small break ZOIs are bounded by the LBLOCA results. Analyzing the Loop "A" crossover break in the Debris Transport Analysis ensures the maximum amount of TempMat debris is evaluated.

# Figure 1-1 CAD Modeling a Spherical ZOI for TempMat Debris Generation



Loop A showing a RCS Cross-over Line Break 3.7D & 11.7D (Temp-mat) Zones of Influence Document Control Desk Attachment I RC-09-0134 Page 3 of 121

### NRC RAI #2

Identify the insulating materials installed on the reactor vessel. If the material is other than reflective metal insulation, please provide the amount of material damaged by various breaks and size distribution for the damaged insulation.

### SCE&G Response:

The reactor vessel has all Reflective Metal Insulation (RMI). The break location at the Reactor Vessel Cold Leg nozzle presented in Table 5 of the supplemental response letter RC-08-0031 (ML080640545) shows the debris generation which includes the Reactor Vessel insulation.

# NRC RAI #3

Provide the following additional information needed to support the assumption of 10 percent erosion of fibrous debris pieces in the containment pool.

- a. Demonstrate the similarity of the flow conditions (velocity and turbulence), chemical conditions, and fibrous material present in the erosion tests to the analogous conditions applicable to the plant condition.
- b. Identify the length of the erosion tests and how the results were extrapolated to the sump mission time.

### SCE&G Response:

All fibrous debris at V.C. Summer is the high density fiberglass TempMat. All erosion fiber is considered as a part of the initial fiber load as an additional conservatism. The ten percent erosion of fibrous debris pieces in the containment pool assumption is based on erosion tests that were performed by Alion Science and Technology. Alion performed generic fiberglass erosion tests to determine the erosion fraction that would be expected from fibrous material on a generic basis.

#### General Overview of Alion Fiber Erosion Testing-

The erosion tests were conducted both in Alion's Hydraulic Test Lab Vertical Test Loop (VTL) and Alion Transport Flume (TF) as described in Figures 3-1 and 3-2. The VTL consists of a closed loop with flow circulated through the loop approaching the sample location from above. The fibers eroded off the samples are captured in the filter located downstream of valve TL-V07. The fiberglass small pieces are supported on a perforated plate at the sample location as flow passes through the samples.

For the TF, flow enters the Flume from the right side of the tank, flows through a vertical flow straightener to collimate the flow and then through the samples. The fiberglass samples are supported on a vertically mounted perforated plate and encompassed by an insulation cage to prevent the samples from escaping the sample location and not being exposed to the flow. The insulation cage is constructed of large mesh wire, to prevent interfering with the flow passing through the samples. Flow passing through the sample location is filtered to capture fibers eroded from the fiberglass samples.

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# NRC RAI #3 (Cont.)

### NUKON<sup>®</sup> Testing

The NUKON<sup>®</sup> fiberglass samples of interest used for these tests consist of several 1 inch diameter balls of fiberglass (small pieces). The samples were prepared by shredding suitable size samples from the bulk material then boiling the fiberglass balls to simulate aging and the containment environment prior to the testing. The balls are then placed on the perforated plate to perform the test. The flow rate passing through the sample during the test is based on the incipient tumbling velocity of the material being tested. The NUKON<sup>®</sup> fiberglass tests were performed at incipient tumbling velocity of 0.12 ft/s for small pieces and 0.37 ft/s for large pieces. The testing was performed with tap water at ambient temperature.

The results of the NUKON<sup>®</sup> small piece fiberglass testing are plotted in Figure 3-3. The erosion fractions are plotted against the durations that the samples were exposed to the erosion flow. Durations run from 2 hours to approximately 30 days. Data from both the Vertical Test Loop (diamond symbols) and the Flume (square symbols) are plotted on the graph. The distribution of the test results indicate that an erosion rate mechanism does not occur over the duration of the tests. If this mechanism were present, there should be an upward trend of erosion fraction with increasing duration, which is not indicated. The distribution of the test results reflects a mechanism by which loss of fibers result from loose fibers initially present on each sample being forced off the sample during the test. Once these loose fibers are removed, no further fiber loss occurs. Based on this mechanism, averaging the erosion fractions for all the samples would reflect the expected erosion fraction. This averaging results in an average erosion fraction of 5.93% ± 4.37%. The total erosion of all pieces of LDFG is conservatively estimated to be 5.93% + 4.37% ≈ 10% of initial weight.

### TempMat Testing

The TempMat testing was performed with the VTL and Flume testing. Sample sizes used for the small piece TempMat testing were 3in. x 3in. x 1in (2 hr test in the Flume, 4 hr test in the Flume, 4 hr test in the VTL, 8 hr test in the VTL, 12 hr test in the VTL, 16 hr test in the Flume). Sample size used for the large piece TempMat testing was 6in. x 3in. x 1in (4 hr test in the Flume). The testing was performed with tap water at ambient temperature as was done for the NUKON<sup>®</sup> fiberglass tests.

All TempMat samples were boiled to simulate aging and the containment environment. The TempMat tests were performed at an incipient tumbling velocity of 0.50 ft/s for small pieces and 0.90 ft/s for large pieces.

Figure 3-4 provides the results for the TempMat testing. The erosion fraction is plotted against the duration the samples were exposed to the flow. The tests were performed at durations of 2, 4, 8, 12, and 16 hours. Comparing the TempMat and NUKON<sup>®</sup> fiberglass data contained in Figures 3-3 and 3-4, the TempMat data points are well below the scatter of the NUKON<sup>®</sup> fiberglass data. The highest erosion fraction from any TempMat was 0.8 %. The raw data for the TempMat tests is provided in Figure 3-5.

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## NRC RAI #3 (Cont.)

#### Comparison of Flow Conditions

The ten percent erosion of fibrous debris pieces in the containment pool assumption is based on erosion tests that were performed at generic incipient tumbling velocity metrics. The incipient tumbling velocity is the velocity at which the debris would start moving and this velocity bounds the greatest velocity that a piece of insulation lying in the containment pool would experience without being carried to the sump strainer. Therefore, it is considered the velocity that would produce the most insulation fines that would travel to the sump strainer while the piece of insulation itself would remain stationary in the pool. In the generic testing, the sample flow erosion velocities were not based on V.C. Summer specific pool analysis, but rather the incipient tumbling velocity, then the erosion that was observed during testing is bounding. If the pool velocities exceed the incipient tumbling velocity, then the erosion will be irrelevant.

The incipient tumbling velocities that were used to model debris transport in the V.C. Summer CFD Analysis were 0.12 ft/s for small pieces of TempMat, and 0.90 ft/s for large pieces of TempMat. The Alion generic testing velocities were 0.50 ft/s for small pieces of TempMat and 0.90 ft/s for large pieces of TempMat. Therefore, the tested small piece TempMat incipient tumbling velocity metric significantly bounded the plant's analyzed value and the tested large piece TempMat incipient tumbling velocity metrics are equal.

Since the testing covered a velocity range four times larger than the modeled plant specific velocity, it is reasonable to assume that any turbulence variations are encompassed sufficiently in the test data taken at the higher velocity. If turbulence is high enough to not allow settling, then the insulation debris will be transported to the sump strainers and its flow erosion is not a factor. The test results from the cases that were performed in different test apparatus for the same duration and sample size, showed no preference for test apparatus despite varying turbulence levels, indicating that turbulence is not a significant contributor to flow erosion.

#### Comparison of Chemical Conditions

With respect to chemical conditions, the erosion tests were performed in tap water and not buffered or borated water that would be present in the V.C. Summer containment pool. However, the lack of containment recirculation chemicals and neutral pH of the tap water would have little effect on the flow erosion mechanism. Tap water lacks containment pool chemicals such as aluminum, boron, or pH buffers. These chemicals may affect the individual fiber characteristics in a debris clump, but do not affect the flow erosion of individual fibers from the clump. TempMat high density fiberglass does not use a chemical binder like NUKON<sup>®</sup> and therefore there are no binder associated chemical effects for TempMat.

#### **Comparison of Tested Materials**

The fibrous materials tested, NUKON<sup>®</sup> low density fiberglass and TempMat high density fiberglass, were each tested using the same test protocol outlined in the specific test reports.

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### NRC RAI #3 (Cont.)

These materials compare well to V.C. Summer insulation materials listed in the Debris Generation Analysis. The Debris Generation Analysis indicates that V.C. Summer contains two types of fiberglass that are subject to erosion; TempMat and Kaowool M-board. The generic erosion testing covered high density fiberglass, TempMat, and low density fiberglass, NUKON<sup>®</sup>. The high density fiberglass resulted in much lower erosion values, all 0.8 percent or less, as compared to the low density fiberglass erosion values, ranged from 1 percent to 18 percent. The low density fiberglass erosion numbers were conservatively applied to all of the V.C. Summer specific types of fiberglass, which only includes high density fiberglass. Note that Kaowool M-board debris is bounded by the TempMat fiber quantities as discussed in RAI response 6a.

#### Test Duration

The generic testing analysis in Reference 5 is based on a mission time of 30 days. The V.C. Summer mission time is 40 days. Although the analysis is based on 30 days, the data can be extrapolated to a 40 day mission time without any additional erosion increase, due to several factors. The generic testing was performed at a number of different durations, up to and including approximately 30 days and the erosion factor of ten percent was based on the average of all of the small sample erosion values regardless of test duration, so it was not time-based. The generic testing data trends shown in Figure 4-4 indicate that the large majority of the erosion occurred in the beginning hours of the testing. The low density fiberglass value of ten percent was conservatively applied to high density fiberglass for V.C. Summer.

#### Summary

For the generic TempMat testing, the erosion mechanism yielded erosion data that ranged from 0% to 0.8% of initial weight for small samples after different erosion durations. It is noted that scissor cut pieces were tested as opposed to shredded pieces; however, any uncertainty associated due to cutting as opposed to shredding the samples is offset by the fact that the samples were tested at a much higher velocity and the NUKON<sup>®</sup> erosion results were used. The TempMat test results had a large data scatter; however, for each identical test duration, the average TempMat weight loss was much lower compared to the NUKON<sup>®</sup> weight loss. These generic TempMat erosion test results represent the TempMat at V.C. Summer. Thus, the TempMat debris at V.C. Summer is estimated to erode less than NUKON<sup>®</sup> after 40 days of erosion.

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# NRC RAI #3 (Cont.)



Figure 3-1: Vertical Loop Schematic for Fiber Erosion Testing



Figure 3-2 Transport Flume Schematic for Fiber Erosion Testing

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# NRC RAI #3 (Cont.)







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# NRC RAI #3 (Cont.)



Figure 3-5 TempMat Raw Test Data

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### NRC RAI #4

Provide the methodology used to calculate the tumbling velocity metrics used for paint chips that are listed in Table 8 of the supplemental response. Also identify the test data from NUREG/CR-6916 from which the velocity metrics are derived, and justify how the methodology used to derive the calculated velocity metrics accounts for the differences between the paint chips that were tested and the paint chips predicted to be formed under actual post-loss-of-coolant accident (LOCA) conditions for the plant.

### SCE&G Response:

The methodology used to calculate the tumbling velocity metrics used for paint chips is located in the Computational Fluid Dynamics calculation (included as Attachment 4-1), which contains an analysis of paint chip transport metrics based on the testing described in NUREG/CR-6916. The paint chip transport metrics appendix analyzes the raw data from NUREG/CR-6916, to develop a curve fit of the data trend. The specific chip data is then normalized to compare the various chip types with each other and then identify data trends that can be used to interpolate settling velocities for chips with different size and density properties.

Although the test results indicate some clear trends, there is some scatter in the data. This scatter is believed to be predominantly due to variations in the chip size, since each size is specified in a range, and the data was plotted based on the average size in each range. Figures 4-1 and Figure 4-2 show the difference between the measured and calculated settling velocities for the various chips and the measured and calculated bulk tumbling velocities for the various chips. In general, the calculated settling and bulk tumbling velocities are reasonably close to the measured values with the exception of a few outlier points.

Note that the tumbling velocity used in the correlation is based on the bulk tumbling velocity rather than the incipient tumbling velocity. Incipient and bulk tumbling velocities are defined differently in different tests. In many tests, such as the testing described in NUREG/CR-6772, a piece of debris is placed on the floor of a flume, and the velocity is slowly increased. The incipient tumbling velocity is defined as the velocity at which a piece of debris first starts to move (i.e. it slides for an inch or two and then stops). The bulk tumbling velocity is defined as the velocity at which a piece of debris moves all the way down the length of the flume. The NUREG/CR-6916 testing was similar, except that a number of chips within the specified size range were tested simultaneously. For this testing, the incipient tumbling velocity was defined as the velocity at which one of the chips starts to move, and the bulk tumbling velocity was defined as the velocity at which approximately 80% of the chips start to move. Although the incipient tumbling velocity is conservative, it is a fairly poor measure of the actual velocity required to transport the chips of a given type and size since one chip that is smaller and lighter than the others may start to move at a much lower velocity than the rest of the chips. Since the bulk tumbling velocity represents the velocity required to transport the majority of chips, these values are more representative of the actual velocity required to transport the chips.

The resulting transport metrics for the chips at V.C. Summer are listed in Table 4-1.

# NRC RAI #4 (Cont.)

Table 4-1 Paint Chip Transport Metrics						
Debris Type	Size	Terminal Settling Velocity (ft/s)	Minimum TKE Required to Suspend (ft <sup>2</sup> /sec <sup>2</sup> )	Flow Velocity Associated with Incipient Tumbling (ft/s)		
Unqualified Epoxy Paint Chips	1/8" 6 mil chips (94 lb/ft <sup>3</sup> )	0.15	3.5E-02	1.08		
	2" 6 mil chips (94 lb/ft <sup>3</sup> )	0.23	7.8E-02	1.76		
	Curled 1.5" 6 mil chips (94 lb/ft <sup>3</sup> )	0.22	7.2E-02	0.12		

During discussion with the NRC on November 18, 2009, a concern was expressed that the model did not appear to match the actual test data well for the 2" 6 mil chips. While the model predicts a 1.76 ft/sec tumbling velocity, the test measured velocity is approximately 0.85 ft/sec. This can be seen in Figure 4-2 as well.

Figure 4-3 provides a velocity profile of the sump pool developed in the Computational Fluid Dynamics (CFD) model. The approach velocity to the "B" train strainer (which is the smaller, limiting strainer) is approximately 0.47 ft/sec (Location D on Figure 4-3). Transport of 1" to 2" flat chips to the "B" strainer would remain 0% if a lower tumbling velocity were applied. The approach velocity to the "A" train strainer is 0.86 ft/sec. As noted in response to RAI #16, the flows used in the CFD model are 4.9% higher than the maximum calculated flow rates. Additionally, the CFD model used a water depth of 2.93 ft. The calculated minimum level under the limiting large break LOCA debris generation is 3.42 ft. These two transport conservatism would drop the approach velocity to the "A" train strainer below the tested tumbling velocity of 0.85 ft/sec. The transport of 1" to 2" epoxy chips to the "A" train strainer would not change.

A reduction in the tumbling velocity would have minimal impact on the analytical model and is within the conservatism of the paint chip debris transport. The debris loading remains conservative.

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# NRC RAI #4 (Cont.)



Figure 4-1 Calculated Versus Measured Settling Velocity

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# NRC RAI #4 (Cont.)



Figure 4-2 – Calculated Versus Measured Bulk Tumbling Velocity

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# NRC RAI #4 (Cont.)

Figure 4-3

# Velocity Profile of the Sump Pool



# **Velocity Values at Specific Locations**

Location	Α	В	C	D	E	F	G	Н	1	J
Velocity (ft/s)	1.38	0.61	0.51	0.47	0.82	0.22	0.05	0.42	0.96	0.86

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NRC RAI #4 (Cont.)

# ATTACHMENT 4-1 Paint Tumbling Metrics Calculation 13 Pages

	V.C. Summer Reactor Building GSI-191 CFD Analysis Calculation				
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### **APPENDIX 5**

This appendix contains an analysis of paint chip transport metrics based on the testing described in NUREG/CR-6916. Table 5-1 shows the raw data from NUREG/CR-6916. Note that the settling and tumbling velocity data for curled chips was not included in this table since the forces and drag coefficient on a curled chip would be significantly different than for a flat chip.

Coating Type	Chip Length (in)	Measured Chip Thickness (mil)	Measured Coating Density <sup>1</sup> (lb <sub>n</sub> /ft <sup>3</sup> )	Settling Velocity (ft/s)	Bulk Tumbling Velocity (ft/s)
Alkyd (one coat)	1 to 2	2.2	71.8	0.09	0.46
Alkyd (one coat)	1/8 to 1/4	2.2	71.8	0.08	0.85
Alkyd (one coat)	1/64 to 1/32	2.2	71.8	0.04	0.92
Zinc-Epoxy (one coat each)	1/8 to 1/4	7.1	161.1	0.21	1.34
Zinc-Epoxy (one coat each)	1/64 to 1/32	7.1	161.1	0.26	1.36
Epoxy (two coat)	1 to 2	8.6	111.1	0.22	0.85
Epoxy (two coat, cured 2 days)	1 to 2	8.3	107.4	0.18	-
Epoxy (two coat, cured 14 days)	1 to 2	8.1	108.6	0.17	-
Epoxy (two coat)	1/8 to 1/4	8.6	111.1	0.15	1.19
Epoxy (two coat)	1/64 to 1/32	8.6	111.1	0.13	1.01
Epoxy (six coat)	1 to 2	23.0	110.5	0.32	1.36
Epoxy (six coat, cured 2 days)	1 to 2	24.3	108.0	0.28	-
Epoxy (six coat, cured 14 days)	1 to 2	21.9	109.9	0.27	-
Epoxy (six coat)	1/8 to 1/4	23.0	110.5	0.24	1.15
Epoxy (six coat)	1/64 to 1/32	23.0	110.5	0.16	0.77
Epoxy (three component)	1 to 2	25.0	115.5	0.29	1.01
Epoxy (three component, cured 2 days)	1 to 2	23.4	117.4	0.24	-
Epoxy (three component, cured 14 days)	1 to 2	23.5	114.9	0.31	-
Epoxy (three component)	1/8 to 1/4	25.0	115.5	0.24	1.28
Epoxy (three component)	1/64 to 1/32	25.0	115.5	0.16	0.98

#### Table 5-1 – NUREG/CR-6916 paint chip transport metric data

<sup>&</sup>lt;sup>1</sup> The coating densities used in this analysis were taken from the measured coating densities reported in NUREG/CR-6916 with the exception of the alkyd coatings. The density measured for these coatings was 62.4 lb<sub>m</sub>/ft<sup>3</sup>. Since this density is the same as water, if it were correct, the chips would be neutrally buoyant. Since the chips are shown to settle, however, the manufacturer density of 71.8 lb<sub>m</sub>/ft<sup>3</sup> was judged to be a more realistic density.

	V.C. Summer Reactor Building GSI-191	CFD Anal	ysis Calculation
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The forces acting on a given chip as it settles are the weight of the chip, the buoyancy of the chip, and the drag force. The weight and buoyancy can be directly calculated using the chip size. thickness, and density. The drag force, however, is a function both of the chip area and the drag coefficient. Since the orientation of settling paint chips is not stable (i.e. the chips are free to rotate in any direction as they fall), the drag coefficient and the effective drag area are not known. However, the chip data shown in Table 5-1 can be normalized to compare the various chip types with each other and then identify data trends that can be used to interpolate settling velocities for chips with different size and density properties. One way to normalize the data would be to calculate the effective weight (weight minus buoyancy) of each chip. Since the effective weight is a function of the chip area, this term would implicitly contain all of the physical parameters that affect transport. Note, however, that for the chips shown in Table 5-1, only the chip thickness and density are directly measured. The chip length varies because a group of chips within a given size range was tested. Therefore, if one were to calculate the chip area by assuming that on average the chips were square, the uncertainty in the area would be significantly greater than the uncertainty in the length since the uncertainty in the length is being squared (i.e. a 1 to 2 inch chip has a length of 1.5 in  $\pm$  33% and an area of 2.25 in<sup>2</sup> +78%/-56%). For this reason, the chips were not normalized by calculating the weight, but were instead normalized using the following equation:

$$X = L \cdot t \cdot (\rho_{chip} - \rho_{f})$$

where:

X = Normalization parameter L = Average chip length (in) t = Chip thickness (mil)  $\rho_{chip} = \text{Chip density (lb_m/ft^3)}$  $\rho_f = \text{Fluid density (lb_m/ft^3)}$ 

It was assumed that the density of the water during the testing was approximately  $62.4 \text{ lb}_m/\text{ft}^3$ . The normalization parameter is shown for each chip type and size tested in Table 5-2.

Equation 5-1

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	V.C. Summer Reactor Building GSI-191	CFD Anal	ysis Calculation
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Table 5-2 – Normanzed paint cmp transport metric data						
Coating Type	Chip Length (in)	Measured Chip Thickness (mil)	Measured Coating Density (lb <sub>n</sub> /ft <sup>3</sup> )	Normalization Parameter (in·mil· lb <sub>n</sub> /ft <sup>3</sup> )	Settling Velocity (ft/s)	Bulk Tumbling Velocity (ft/s)
Alkyd (one coat)	1 to 2	2.2	71.8	31.0	0.09	0.46
Alkyd (one coat)	1/8 to 1/4	2.2	71.8	3.9	0.08	0.85
Alkyd (one coat)	1/64 to 1/32	2.2	71.8	0.5	0.04	0.92
Zinc-Epoxy (one coat each)	1/8 to 1/4	7.1	161.1	131.4	0.21	1.34
Zinc-Epoxy (one coat each)	1/64 to 1/32	7.1	161.1	16.4	0.26	1.36
Epoxy (two coat)	1 to 2	8.6	111.1	628.2	0.22	0.85
Epoxy (two coat, cured 2 days)	1 to 2	8.3	107.4	560.3	0.18	-
Epoxy (two coat, cured 14 days)	1 to 2	8.1	108.6	561.3	0.17	-
Epoxy (two coat)	1/8 to 1/4	8.6	111.1	78.5	0.15	1.19
Epoxy (two coat)	1/64 to 1/32	8.6	111.1	9.8	0.13	1.01
Epoxy (six coat)	1 to 2	23.0	110.5	1,659.5	0.32	1.36
Epoxy (six coat, cured 2 days)	1 to 2	24.3	108.0	1,662.1	0.28	-
Epoxy (six coat, cured 14 days)	1 to 2	21.9	109.9	1.560.4	0.27	-
Epoxy (six coat)	1/8 to 1/4	23.0	110.5	207.4	0.24	1.15
Epoxy (six coat)	1/64 to 1/32	23.0	110.5	25.9	0.16	0.77
Epoxy (three component)	1 to 2	25.0	115.5	1,991.3	0.29	1.01
Epoxy (three component, cured 2 days)	1 to 2	23.4	117.4	1,930.5	0.24	, -
Epoxy (three component, cured 14 days)	1 to 2	23.5	114.9	1,850.6	0.31	-
Epoxy (three component)	1/8 to 1/4	25.0	115.5	248.9	0.24	1.28
Epoxy (three component)	1/64 to 1/32	25.0	115.5	31.1	0.16	0.98

### Table 5-2 – Normalized paint chip transport metric data

Figure 5-1 shows a plot of the settling velocity versus the normalization parameter. As shown in this figure, a logarithmic curve with the following equation provides a reasonably good fit to the data:

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$$V_{\rm c} = 0.0274 \cdot \ln(X) + 0.065$$

where:

 $V_s = \text{Settling velocity (ft/s)}$   $X = \text{Normalization parameter} = L \times t \times (\rho_{chtp} - \rho_f)$  L = Average chip length (in) t = Chip thickness (mil)  $\rho_{chip} = \text{Chip density (lbm/ft^3)}$  $\rho_f = \text{Fluid density (lbm/ft^3)}$ 

Note that the data scatter in this plot is most likely due predominantly to variations in the characteristic length of the chips tested.



Figure 5-1 - Paint chip settling velocity versus normalization parameter

Figure 5-2 shows a plot of the bulk tumbling velocity versus the normalization parameter, but does not indicate any clear trend.

Equation 5-2

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Figure 5-2 - Paint chip bulk tumbling velocity versus normalization parameter

In order to slide a chip along a floor, the drag and shear forces acting on the chip must exceed the friction force. The Reynolds number can be used in order to determine whether the drag force or shear force is dominant since drag force is dominant at high Reynolds numbers and shear force is dominant at low Reynolds numbers (~1). The following calculations show the minimum and maximum Reynolds numbers based on the data in Table 5-1:

 $\operatorname{Re} = \frac{\rho_f V L}{\mu}$ 

Equation 5-3

where:

Re = Reynolds number  $\rho_f =$  Fluid density V = Velocity Document Control Desk Attachment I RC-09-0134 Page 21 of 121

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L = Average chip length

 $\mu$  = Fluid viscosity

$$\operatorname{Re}_{\min} = \frac{(62.4lb_m/ft^3) \cdot (0.77 ft/s) \cdot \left(\frac{0.023in}{12in/ft}\right)}{(2.34 \times 10^{-5} lb_f \cdot s/ft^2) \cdot (32.2 ft/s^2 \cdot lb_m/lb_f)} = 120$$

$$\operatorname{Re}_{\max} = \frac{(62.4lb_m/ft^3) \cdot (1.36 ft/s) \cdot \left(\frac{1.5in}{12in/ft}\right)}{(2.34 \times 10^{-5} lb_f \cdot s/ft^2) \cdot (32.2 ft/s^2 \cdot lb_m/lb_f)} = 1.4 \times 10^4$$
Equation 5-5

Shear force is dominant at low Reynolds numbers (-1) and drag force is dominant at high Reynolds numbers. Therefore, since the range of Reynolds numbers are fairly high, it is expected that the drag force is dominant.

The friction and drag forces are defined as shown in the following equations:

$F_f = c_\mu \cdot N$	Equation 5-6
$N = m_e \cdot g$	Equation 5-7
$m_e = A_{chip} \cdot t \cdot (\rho_{chip} - \rho_f)$	Equation 5-8
$F_d = \frac{1}{2} \cdot c_d \cdot A_d \cdot \rho_j \cdot v^2$	Equation 5-9

where:

 $F_f = \text{Friction force}$   $c_{\mu} = \text{Coefficient of friction}$  N = Normal force m = Effective mass (including the effects of buoyancy)  $A_{chip} = \text{Chip area}$  t = Chip thickness  $\rho_{chip} = \text{Chip density}$  g = gravity  $F_d = \text{Drag force}$   $c_d = \text{Drag coefficient}$   $A_d = \text{Projected frontal area associated with the drag coefficient}$   $\rho_f = \text{Fluid density}$  v = Fluid velocity

Setting the friction and drag forces equal yields the following equation:

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$$\frac{1}{2} \cdot c_d \cdot A_d \cdot \rho_f \cdot v^2 = c_\mu \cdot A_{chip} \cdot t \cdot (\rho_{chip} - \rho_f) \cdot g$$

Both the coefficient of friction and the drag coefficient in these equations are unknown. The coefficient of friction between the chips and the floor is reasonably judged to be a constant value for all of the chips. The drag coefficient is also judged to be a constant for chips that are the same size. Solving for these two terms gives the following equation:

Equation 5-10

$$\frac{c_d}{c_{\mu}} = \frac{2 \cdot A_{chip} \cdot t \cdot (\rho_{chip} - \rho_f) \cdot g}{A_d \cdot \rho_f \cdot v^2}$$
Equation 5-11

Note that the projected frontal area is also somewhat of an unknown. However, since the chips are flat, and sit flat on the floor, the projected area can be reasonably estimated as the characteristic chip length times the chip thickness.

As discussed previously, calculating the area of the chips based on the average characteristic chip length has significant uncertainty. However, in order to estimate the drag/friction coefficient, it will be assumed that the chips are square on average with each side having a length equal to the average characteristic length.

$\mathbf{A}$	V.C. Summer Reactor Building GSI-191 CFD Analysis Calculation					
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Coating Type	Chip Length (in)	Measured Chip Thickness (mil)	Measured Coating Density (lb <sub>n</sub> /ft <sup>3</sup> )	Bulk Tumbling Velocity (ft/s)	Calculated Drag/Friction Coefficient (c <sub>d</sub> /c <sub>u</sub> )
Alkyd (one coat)	I to 2	2.2	62.4	0.46	38.04
Alkyd (one coat)	1/8 to 1/4	2.2	62.4	0.85	1.39
Alkyd (one coat)	1/64 to 1/32	2.2	62.4	0.92	0.15
Zinc-Epoxy (one coat each)	1/8 to 1/4	7.1	161.1	1.34	1.45
Zinc-Epoxy (one coat each)	1/64 to 1/32	7.1	161.1	1.36	0.18
Epoxy (two coat)	I to 2	8.6	111.1	0.85	19.84
Epoxy (two coat, cured 2 days)	1 to 2	8.3	107.4	-	-
Epoxy (two coat, cured 14 days)	1 to 2	8.1	108.6	- -	•
Epoxy (two coat)	1/8 to 1/4	8.6	111.1	1.19	1.27
Epoxy (two coat)	1/64 to 1/32	8.6	111.1	1.01	0.22
Epoxy (six coat)	1 to 2	23.0	110.5	1.36	7.71
Epoxy (six coat, cured 2 days)	I to 2	24.3	108.0	-	
Epoxy (six coat, cured 14 days)	1 to 2	21.9	109.9	=	÷
Epoxy (six coat)	1/8 to 1/4	23.0	110.5	1.15	1.35
Epoxy (six coat)	1/64 to 1/32	23.0	110.5	0.77	0.38
Epoxy (three component)	1 to 2	25.0	115,5	1.01	14.61
Epoxy (three component, cured 2 days)	I to 2	23.4	117.4	-	-
Epoxy (three component, cured 14 days)	I to 2	23.5	114.9	-	-
Epoxy (three component)	1/8 to 1/4	25.0	115.5	1.28	1.14
Epoxy (three component)	1/64 to 1/32	25.0	115.5	0.98	0.24

Figure 5-3 shows the calculated bulk tumbling velocity drag/friction coefficient for each of the paint chips. As shown in Figure 5-4, when the data is plotted on a logarithmic scale, it shows a linear trend.

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Figure 5-3 – Calculated bulk tumbling velocity drag/friction coefficient versus normalization parameter (linear scale)

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Figure 5-4 – Calculated bulk tumbling velocity drag/friction coefficient versus normalization parameter (logarithmic scale)

Figure 5-4 shows that the relationship of the drag/friction coefficient to the normalization parameter can be estimated using the following equation:

$$c_{A}/c_{u} = 0.0376 \cdot X^{0.6471}$$

where:

 $\begin{array}{l} c_d = \mathrm{Drag} \ \mathrm{coefficient} \\ c_\mu = \mathrm{Coefficient} \ \mathrm{of} \ \mathrm{friction} \\ X = \mathrm{Normalization} \ \mathrm{parameter} = L \times t \times (\rho_{chip} - \rho_f) \\ L = \mathrm{Average} \ \mathrm{chip} \ \mathrm{length} \ \mathrm{(in)} \\ t = \mathrm{Chip} \ \mathrm{thickness} \ \mathrm{(mil)} \\ \rho_{chip} = \mathrm{Chip} \ \mathrm{density} \ \mathrm{(lb_m/ft^3)} \\ \rho_f = \mathrm{Fluid} \ \mathrm{density} \ \mathrm{(lb_m/ft^3)} \end{array}$ 

Equation 5-12

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Rearranging Equation 5-10 to solve for the tumbling velocity yields the following:

$$V_{t} = \sqrt{\frac{2 \cdot A_{chip} \cdot t \cdot (\rho_{chip} - \rho_{f}) \cdot g}{A_{d} \cdot \rho_{f} \cdot \frac{c_{d}}{c_{\mu}}}}$$

Equation 5-13

where:

 $V_t$  = Tumbling velocity  $A_{chip}$  = Chip area t = Chip thickness  $\rho_{chip}$  = Chip density  $\rho_f$  = Fluid density g = gravity  $A_d$  = Projected frontal area associated with the drag coefficient  $c_d$  = Drag coefficient  $c_\mu$  = Coefficient of friction

This equation can be used along with the drag/friction coefficient calculated by Equation 5-12 to determine the tumbling velocity for plant specific chips.

For curled chips, NUREG/CR-6916 shows that the settling velocity is slightly higher in most cases than for an equivalent flat chip. Therefore, the settling velocity calculated using Equation 5-2 can be conservatively used for curled chips. Table 5-4 shows the tumbling velocities for the curled chips. Note that the calculated normalization parameter in this table does not include the characteristic chip length since all of the curled chips tested were the same length:

$$X_{curled} = t \cdot (\rho_{chip} - \rho_f)$$

Equation 5-14

where:

 $X_{curled}$  = Normalization parameter for curled chips t = Chip thickness (mil)  $\rho_{chip}$  = Chip density (lb<sub>m</sub>/ft<sup>3</sup>)  $\rho_f$  = Fluid density (lb<sub>m</sub>/ft<sup>3</sup>) Document Control Desk Attachment I RC-09-0134 Page 27 of 121

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	Table 5-4 –	Normalized c	curled paint	chip trans	port metric data
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Coating Type	Chip Length (in)	Measured Chip Thickness (mil)	Measured Coating Density (lb <sub>n</sub> /ft <sup>3</sup> )	Normalization Parameter (mil· lb <sub>n</sub> /ft <sup>3</sup> )	Bulk Tumbling Velocity (ft/s)
Zinc-Epoxy (one coat each)	Curled 1 to 2	7.1	161.1	700.8	0.43
Epoxy (two coat)	Curled 1 to 2	8.6	111.1	418.8	0.27
Epoxy (six coat)	Curled 1 to 2	23.0	110.5	1,106.3	0.69

Figure 5-5 shows that tumbling velocity for curled chips versus the normalization parameter is linear and the following equation provides a good fit to the data:

$$V_{t,curled} = 0.00062 \cdot X_{curled} = 0.00062 \cdot t \cdot (\rho_{chip} - \rho_f)$$

Equation 5-15

. where:

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 $V_{t.curled} = \text{Tumbling velocity for curled chips (ft/s)}$   $X_{curled} = \text{Normalization parameter for curled chips} = t \times (\rho_{chip} - \rho_f)$  t = Chip thickness (mil)  $\rho_{chip} = \text{Chip density (lb_m/ft^3)}$  $\rho_f = \text{Fluid density (lb_m/ft^3)}$  Document Control Desk Attachment I RC-09-0134 Page 28 of 121





Figure 5-5 - Curled chip bulk tumbling velocity versus curled chip normalization parameter

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### NRC RAI #5

Transport testing performed for Unresolved Safety Issue A-43 was used as a basis for the tumbling velocity metrics assumed for small and large pieces of Temp-Mat. Provide the following information concerning the assumed velocity metrics:

- a. Identify the specific tests from NUREG/CR-2982 that were used as a basis.
- b. Identify the sizes of the test debris pieces for which these metrics were derived and justify why they are conservative or prototypical.
- c. Justify using regularly shaped, scissor-cut debris pieces for representing debris that is likely to be shredded by a LOCA jet into irregular shapes that would typically experience lower frictional forces against the containment floor and offer increased vertical cross-sectional area to promote tumbling.

## SCE&G Response:

The small piece tumbling velocity metric for TempMat has subsequently been revised to conservatively use the NUKON<sup>®</sup> small piece tumbling velocity metric and no longer relies on the use of regularly shaped, scissor cut debris piece data. An update of the TempMat debris loading is presented in Table 5-1. This data replaces the TempMat debris loading presented in Tables 9 and 10 of the Supplement Response.

The large piece tumbling velocity metric for TempMat is unchanged and is based on the Mineral Wool insulation velocity metric. Use of the Mineral Wool velocity metric is conservative as Mineral Wool has a lower density than TempMat (6 lb/ft<sup>3</sup> for Mineral Wool compared to 11.8 lb/ft<sup>3</sup> for Temp Mat) and a lower density requires a lower tumbling velocity. Reduction of the tumbling velocity metric for TempMat results in a conservatively higher transport fraction.

NUREG/CR-2982 tested three types of fiberglass; including mineral wool, Burlglass (a high density fiberglass approximately 10 lbs/ft<sup>3</sup>), and covered Burlglass. The transport test results for individual large pieces (up to two feet on the side) are summarized as having a velocity range of 0.9 to 1.5 ft/sec. The 0.9 ft/sec value was conservatively selected as it is the lowest velocity value of all of the specific large piece tests.

Table 5-1 Updated TempMat Debris Load						
Strainer	Debris	Weight Fraction /	Quantity at the			
	Sump					
Train A (2939 ft <sup>2</sup> )	15.49 ft <sup>3</sup>	19.6%	3.04 ft <sup>2</sup> (35.8 lb)			
Train B (2379 ft <sup>2</sup> )	15.49 ft <sup>3</sup>	12.1%	1.87 ft <sup>2</sup> (22.1 lb)			

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### NRC RAI #6

It was not clear that the testing covered the full range of potential fibrous debris loading for the strainer. Provide information that shows that the following issues were considered in the evaluation and shows how the issues were bounded by the head-loss testing that was conducted.

- a. The surge line break that results in fine Kaowool debris was not tested.
- b. It was not clear that Test 2 included any fibrous debris to represent the Temp-Mat prior to the introduction of the "additional fiber loading."

### SCE&G Response to 6a:

The surge line break that results in fine Kaowool debris is bound by the TempMat fiber quantities developed in the LBLOCA Case 1 scenario. The Debris Generation Analysis justifies the use of a K-Wool size distribution for the Kaowool debris and subsequent calculations have been revised to include the Kaowool size distribution listed in Table 6a-1 below.

	Table 6a-1: Tempillat Debris Source Term – Case 1 LBLOCA						
Amount	Large Piec	es		Fines			
Destroyed	Intact	Exposed	Small	Amount	Density	Size	
Desiloyeu	Blankets	Blankets	Pieces	Amount	Density	Size	
15 40 ft <sup>3</sup>	5.27 ft <sup>3</sup>	4.96 ft <sup>3</sup>	4.18 ft <sup>3</sup>	1.08 ft <sup>3</sup>	162 lbm/ft <sup>3</sup>	2 05 5 05 #	
15.49 π°	(34%)	(32%)	(27%)	(7%)		2.95 E-05 II.	

# Table 6a-1: TempMat Debris Source Term – Case 1 LBLOCA

## Table 6a-2: Kaowool Debris Source Term – 14" Pressurizer Surge Line Break

Amount	Large Pieces			Fines		
Destroyed	Intact Blankets	Exposed Blankets	Small Pieces	Amount	Density	Size
1.48 ft <sup>3</sup>	0 ft <sup>3</sup> (0%)	0 ft <sup>3</sup> (0%)	1.18 ft <sup>3</sup> (80%)	0.30 ft <sup>3</sup> (20%)	160 lbm/ft <sup>3</sup>	2.95 E-05 ft.
0.34 ft <sup>3</sup>	0.13 ft <sup>3</sup> (39%)	0.13 ft <sup>3</sup> (37%)	0.06 ft <sup>3</sup> (19%)	0.02 ft <sup>3</sup> (5%)	160 lbm/ ft <sup>3</sup>	2.95 E-05 ft.

This size distribution applied to the break that destroys Kaowool is bound by the quantity of fiber generated in the loop break Case 1 scenario.

## SCE&G Response to 6b:

Test 2 did not include TempMat as a part of the design basis debris loading. The design basis debris loading for Test 2 was an all particulate case (all coatings assumed to fail as particulate) for a break location that generates Marinite XL debris to the Train B (smaller strainer) with a surface area of 2379 ft<sup>2</sup>. There are no break locations that generate both TempMat debris and Marinite XL debris.

The debris load cases for the Marinite XL are presented on Tables 11 and 12 in the SCE&G supplemental response letter RC-08-0031. The debris loading assumes 100% transport of the Marinite XL as particulate and fiber. The total Marinite XL debris is 8.58 ft<sup>3</sup>. Test 2 used an

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# NRC RAI #6 (Cont.)

equivalent loading of 30.2 ft<sup>3</sup> of Marinite XL based on an early debris generation evaluation. This is 3.5 times the design Marinite XL loading.

After the design basis debris loading test was complete, Test 2 was continued to evaluate the onset of thin bed formation. Additional fiber was added in the form of TempMat as a means of demonstrating that the design basis fiber loading at V.C. Summer is below thin bed. The TempMat was added in equivalent 1/16" theoretical bed thickness. The test is based on a surface area of 2229 ft<sup>2</sup>, so each TempMat fiber addition is equivalent to 11.6 ft<sup>3</sup> (2229 ft<sup>2</sup> X 1/16 in). This is compared to conservative TempMat fiber load of 1.87 ft<sup>3</sup> as detailed in response to RAI #5a. The second TempMat addition was again an equivalent 1/16" load. The total fiber loads are summarized below.

Table 6b-1           Summary of Fiber Load for Test 2 Particulate Case						
	Design Value	Test Value	After First TempMat	After Second TempMat		
Latent Fiber	16 lbs	16 lbs	16 lbs	16 lbs		
Marinite XL Fiber	19.8 lbs	126.4 lbs	126.4 lbs	126.4 lbs		
TempMat Fiber	0 lbs	0 lbs	136.9 lbs	273.8 lbs		
Total Fiber	35.8 lbs	142.4 lbs	279.3 lbs	416.2 lbs		

The only conclusions that may be drawn from the TempMat additions is that V.C. Summer strainer design is well below the onset of thin bed formation. The TempMat additions were significantly greater than the design condition. Total design basis fiber loading is approximately 36 lbs. The total fiber added during the test was approximately 360 lbs. The increase in head loss following the TempMat additions is based on the significant increase in fiber loading and approach to thin bed. The test does not indicate a different bed formation when TempMat is added. It indicates an order of magnitude increase in fiber loading results in approach to thin bed.

As discussed during several teleconferences between SCE&G and the NRC, the testing for V.C. Summer is based on the design limiting Marinite XL loading. The Marinite XL loading case is limiting based on the following points:

 The total mass of fiber in the Marinite XL debris loading case is greater than TempMat. The limiting break for Marinite XL conservatively results in 8.58 ft<sup>3</sup> of debris at the sump strainer location. The density of Marinite is 46 lb/ft<sup>3</sup> with 5% fiber content by mass. The total Marinite XL fiber loading is 19.8 lbs. Total latent debris fiber loading is 16 lbs for a total of 35.8 lbs. This could be for either the A strainer or B strainer. Since the strainer surface areas are different, loading for the TempMat cases are strainer specific. A summary of the loading is as follows:

### NRC RAI #6 (Cont.)

Table 6b-2						
Comparison of Design Cases with Test Fiber Loading						
	Marinite XL	TempMat	TempMat	Test 2	Test 3	
	Strainer B	Strainer A Case	Strainer B Case	Particulate	Paint Chip	
Latent Fiber	16 lbs					
Marinite XL Fiber	19.8 lbs	0 lbs	0 lbs	126.4 lbs	35.9 lbs	
TempMat Fibe <u>r</u> (vol)	0 ft <sup>3</sup>	3.04 ft <sup>3</sup>	1.87 ft <sup>3</sup>	0 ft <sup>3</sup>	0 ft <sup>3</sup>	
TempMat Fiber (mass)	0 lbs	35.8 lbs	22.1 lbs	0 lbs	0 lbs	
Total Fiber	35.8 lbs	51.8 lbs	38.1 lbs	142.4 lbs	51.9 lbs	
Strainer Surface Area	2379 ft <sup>2</sup>	2939 ft <sup>2</sup>	2379 ft <sup>2</sup>	2379 ft <sup>2</sup>	2379 ft <sup>2</sup>	
Sacrificial Area	150 ft <sup>2</sup>					
Total Area Available	2229 ft <sup>2</sup>	2789 ft <sup>2</sup>	2229 ft <sup>2</sup>	2229 ft <sup>2</sup>	2229 ft <sup>2</sup>	
Fiber Loading	0.0161 lb/ft <sup>2</sup>	0.0186 lb/ft <sup>2</sup>	0.0171 lb/ft <sup>2</sup>	0.0639 lb/ft <sup>2</sup>	0.0233 lb/ft <sup>2</sup>	
Flow Rate	7500 gpm	7600 gpm	7500 gpm	7500 gpm	7500 gpm	
Velocity	0.0075ft/sec	0.0061 ft/sec	0.0075ft/sec	0.0075ft/sec	0.0075ft/sec	

The fiber loading for the Marinite I test  $(0.0233 \text{ lb/ft}^2)$  is limiting for all cases. Additional margin for the Strainer A case is provided in the lower approach velocity at the strainer surface due to the large size of Strainer A.

- 2. The TempMat fiber diameter is given as 9 microns in NEI 04-07. The Scanning Electron Microscope (SEM) completed on the Marinite I powder used in the actual test determined an average fiber diameter of 10 micron. Based on NUREG/CR-6224 correlations, smaller diameter fibers yield a higher head loss when forming a debris bed.
- 3. The Marinite XL fiber length was questioned by the NRC during the July 27, 2009 teleconference. Atomic Energy of Canada Limited (AECL) performed SEM analysis of the Marinite I test material. The results showed that the Marinite fiber average length is 37 microns. The mass concentration of fiber is 9.1%, which is higher than the specified value for Marinite XL installed at the plant. The fiber size distribution is provided under the RAI #7 response in Table 7-1. Fibers greater than 1 mm (1000 microns) make up 0.94% of the Marinite I test materials. No specific concerns with regard to fiber length could be found in industry or regulatory documents. Any concerns regarding short fibers bypassing the strainer are addressed by the bypass testing completed. As further detailed in response to RAI #11, the maximum bypass was 0.70% early in Test 2. All other bypass measurements decreased with time indicating the Marinite I fibers used in the test does not adversely affect the tests.

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## NRC RAI #6 (Cont.)

4. The SEM photos provided with response to RAI #12 clearly show fiber release from the Marinite I particulate. There is no concern the fibers were not available to form a debris bed.

Based on review of relevant data and technical resources, the Marinite I test cases bound both the Marinite XL and the TempMat debris loading cases.

To confirm this position and address NRC concerns regarding fiber length, SCE&G will complete two additional small scale tests. The tests will be completed at the AECL facility using the Chemical Effects test Rig #89 which is familiar to the NRC staff. Debris loading will be based on the current analysis debris loading and will not directly reflect the previous large scale tests. As discussed with the NRC, the paint chip loading in the Rig #89 test will be modeled as 75% of paint chip surface area consistent with the modeling of labels, tape and other miscellaneous debris.

#### NRC RAI #7

The licensee did not verify that the fibrous debris that was added to the testing was prepared sufficiently. Because most fibrous debris for this plant is latent, and the majority of the other fibrous debris that transports is fine, almost all fibers should have been individual or easily suspendable. The use of fibrous shreds for the VCSNS test cases could prevent the potential formation of a thin bed because sufficient fines would not be available to cover the strainer. Because the fibrous debris predicted to arrive at the strainer is a relatively small amount and it is added directly on top of the strainer, the results of the test are likely strongly dependent upon the preparation and introduction of the debris. Provide information that shows that the size distribution of debris in each test matches the debris size predicted to reach the strainer by the transport calculation for that case. Alternately verify that the debris was prepared conservatively fine.

### SCE&G Response:

Three large-scale strainer tests were performed by AECL using debris loads specified by SCE&G. In Tests 1 and 2, Nukon and TempMat fibreglass were used; in Test 3, only PCI Nukon was used to simulate latent fiber. The procured fibrous insulations were cut into pieces of approximately 6 inches by 6 inches. A leaf shredder was used to break down the debris further. The fibrous debris weighed out for testing is shown in Figure 7-1 and Figure 7-2. As can be seen from these photos, the fibrous debris became small and fluffy after shredding.

The measured fibrous debris was added into a plastic tub and wetted with water. A water jet from a pressure washer was used to separate the fibers. Particulate debris for each batch addition was also added into the tub and mixed with fibrous debris by using a water jet (approximately 2000 psi) and a rake. The debris mixture was then added from the tub to the test tank through a submerged sludge pump, shown in Figure 7-3. It was almost impossible to add large fibrous shreds into the test tank through the pump. As shown in Figure 7-4, after being pumped into the test tank, the fibers had become separated into individual filaments. Any floating debris was skimmed out into a bucket and added into the test tank again.

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# NRC RAI #7 (Cont.)

The debris preparation method was the same as in the Dominion chemical effects tests, which was approved by the NRC during a field trip to AECL in May 2008. The debris preparation and addition to the test tank were conservative as compared to the plant situation.

Another source of fibrous debris that could contribute to the debris bed head loss is the Marinite I debris addition. SEM analysis performed by AECL indicated that fiber release from Marinite I powder had an average diameter of 10 microns and an average length of 37 microns. The mass concentration of the fiber is 9.1%. The mass percentage of long fibers (greater than 1 mm) is 0.94%. The distribution of fiber length is shown in Tale 7-1.

Marinate I debris was added in Tests 2 and 3. Prior to the debris addition, Marinite I powder was mixed with fibrous debris in a plastic hub. The mixture was then pressure washed and pumped to the test tank. The debris preparation process adopted by AECL ensured that fibrous debris was separated into single fines. Debris bed photos shown in Figure 7-5 and Figure 7-6 supported the above statements.

Table 7-1					
Distribution of Fiber Length					
Range					
(µm)	Percentage (%)				
<10	3.167				
10-20	19.883				
20-30	27.801				
30-40	17.947				
40-50	12.317				
50-60	5.631				
60-70	5.986				
70-80	1.935				
80-90	1.059				
90-100	1.255				
100-200	2.74				
200-300	0.229				
300-400	0.011				
400-500	0.009				
500-600	0.004				
600-700	0.005				
700-800	0.009				
800-900	0				
900-1000	0.002				
>1000	0.012				
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### NRC RAI #7 (Cont.)

### **Distribution of Fiber Length**



Figure 7-1 Fibrous Debris Used in V.C. Summer Tests 1 and 2



Figure 7-2 Fibrous Debris Used in V.C. Summer Test 3

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Figure 7-3 Debris Mixture Being Pumped from the Tub to the Test Tank



Figure 7-4 Fibers Being Separated into Individual Filament



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Figure 7-5 Debris Bed Formed in V.C. Summer Test 2



Figure 7-6 Debris Bed Formed in V.C. Summer Test 3

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#### NRC RAI #8

It was not clear that the debris was diluted sufficiently to prevent agglomeration of debris during testing. Provide information that shows that non-conservative agglomeration of debris did not occur during testing.

### SCE&G Response:

For debris preparation, the fiber batts were cut into pieces of approximately 6 in. by 6 in. The pieces of fiber were further broken into smaller pieces using a leaf shredder. Particulate debris, including walnut shell flour and Marinite I powder, were procured in powder form. SEM analysis indicated that Marinite I powder had an average particle size less than 10 µm.

The measured fibrous and particulate debris were mixed in a plastic tub. A high-pressure water jet (approximately 2000 psi) was used to separate fiber shreds and thoroughly mixed the debris. The slurry of mixed debris was then pumped from the plastic tub to the test tank. The gratings of the submerge pump prevented any large pieces from being added to the tank.

Figure 8-1 shows a technologist agitating the debris slurry in the plastic tub using a rake while the submerge pump was turned on. Debris was sufficiently diluted and finely separated before it was pumped into the test tank. The debris bed photo shown in Figure 8-2 indicated that debris agglomeration did not happen during the testing. By strictly following the debris preparation procedure developed for the V.C. Summer tests, debris agglomeration was prevented in all stages of the testing.

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Figure 8-1 Debris Slurry Prepared in a Plastic Tub



Figure 8-2 Debris Bed Formed in V.C. Summer Test 3

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### NRC RAI #9

The supplemental response stated that the test results were viscosity corrected based on the decrease of water viscosity with increasing temperature. The presence of bore holes or lack of a continuous bed could result in turbulent flow conditions across at least part of the strainer that would invalidate the use of a straight viscosity correction for head loss. State whether flow sweeps were conducted to ensure that bore holes or other pressure driven phenomenon did not occur during testing. Provide the results of the flow sweeps. Provide the methodology used for the viscosity correction. If flow sweeps were not conducted, justify the method used to perform the viscosity correction.

### SCE&G Response:

Flow sweeps were not conducted for V. C. Summer large-scale tests. At the time when these tests were performed (from September 2006 to July 2007), the information that the NRC would accept head loss behaving linearly with a change in flow rate as a demonstration of lack of boreholes was not available. Instead, a defensive method was used. After the test, debris bed on each fin was carefully checked and photos were taken to demonstrate that the debris bed was complete and boreholes did not exist.

After Test 3, photos of debris bed, indicating possible boreholes, were carefully examined as shown in Figure 9-1 and Figure 9-2.



Figure 9-1 Spider Web Features between the Corrugations

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Figure 9-2 Spider Web with hole in top valley.

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### NRC RAI #9 (Cont.)

Close-up photos indicate that those apparent holes did not extend through the debris bed, only through the fluffy "web" joining adjacent corrugations as shown in Figure 9-3 and Figure 9-4.



Figure 9-3 Blow-up of the Spider Web in Upper Valley.

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### NRC RAI #9 (Cont.)



Figure 9-4 Close-up of Another Similar Feature.

Note in Figure 9-4 that the bottom of the hole in the spider web stops at the top of the main part of the debris bed. Paint chips are white and the gray is due to the zinc powder. (The yellow tinge is due to the overhead lighting.)

In addition, the fact that the head loss vs. time plot for Test 3 did not exhibit sudden drops in pressure also indicated that there were no boreholes, because if boreholes were forming, then sudden drops in pressure would accompany the formation of such holes.

The total test module surface area was 357 ft<sup>2</sup>. With a test flow rate of 1201 gpm, the flow approach velocity to the test module was calculated to be 0.0075 ft/s. Hence, we would expect laminar flow. Referring to NUREG/CR-6224, for laminar flow, the debris bed head loss is proportional to fluid viscosity.

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### NRC RAI #10

The basis for combining the head loss results for one paint chip addition (from Test 3) with the results of the head-loss from the fiber and particulate case (Test 2) was not clear. If it is anticipated that paint chips will transport to the strainer, thereby, reducing the effective area for debris to collect, the chips should be added to the limiting case. A simple addition of the results may not produce a conservative result. Provide a justification for combining the two test results instead of performing an integrated test.

#### SCE&G Response:

Test 2 was run to bound the sump strainer head loss with an all particulate debris load (all coatings assumed to fail as particulate). The test used a Marinite XL debris load of  $30.2 \text{ ft}^3$ , which was based on the original analysis for the initial GL 2004-02 response in September 2004. Test 3 was run with the refined design basis Marinite XL debris load of  $8.58 \text{ ft}^3$ , but with an excess of paint chips ( $3436 \text{ ft}^2$  compared with a 747 ft<sup>2</sup> design load). The use of the Test 3 total head loss was overly conservative with 4.5 times the design basis paint chips used. Therefore, a combination of the Test 2 and Test 3 results was developed to define an appropriately conservative design basis head loss for the sump strainer.

Based on several teleconferences, the NRC suggested that the head loss be based on a single bounding test. To that end the head loss will be based on Test 3 with paint chips. Table 10-1 presents the measured pressure drop after each debris addition.

Table 10-1			
<b>Test 3 Pressure Drop During Debris Addition</b>			
Debris Addition	kPa	psi	
Clean	0.13	0.02	
1/3 Fiber/Particulate	0.31	0.05	
1/3 Chips	0.68	0.10	
1/3 Fiber/Particulate	6.33	0.92	
1/3 Chips	10.02	1.45	
1/3 Fiber/Particulate	21.73	3.15	
1/3 Chips (peak)	27.35	3.97	
Stabilized final	23.92	3.47	

The design head loss for the strainer was chosen as the pressure drop after the third fiber addition, but before the 3<sup>rd</sup> (and final) paint chips addition. The pressure drop was measured at 3.15 psi at 104°F test conditions.

The 3.15 psi is bounding based on the following points.

1. The entire fiber and particulate load is included in the test. This includes both the Marinite I and latent fiber. Marinite I (test material) fiber content of 9.1% bounds the 5% fiber content of Marinite XL (actually installed).

### NRC RAI #10 (Cont.)

2. The paint chip loading is 1145.3 ft<sup>2</sup> x 2 = 2290.6 ft<sup>2</sup>. This is approximately 3 times the analysis paint chip loading of 747 ft<sup>2</sup>. Comparing the particulate test (Test 2) and the paint chip test (Test 3) the significant impact of increasing paint chip loading is clearly established. The excess paint chip load provides a significant margin in the test results.

An additional concern is the termination criteria for the test. The mission time for the V.C. Summer GSI-191 resolution has been established at 40-days based on the Environmental Qualification temperature restraints. Since strainer tests are not run for the full mission time, the concern is that pressure drop may increase over time. Acceptable means of qualifying a test run have been an equivalent number of turnovers or demonstrate that the head loss is stable or decreasing.

The stable or decreasing head loss can be demonstrated for Test 3 after the final paint chip addition as discussed in response to RAI #13. The peak pressure drop is clearly conservative for Test 3.

Using the intermediate test data point from Test 3 does not allow for this type of analysis. The following arguments are provided for the 3.15 psi being a conservative limiting head loss that bounds the expected debris loads.

- 1. The evaluation of the head loss after the third paint chip addition shows the debris bed was formed and stable (RAI #13). The paint chips block additional screen surface, increasing head loss across the strainer. There are no changes to the fiber bed. If the fiber bed was formed and stable after the last paint chip addition, then the fiber bed was formed and stable before the last paint chip addition.
- 2. Head loss stabilized at 3.47 psi from a peak of 3.97 psi after the last paint chip addition. This means the stable head loss with an additional paint chip load is only 0.32 psi greater than 3.15 psi being used. The pressure drop versus time plot for Test 3 is shown on Figure 10-1.

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### NRC RAI #10 (Cont.)



The increase is design pressure from 2.72 psi in the Supplement Response to 3.15 psi at 104°F has been incorporated into the Net Positive Suction Head (NPSH) calculations for both the RHR Pumps and the Reactor Building Spray Pumps. This is included in the response to RAI #16.

The evaluation of flashing is based on the submergence of the strainer fin, pressure inside the reactor building, vapor pressure of the sump water and the pressure drop across the sump strainer. The vapor pressure and pressure drop are both temperature dependent. If the pressure inside the strainer falls below the vapor pressure, then flashing would occur.

$$\begin{split} P_{S} &= P_{RB} - \Delta P_{T} + Z \ x \ (\rho_{T} \ / \ 144 \ in^{2} / ft^{2}) \\ Where \\ P_{S} \ is the pressure inside the strainer (psia) \\ P_{RB} \ is the reactor building pressure (psia) \\ \Delta P_{T} \ is the pressure drop at Temperature (T) of interest (psi) \\ Z \ is the submergence (ft) \\ \rho_{T} \ is the water density at Temperature (T) of interest (lb/ft^{3}) \end{split}$$

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### NRC RAI #10 (Cont.)

If the water vapor pressure equals the reactor building pressure, this reduces to a comparison between submergence and pressure drop.

The Reactor Building saturation temperature is based on initial Reactor Building conditions established by Technical Specification 3.6.1.4 which limits pressure to -0.1 and +1.5 psig. Therefore, a saturation temperature of 212°F was evaluated for flashing. No credit is taken for subcooling at or above this temperature. Subcooling is credited for lower temperatures. Several sump temperatures were evaluated to confirm the limiting temperature was selected. The strainer pressure drop was adjusted to the appropriate temperature based on water viscosity.

Temperature	Strainer Pressure Drop	Level Margin	
70°F	4.72 psi	25.5 ft	
104°F	3.15 psi	27.6 ft	
130°F	2.46 psi	26.7 ft	
212°F	1.37 psi	0.3 ft	

The submergence is based on the strainer fins. The strainer design provides vent holes in a rise above the fin elevation. These vents holes have less submergence; however, no credit is taken for the vent holes in terms of strainer head loss. Flashing across these holes would not have an adverse impact.

The above flashing evaluation was completed using sump water levels associated with large break LOCA. This is appropriate for two reasons.

- 1. The head loss used in the analysis is based on debris generation and transport that would only occur following a large break LOCA.
- 2. For a small break LOCA water level, it is assumed the Reactor Coolant System pressure remains above the accumulator pressure. If this were the case, then the pressure would also be above the RHR pump shutoff head. This would substantially reduce the strainer flow rate and therefore the potential vortex formation.

The design basis strainer head loss is also within the strainer design allowable pressure drop of 6.5 psid. Therefore, the design strainer head loss of 3.15 psid at 104°F is acceptable for system operation.

#### NRC RAI #11

The section of the supplemental response that describes bypass fraction testing states that samples for bypass fraction were taken for all three tests at 2-hour intervals. The supplemental response also states that the quantity of fiber bypass decreased exponentially over time. It is

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### NRC RAI #11 (Cont.)

not clear when the first grab sample was taken. It also appears that more frequent sampling near the beginning of the test may be appropriate. Provide the schedule upon which samples were taken. Considering that the bypass decreases exponentially with time, provide the methodology used to determine the total bypass.

#### SCE&G Response:

Test 1 was a RMI blockage test. The first batch of debris addition started at 1415, September 6, 2006 and the last batch of debris addition finished at 1736, three hours later. The first bypass sample was taken at 1800. A total of 11 bypass samples were taken at 2-hour intervals. Test 1 will not be discussed further since it included large amounts of Reflective Metal Insulation (RMI) debris. The bypass fraction was substantially lower and not applicable to the V.C. Summer final strainer design basis.

Test 2 was a thin bed test. The first batch of latent fiber and particulate mixture addition started at 1940, October 3, 2006. A total of 7 batches were added to the test during a period of 2 hours. Following these 7 batches, a second and then third addition consisting of TempMat fiber only was added to the test at 2219, October 3 and 1300, October 4, 2006 respectively. These TempMat additions were beyond the strainer design basis and were not included in the bypass sampling. The first bypass sample (Sample 2) was taken at 2135 after the latent fiber and Marinite I were added to the test.

Bypass sampling for Test 3 started after completion of the fiber/particulate and paint chips additions and continued until the test was terminated. A detailed bypass sample schedule for all three tests is listed in Table 11-1.

- ·	Time		
Sample	Test 1	Test 2	Test 3
1	2006 Sep. 26 1800	Test clean water sample	2007 Jul. 24 1700
2	2000	2006 Oct. 3 2135	1900
3	2200	2335	2100
4	2400	2006 Oct. 4 0135	2300
5	2006 Sep. 27 0200	0335	2007 Jul. 25 0100
6	0400	0535	0300
7	0600	0735	0500
8	0800	1325	0700
9	1000	/	/
10	1200	1	/
11	1400	/	/

# Table 11-1 V.C. Summer Large-Scale Strainer Tests Bypass Sample Schedule

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### NRC RAI #11 (Cont.)

For Test 2, fiber bypass was measured via SEM analysis of Samples 2, 3, 5, 7 and 8 (see Table 11-1). Individual fiber lengths were measured from SEM micrographs of filtered portions of these samples. Most of the fibers (90%) were less than 0.039 in. (1.0 mm) in length. The volumes and masses of fiber bypass were calculated from the measured fiber lengths. Fiber concentrations calculated in this fashion are plotted versus time in Figure 11-1. The greatest observed fiber bypass of 5.3 mg/L from Sample 2 corresponds to a bypass fraction of 0.70%. This uses a Marinite I fiber content of 9.1% as determined by the SEM analysis. The quantity of fiber bypass decreased over time. An exponential least-squares trend line fits the measurements reasonably well. From the curve equation, the maximum fiber concentration of 3.5 mg/L was obtained by setting the time to zero.

For Test 3, the first bypass sample was taken at 1700 on July 24, 2007. Fiber bypass was measured via SEM analysis of Samples 1, 2, 4, 6 and 8 (see Table 11-1). Individual fiber lengths were measured from SEM micrographs of filtered portions of these samples. Most of the fibers (95%) were less than 0.039 in. (1.0 mm) in length. The volumes and masses of fiber bypass were calculated from the measured fiber lengths. The calculated fiber concentrations are plotted versus time in Figure 11-2. The greatest observed fiber bypass of 0.7 mg/L from Sample 1 corresponds to a bypass fraction of 0.26%. This uses a Marinite I fiber content of 9.1% as determined by the SEM analysis. The quantity of fiber bypass decreased over time. An exponential least-squares trend line fits the measurements reasonably well. From the curve equation, the maximum fiber concentration of 0.42 mg/L was obtained by setting the time to zero.

Bypass testing started just after the design basis debris additions were completed. The samples were then repeated at two hours intervals. The sampling showed a consistent exponential decline in bypass for both tests. The peak bypass was calculated to be 0.70%. This is 3 times higher than other samples.

During the September 14, 2009 public phone call, the NRC asked if bypass data during debris addition was available. AECL conducted a review of the sample history and confirmed this data is not available for VCSNS testing. The concern is that bypass fractions are often higher during debris bed build up compared with bypass after the debris bed is formed. Tests with low fiber loading were commissioned by the NRC and documented in NUREG/CR-6885. The following is taken from Table 5-1 of the NUREG for leaf shredded NUKON insulation with 1/16" screen openings.

<u>Velocity</u>	<u>Bypass</u>
0.208 ft/sec	3.92%
0.513 ft/sec	4.31%
1.065 ft/sec	5.09%

This data shows that under low fiber loading conditions, bypass fractions are expected to be less than 5%. The data also shows that as velocity decreases, the bypass fraction also decreases. With a minimum screen size of 2379 ft<sup>2</sup> and flow of 7500 gpm, the velocity for the V.C. Summer screens is less than 0.01 ft/sec. Bypass would therefore be expected to drop below 3.92%.

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### NRC RAI #11 (Cont.)

Fiber bypass plays a negligible role for VCSNS in the component and piping downstream effects when compared to the particulate loading which assumes 100% bypass. For the incore downstream effects evaluation consistent with WCAP-16793-NP, a 5% fiber bypass fraction will conservatively be assumed when the SE is issued. A 5% bypass fraction is conservative compared with the tested 0.7% peak bypass fraction which decreases exponentially. The value is also conservative compared with the generic low fiber loading test data presented in NUREG/CR-6885.



Figure 11-1 Fiber Concentration vs Time – Test V.C. Summer-2

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Figure 11-2 Fiber Concentration vs Time – Test V.C. Summer-3

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### NRC RAI #12

It was not clear that the properties of Marinite sawdust were equivalent to the predicted crushed Marinite. Provide a justification for the use of Marinite sawdust instead of crushed Marinite.

### SCE&G Response:

The Marinite I debris used in the V.C. Summer tests was procured in the powder form as shown in Figure 12-1 The Marinite I powder is sander dust collected from sanding Marinite boards with 53" wide, fiberglass reinforced sand paper belts imbedded with 24 to 50 grit silicon carbide particles. The Marinite I powder contains 4% to 16% fiber by mass according to manufacturer's Material Safety Data Sheet (MSDS).

A sample of Marinite I powder was analyzed using SEM. The following SEM photos (Figure 12-2 and Figure 12-3) clearly show that Marinite I debris used in the tests is a very fine powder and that the majority of the particles are less than 10  $\mu$ m. Also fiber release is clearly shown in the photos.

SEM analysis performed by AECL indicated that fiber release from Marinite I powder had an average diameter of 10 microns and an average length of 37 microns. The fiber length distribution is provided on Table 7-1 in response to RAI #7. The fiber content in the Marinite I test material was determined to be 9.1% by mass. This is greater than the reported fiber content of 5% by mass for the Marinite XL installed at the plant.

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Figure 12-1 Marinite I Powder Used in V.C. Summer Tests

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X3,000 10Mm WD20

e) X 3,000



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#### NRC RAI #13

It was not stated that the test results were extrapolated to the strainer mission time. Results were not provided in a format that showed that the head loss was steady or decreasing at test termination. Provide any extrapolation of test results to the mission time. If the results were not extrapolated provide a justification for the lack of extrapolation. Provide head loss graphs for tests 2 and 3 showing debris additions, test termination, and noting other significant events during the tests.

#### SCE&G Response:

For Test 2, the design basis debris load of latent fiber and particulate debris was added in seven increments starting at approximately 1940 on October 3, 2006 and continuing over a 2 hour period. The head loss increased linearly, stopping when the addition of the last increment was completed as shown in Figure 13-1. The head loss remained stable at 1.9 psid (13 kPa) for 42 min after the addition of the last increment was completed. The test stability criterion was 36 min. (12 turnovers). The next two additions (TempMat debris only) were beyond the latent fiber load and were only intended to determine the maximum fiber accommodation of the sump strainer (i.e. approach to thin bed formation).

As shown in Figure 13-2, the best-fit curve of head loss after the first addition has a negative slope, which means head loss was in a decreasing trend.

For Test 3, as shown in Figure 13-3, after the debris addition, head loss quickly peaked at 3.97 psi (27 kPa). After reaching the peak value, head loss was in a decreasing trend even though two tank floor sweeps were performed. Figure 13-4 shows the best-fit trend of head loss curve has a negative slope, which indicates that the head loss was decreasing.

In both Tests 2 and 3, since the peak head loss was used for strainer performance evaluation and the best-fit head loss trend had a negative slope, there was no need to run the test for the whole mission time.

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Figure 13-1 Test Parameters vs. Time for Test 2

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Figure 13-2 Least-Square Trend Line of Head Loss Curve for Test 2 after the First Debris Addition

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Figure 13-3 Test Parameters vs. Time for Test 3.

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Figure 13-4 Least-Square Trend Line of Head Loss Curve for Test 3.

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### NRC RAI #14

It was not clear that the refueling water storage tank (RWST) volume credited in the water level evaluation was based on a technical specification (TS) minimum RWST level. Please verify that the mass of water credited from the RWST is based on a minimum TS level.

### SCE&G Response:

Yes, the mass of water credited from the RWST is based on a minimum Tech Spec level. The water level evaluation is discussed in Section 3g.3 of the V.C. Summer supplemental response provided in letter RC-08-0031. The RWST minimum injected mass credited is 2,763,276 lbs; which is equivalent to a volume of 44,518.7 ft<sup>3</sup> or 333,023 gallons. This volume is derived from the Technical Specification RWST minimum contained volume of 453,800 gallons. As stated in the supplemental response, instrument uncertainty and instantaneous swap over from injection to recirculation were modeled, thus reducing the injected flow.

### NRC RAI #15

The amount of holdup in the refueling canal was not clearly specified. Specify the amount of holdup in the refueling canal and its drain line. Provide a justification for the assumption that the refueling canal cannot be blocked by debris (as stated in the Upstream Section of the supplemental response).

### SCE&G Response:

The Reactor Building minimum flood level calculation was updated to incorporate a water hold up volume for the Refueling Canal floor, to account for the increase in RB Spray Pump flow rate (discussed in response to RAI #16), and to remove a simplification that resulted in an over conservatism in the RB spray transit holdup volume. The Refueling Canal floor holdup was calculated to be 6978 lbs of water. The net effect of these three changes was no change in RB sump minimum flood level, which remains as follows:

Large Break LOCA	3.42 ft
Small Break LOCA	2.60 ft

Blockage of the Refueling Cavity was addressed in the supplemental response in Section 3I.4 and is provided below.

### 3I.4 Refueling Cavity

The Refueling Cavity is drained by an 8 inch diameter pipe. The drain opening into the pipe is located on the floor level in the cavity at elevation 423 feet, 5.25 inches. The centerline line of the pipe outlet into the normal RB sump (at a location away from the recirculation sump strainers) is 409 feet, 2 inches. There are no valves in the line. During refueling operation, a blind flange is installed to block the drain flow path. Based on the assessment summarized below, a debris interceptor for the Refueling Cavity drain is not required.

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### NRC RAI #15 (Cont.)

A continuous two inch curb is provided around the Refueling Cavity at the 463 ft operating deck elevation. During post-LOCA conditions, this curb prevents water collected on the operating deck (from the spray flow) from entering the refueling cavity. This limits the amount of water that must drain from the refueling cavity through the 8 inch pipe. The curb also prevents wash down of any debris from the operating deck into the Refueling Cavity.

V.C. Summer containment is highly compartmentalized. The shield wall around the S/Gs extends up to the 475 ft, 5 inch elevation on the side facing the Refueling Cavity. The limiting design break at the S/G outlet is at the 431 ft elevation. Debris large enough to block the 8 inch diameter drain is not expected to be carried up and over this elevation difference.

If it were postulated that large debris were to dislodge from the top of the S/G and fall laterally into the Refueling Cavity, it would then have to transport to the 8 inch drain line. The insulation on the S/Gs is reflective metal cassettes. The failure mechanism for cassette located near the top of the S/G is for the cassette buckle to fail and the cassette to break open as it impacts the floor. The Refueling Cavity drain line is located near the containment wall in the fuel transfer channel. This is well away from the S/Gs. Testing has shown that water readily flows through a pile of crumpled reflective metal insulation debris.

Based on teleconferences with the NRC staff a more detailed discussion with an explanation of the layout is needed.

The fibrous debris for V.C. Summer is TempMat used to insulate the Steam Generator Wide Range Level instrument tubes in Loop A and C S/G compartments. The TempMat is located at approximately the 439 ft elevation and above. A review of each loop compartment was completed to detail the grating and tortuous path that large pieces of TempMat would encounter.

The Diamond Power Reflective Metal Insulation (RMI) on the steam generators must also be addressed. The insulation cassettes are very heavy and not expected to be transported vertically. However, the Diamond Power RMI has a very low destruction pressure. The failure mechanism is the latch coming open and the cassette falling to the ground and bursting open. In discussions with the NRC staff on the July 6, 2009 complete blockage of a drain is not expected due to RMI debris, but additional water hold up due to increase flow resistance should be addressed if RMI can get to the drain.

The following sections detail the review of the refueling cavity for potential debris introduction and drain blockage.

- Drain and refueling cavity layout
- Steam generator A TempMat, grating and tortuous path
- Steam generator C TempMat, grating and tortuous path
- RMI Debris Transport and potential for additional water holdup

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### NRC RAI #15 (Cont.)

### Drain and Refueling Cavity Layout

The Refueling Cavity drain is an 8" -150 lb flange located on the 423 ft, 5 ¼ inch elevation in the north section of the Reactor Building. Figure 15-1 is a 3D CAD rendering of the Reactor Building with the Refueling Cavity drain, steam generators and TempMat locations denoted.

For debris to enter the drain location, it would have to fall into the Refueling Cavity and be transported to the drain location. The Refueling Crane is stationed directly above the drain location making it unlikely that anything could fall directly into the drain. This is shown in Figure 15-3.

As discussed in the supplemental response, the Refueling Cavity is surrounded by a two inch curb. There will be no wash down into the cavity.



Figure 15-1 – 3D CAD Rendering of Reactor Building with Refueling Cavity Drain Denoted – TempMat Locations indicated with a star.

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### NRC RAI #15 (Cont.)

#### Steam Generator A TempMat, Grating and Torturous Path

The TempMat in Loop A is located on the bio-shield wall, opposite the refueling canal. There is a vertical run starting at approximately the 439 ft elevation. It extends up to the 457 ft with a horizontal run at that elevation. This is shown (approximately) in Figure 15-2.

To exit Loop A, the TempMat would have to transport up and then around the Steam Generator and out into the canal. Figure 15-3 provides a photo of S/G A loop compartment as seen from the Loop B compartment. The lowest wall elevation of the S/G A cubicle is at the 475 ft elevation. There is a platform across the opening as shown in Figure 15-4. The next platform elevation is at the 482 ft elevation. This is shown in Figure 15-5. The top platform is on the 488 ft elevation. This platform completely encircles the S/G and is shown in Figures 15-6a, 15-6b, 15-6c and 15-6d. There is approximately a 19" to 46" gap between this 488 ft platform and the bio-shield wall (this is the west wall opposite the Refueling Cavity) as shown in Figure 15-6b.

S/G Loop A is also provided with a solid platform at the 457 ft elevation that would restrict flow up S/G cubicle on the Refueling Cavity side. There are two additional platforms on each side of S/G A at the 466 ft 11 inch elevation. Figure 15-7 provides photo of these platforms from below (436 ft elevation) along the north wall of the S/G A cubicle.

The platform and concrete wall on the S/G A cubicle are shown in Figures 15-8a and 15-8b. The location of the TempMat is also included. For a large piece of TempMat to exit the S/G A loop cubicle to the Refueling Cavity it would have to lift vertically to between the 475 ft and 488 ft elevation, then move horizontally around the steam generator. The other path would be to hug the bio-shield wall up through the opening at the 488 ft elevation grating and then move horizontally. These tortuous paths will restrict the transport of large TempMat to the Refueling Cavity and significantly limit the potential for Refueling Cavity drain blockage.

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NRC RAI #15 (Cont.)

Figure 15-2 – A Loop TempMat Approximate Location (Note that Loop walls only shown to 463 ft elevation





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NRC RAI #15 (Cont.)



Figure 15-3 – Photo of S/G A Loop Compartment and Location of Refuel Crane

Refueling Crane parked over the drain location inhibiting direct deposition of debris

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# NRC RAI #15 (Cont.)



Figure 15-4 – S/G Loop A at 475 Ft Elevation – Looking North

Figure 15-5 – S/G Loop A – 482 ft Elevation Looking North



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# NRC RAI #15 (Cont.)

# Figure 15-6a – S/G Loop A – 488 ft – North Wall



Figure 15-6b – S/G Loop A – West Wall (opposite the RF cavity)



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### NRC RAI #15 (Cont.)



# Figure 15-6c – S/G Loop A – 488 ft – South Wall

Figure 15-6d – S/G Loop A – 488 ft – East Wall (next to Refueling Cavity)



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# NRC RAI #15 (Cont.)



# Figure 15-7 – S/G Loop A – North Wall looking up from 436 ft elevation
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## NRC RAI #15 (Cont.)



Figure 15-8a – Platform Elevation Section for Loop A – Looking North

**Refueling Cavity** 

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## NRC RAI #15 (Cont.)



Figure 15-8b – Platform Elevation Section for Loop A – Looking West from Refueling Cavity

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#### NRC RAI #15 (Cont.)

#### Steam Generator C TempMat, Grating and Torturous Path

The TempMat location of the C Loop is on the bio-shield wall, opposite the refueling canal. There is a horizontal run at approximately the 439 ft elevation. Then there is a vertical run up to locations outside the Zone of Influence. This is shown (approximately) in Figure 15-9. Figure 15-10 provides a picture of the 443 ft platform directly above the horizontal section of the TempMat.

To exit the S/G C loop compartment, the TempMat would have to transport up and then around the Steam Generator and out into the cavity. Figure 15-11a provides a photo of S/G C loop compartment as seen from the Loop A compartment. The Loop C compartment wall along the Refueling Cavity goes up to the 488 ft elevation and then angles even higher on the southern portion of the wall. Figure 15-11b provides a photo of S/G C Loop compartment as seen from the 463 ft operating deck, just north of the compartment. The wall which projects out over the 463 operating deck goes up to the 475 ft elevation.

Figure 15-12 shows a small platform at the 467 ft elevation. Though not directly over the TempMat, it does provide another barrier to vertical transport. Figure 15-13a and 15-13b show a large platform at the 488 ft elevation. Figure 15-13a shows the platform directly against the wall over the TempMat installation. Figure 15-13b shows the platform from the bottom, blocking TempMat vertical transport. Another small platform at the 488 ft elevation along the west side is also provided. This can be seen on Figure 15-11a.

The S/G loop C is also provided with a snubber access platform at the 457 ft elevation. This solid platform would restrict flow up the southern side of the S/G cubicle compartment. This is clearly seen in Figure 15-14 showing the platform from the 443 ft elevation.

The platform and concrete wall on the S/G C compartment are shown in Figures 15-15a and 15-15b. The location of the TempMat is also included. For a large piece of TempMat to exit the S/G C compartment to the Refueling Cavity it would have to lift vertically to between the 467 ft and 488 ft elevation, then move horizontally south around the steam generator, then lift vertically again above the top of the steam generator wall around the 500 ft elevation and move west horizontally out to the Refueling Cavity. Any TempMat that moved north horizontally and exited the compartment at the 475 ft elevation to the north would fall to the 463 ft operating deck and not enter the Refueling Cavity. These tortuous paths will restrict the transport of large TempMat to the Refueling Cavity and significantly limit the potential for Refueling Cavity drain blockage. Document Control Desk Attachment I RC-09-0134 Page 74 of 121

## NRC RAI #15 (Cont.)

Figure 15-9 – S/G Loop C Approximate TempMat Locations (Note that concrete wall elevations are only shown to the 463 ft elevation for clarity)



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## NRC RAI #15 (Cont.)

# Figure 15-10 – Platform at the 443 ft Elevation



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## NRC RAI #15 (Cont.)



Figure 15-11a – S/G Loop C Loop Compartment seen from Loop A

Figure 15-11b – S/G Loop C Loop Compartment seen from 463 ft operating deck



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# NRC RAI #15 (Cont.)

# Figure 15-12 - C Loop – 467 ft Elevation on the East Wall (looking north)



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## NRC RAI #15 (Cont.)

Figure 15-13a - C Loop – 488 ft Elevation – East Wall (above TempMat Location, opposite the RF cavity)



Figure 15-13b - C Loop – 467 ft elevation looking up at 488 ft grating



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## NRC RAI #15 (Cont.)

# Figure 15-14 – Loop C – 457 ft Snubber Platform seen from below (443 ft elevation)



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## NRC RAI #15 (Cont.)



## Figure 15-15a – Platform Elevation Section for Loop C – Looking South

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## NRC RAI #15 (Cont.)



Figure 15-15b – Platform Elevation Section for Loop C – Looking East from Refueling Cavity

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#### NRC RAI #15 (Cont.)

#### RMI Debris Transport and Potential for Additional Water Holdup

The Diamond Power Reflective Metal Insulation (RMI) has a large Zone of Influence, so theoretically RMI cassettes could be dislodged from the Steam Generator at elevations above the loop compartment walls. Each loop is considered separately for the potential of cassettes and RMI debris from entering the refueling cavity.

For Loop A, the wall to the north as shown in Figure 15-3 is above the steam generator and RMI and would preclude RMI cassettes from falling towards the drain location. For an RMI cassette to enter the refueling canal it would have to fall over the loop compartment. The loop compartment projects about 5 to 6 feet away from the steam generator. If the RMI cassette cleared the loop compartment, it could fall into the refueling canal, but at a location well away from the 8" drain line.

For Loop B, the compartment is on the south end of the Reactor Building. The RMI debris would again have to clear the loop compartment and project out horizontally. The reactor head missile shield would provide an impediment for debris transport. Also, the flow rate on the floor at this location is minimal since it is the furthest from the drain location, as shown on Figure 15-1.

For Loop C, the wall facing the refueling cavity is at a higher elevation as shown in Figure 15-11a. This leaves only a small section at the 488 ft elevation (52 feet above the break location) that RMI debris could theoretically leave the loop compartment. Again, the RMI cassette would have to project out horizontally approximately 5 to 6 feet to clear the loop compartment wall. RMI cassettes from Loop C would not fall into the refueling canal. There is a 9 ft 6 inch wide platform at the 463 ft elevation between the Loop C compartment and the refueling canal. RMI cassettes would fall to this area from Loop C. There is a 2 inch curb as noted in the supplemental response that will preclude RMI debris from entering the refueling canal.

There is a low probability RMI debris will enter the refueling cavity. If by some unlikely chance a cassette projected out over the Loop A compartment, from here the RMI would have to transport based on water in the cavity (at that location) due to spray flow.

From this location, large stainless steel pieces of RMI adequate to block off the 8 inch drain line are not expected to transport. Smaller pieces of RMI may transport depending on the water depth in the refueling canal. If the small pieces of RMI transport to the 8 inch drain, they would not block flow at the drain opening by themselves. The RMI debris would fall into the drain piping. Small RMI debris have been shown to transport at less than 0.5 ft/sec.

The drain line has two horizontal runs (at the 422 ft and 409 ft elevations) and no high points or goose necks that could trap RMI debris. The flow in the 8 inch drain line pipe is 712.8 gpm or 1.59 ft<sup>3</sup>/sec. The flow velocity is 4.6 ft/sec. This is more than adequate to sweep the small RMI pieces through the drain line.

The drain line empties into the normal reactor building sump at the 409 ft elevation. The top of the normal reactor building sump is on the 412 ft floor elevation. The normal reactor building sump is 5 ft x 5 ft with the bottom at the 401 ft elevation. Small RMI debris would fall to the

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#### NRC RAI #15 (Cont.)

bottom of the sump. The volume beneath the refueling cavity drain line is approximately 187 ft<sup>3</sup> (5 ft x 5 ft x [408.5 ft - 401 ft]). This is depicted in Figure 15-16.

The volume is converted to an area of 2.5 mil stainless steel foil based on the Utility Resolution Guidance (URG) Volume 2, Appendix B (Ref. 15-1).

Area = Volume / K<sub>t</sub>

From Table B-2 (Ref. 15-1), the K<sub>t</sub> factor is 0.015, so 187 ft<sup>3</sup> is equivalent to 12,467 ft<sup>2</sup> of RMI debris for 2.5 mil foil. From Table 3 of the V.C. Summer supplemental response, a total of 47,577 ft<sup>2</sup> of RMI debris may be generated from the limiting Loop A break. The only theoretical RMI debris source for the Refueling Cavity is the Loop A Steam Generator above the 475 ft elevation, facing the cavity. This is less than  $\frac{1}{4}$  of the Steam Generator surface and substantially less than  $\frac{1}{4}$  of the total RMI generation.

Based on this discussion, a debris interceptor or cage over the refueling cavity drain is not required for RMI debris. Any RMI that reaches the drain will be swept through the pipe into the normal RB sump pit. There will be no additional holdup in the refueling cavity due to increased flow resistance.

#### **Reference for RAI #15**

15-1 Utility Resolution Guidance for ECCS Suction Strainer Blockage, Volume 2, October 1998 (Appendix B)



Figure 15-16 Normal RB Sump Showing Refuel Cavity Drain Line

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#### NRC RAI #16

A technical basis for the pump flow rates was not provided. Provide the basis for the flow rates used in the net positive suction head (NPSH) evaluation. For example, are the flow rates based on pump runout or are they based on a calculated value? If the value was calculated, provide the methodology, assumptions, and inputs used in the evaluation.

#### SCE&G Response:

The pump flow rates used in the Debris Transport analysis and NPSH calculations are discussed in Supplement Response Section 3g.2. The flows are repeated here for clarity.

RHR Pump Flow Rates		
Single Train Operation	Analytical Maximum	NPSH Flow Assumption
	(Ref. 2)	(Ref. 3)
RHR Pump A	4290 gpm	4500 gpm
RHR Pump B	4196 gpm	4500 gpm
Two Train Operation	Analytical Maximum	Debris Transport Flow
	(Ref. 1)	Assumption (Ref. 4)
RHR Pump A	3669 gpm	4288 gpm
RHR Pump B	3590 gpm	4288 gpm

The RB Spray Pumps have separate spray headers. The pumps do not interact when both trains are operating. The individual pump flow rate is the same for one pump and two pump operation. The maximum RB Spray Pump flow is 3000 gpm per operating pump.

The total recirculation flow rate used in the Debris Transport for two trains operating is 14576 gpm (4288 + 4288 + 3000 + 3000). The total recirculation flow rate used in the NSPH calculation for a single sump strainer is 7500 gpm (4500 + 3000).

The maximum RHR Pump recirculation flow rate calculation was completed in 2006 by Westinghouse using the Fathom computer code. Pertinent modeling and design input are:

- 1. The model development used current piping isometrics and component data.
- 2. For the maximum flow rates, the model was bench marked against startup test data. This conservatively lowers system resistance to maximize flow.
- 3. The RHR Pump maximum allowable performance curve was used. RHR Pump performance within this allowable maximum is confirmed via surveillance testing in support of Technical Specification requirements.
- 4. The Reactor Coolant System and Reactor Building pressure are equal.
- 5. The Reactor Building sump water level is set to a maximum depth (420 ft elevation).
- 6. Head loss across the sump strainer is assumed to be 0 psig to conservatively reduce system resistance.

In summary, the RHR Pump maximum flow rates for post-LOCA recirculation were calculated with the same conservative bounding methodologies used for RHR Pump performance in FSAR Chapters 6 and 15 analyses.

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#### NRC RAI #16 (Cont.)

During the course of the RAI resolution, a difference between the RB Spray Pump curve used in the system design calculation and the vendor certified calculation was noted. Further investigation identified a historical calculation which increased maximum RB Spray Pump flow rate during post-LOCA recirculation (due to the pump curve change) that was not reflected in the historical NPSH calculation. The maximum RB spray Pump flow rate during post-LOCA recirculation. The maximum RB spray Pump flow rate during post-LOCA recirculation. The maximum RB spray Pump flow rate during post-LOCA recirculation has now been appropriately documented (as described below) and has increased from 3000 gpm to 3300 gpm. The impact of this flow increase is also addressed in this RAI response.

The maximum Reactor Building Spray Pump flow rate calculation was recently updated. The calculation does not rely on computer hydraulic modeling. The system resistance curve is plotted against the Reactor Building Spray Pump maximum performance curve, accounting for elevation differences. The curve intersection yields the flow rate. Pertinent modeling and design input are:

- 1. Pipe, piping fitting and valve head losses were reduced by 20% to allow for conservatisms in the literature values.
- 2. The Reactor Building Spray Pump maximum allowable performance curve was used. Reactor Building Spray Pump performance within this allowable maximum is confirmed via surveillance testing in support of Technical Specification requirements.
- 3. The Reactor Building sump water level is set at the 416 ft elevation. This is slightly greater than the water depth used in the NPSH calculations and Computational Fluid Dynamics modeling and remains conservative for the analysis.
- 4. Head loss across the sump strainer is assumed to be 0 psig to conservatively reduce system resistance.

In summary, the Reactor Building Spray Pump maximum flow rates for post-LOCA recirculation were calculated with the same conservative bounding methodologies used for Reactor Building Spray Pump performance in FSAR Chapters 6 and 15 analyses.

This Reactor Building Spray Pump flow rate increase is within the margin included in both the strainer testing program and the Debris Transport calculations. The strainer tests were carried out at 7500 gpm to reflect single train operation which increases RHR Pump flow rate. The maximum calculated flow through each strainer is shown below (note that RHR Pump flow rates are rounded up for simplification).

	Train A	Train B
RHR Pump Flow	4300 gpm	4200 gpm
RB Spray Pump Flow	3300 gpm	3300 gpm
Total Flow	7600 gpm	7500 gpm

The Train B strainer is significantly smaller and was used for the test scaling. The approach velocity for each strainer and the test module are shown below.

#### NRC RAI #16 (Cont.)

	Train A	Train B	Test Module
Total Flow Rate	7600 gpm	7500 gpm	1201 gpm
Total Flow Rate	16.93 ft <sup>3</sup> /sec	16.71 ft <sup>3</sup> /sec	2.68 ft <sup>3</sup> /sec
Total Surface Area	2939 ft <sup>2</sup>	2379 ft <sup>2</sup>	357 ft <sup>2</sup>
Sacrificial Area	150 ft <sup>2</sup>	150 ft <sup>2</sup>	0 ft <sup>2</sup>
Total Flow Area	2789 ft <sup>2</sup>	2229 ft <sup>2</sup>	357 ft <sup>2</sup>
Flow velocity	0.00607 ft/sec	0.0075 ft/sec	0.0075 ft/sec

The flow velocity through the strainer fins for both trains stays within the flow velocity used in the strainer test.

The Computational Fluid Dynamics (CFD) Model calculation total flow rate is 14,576 gpm or 7288 gpm per train assuming two trains operating to maximize flow rate and transport velocities. A comparison of the CFD flows and the update flow is as follows:

Pump	Used in the CFD Model	Updated Flow Rate	Difference	Percent Difference
RHR Pump A (Break Flow)	4287.5 gpm	3669 gpm	1 210	45 20/
RHR Pump B (Break Flow)	4287.5 gpm	3590 gpm	-1,316 gpm	-15.3%
Spray Pumps	6000 gpm	6600 gpm	600 gpm	10.0%
Total Flow	14,575 gpm	13,859 gpm	-716 gpm	-4.9%

The increase in Spray Pump flow is offset in all areas by the decrease in break flow except for possibly wash down of some debris types from upper containment. (Note: The transport of fines from upper containment is 100% regardless of spray flow rate or location.) Three wash down locations are modeled as shown on Figure 16-1 (Note: This was Figure 2 in the Supplemental Response).

- 1. The southern stairwell is adjacent to the Train A sump and has a transport fraction to Train A of 0.54 for all debris types based on area outside the bio-shield wall. The increase in RB Spray flow has no impact.
- 2. The eastern stairwell is well outside the flow stream to the sump strainers (which are located in the southern and western portions of the containment). The transport fraction is zero and will remain zero.
- 3. The equipment hatch is located in the south eastern side of the Reactor Building. Increasing the spray flow rate increases the drain down flow and, therefore, increases the localized turbulence.
  - a. For small fiber clumps and curled paint chips there is no impact since Debris Transport is already 100% from the equipment hatch.
  - b. For large fiber, reflective metal insulation, 2" flat paint chips and 1/8" flat paint chips there is no impact. These debris types have a large quiet area with no transport between the equipment hatch and sump area. Debris will continue to settle out before reaching the strainer.

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#### NRC RAI #16 (Cont.)

c. For 1/64" flat paint chips, there is a mix of results. For a break modeled in the A loop, the transport fraction is 100% from the equipment hatch to Train A strainer. For breaks modeled in the B and C loops, the transport fraction is 0%. However, the quiet zone of no transport is relatively small. For conservatism, the Debris Transport fraction is set to 100% for 1/64" flat paint chips for all three loop break locations to account for the increase in spray flow. There is no net impact on debris loading at the Train A strainer. The A Loop break location continues to bound the B and C Loop break location debris loadings. The transport fraction to Train B strainer remains 0%.

The NPSH calculations for both the RB Spray Pumps and the RHR Pumps were updated to reflect the change in the flows. The following table supersedes Table 17 of Section 3g.4 of the supplemental response. Also note that the strainer pressure drop was updated to 3.15 psi at 104°F as covered in response to RAI #10.

NPSH Margin – No Credit for Subcooling of sump water						
Pump	Flow rate	NPSH	NPSH	NPSH	Temperature	
·		Required	Available	Margin		
RHR Pump A	4300 gpm	17 ft	18.8 ft	1.8 ft	70°F	
RHR Pump A	4300 gpm	17 ft	26.4 ft	9.4 ft	212°F	
RHR Pump B	4200 gpm	16 ft	19.4 ft	3.4 ft	70°F	
RHR Pump B	4200 gpm	16 ft	27.0 ft	11.0 ft	212°F	
Spray Pump A	3300 gpm	17 ft	20.7 ft	3.7 ft	70°F	
Spray Pump A	3300 gpm	17 ft	28.3 ft	11.3 ft	212°F	
Spray Pump B	3300 gpm	17 ft	20.2 ft	3.2 ft	70°F	
Spray Pump B	3300 gpm	17 ft	27.8 ft	10.8 ft	212°F	

The increase in Reactor Building Spray Pump maximum flow rate during post-LOCA recirculation was captured in the Corrective Action Program to ensure all impacts are evaluated and documented.

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## NRC RAI #16 (Cont.)

## Figure 16-1

CAD Model with Spray Drainage, Break Locations and Sump Locations



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#### NRC RAI #17

A technical basis for the NPSH required (NPSHr) for each pump was not provided. Please provide the basis for the NPSHr values used in the evaluation (e.g., is the NPSHr based on a 3 percent decrease in discharge head or some other acceptance criterion?).

#### SCE&G Response:

The NPSH required (NPSHr) for the RHR Pumps is taken directly from the vendor certified performance curves which covered a range of data points up to 4500 gpm. Procurement specifications for RHR Pump NPSH testing invoked the Hydraulic Institute guidelines.

The NPSH required test for the Reactor Building (RB) Spray Pumps was similarly based on the Hydraulic Institute guidelines, but was only tested at one data point (2520 gpm design flow) as required by the Procurement Specification. The NPSH required is 9.4 ft (Train A) and 10.1 ft (Train B). The required NPSH at 3300 gpm is based on comparison with the vendor characteristic curve for the pump and impeller size.

Flow Rate	Train A	Train B	Characteristic Curve	Difference
2520 gpm	9.4 ft	10.1 ft	14.5 ft	4.4 ft
3300 gpm	17 ft	17 ft	20.3 ft	3.3 ft

Based on this comparison, 17 ft is used for the NPSH required at 3300 gpm for both RB Spray Pumps.

#### NRC RAI #18

An evaluation of NPSH margin during hot-leg recirculation was not provided. If the maximum flow rate is not based on pump runout, provide the maximum flow rate during hot-leg recirculation. Include the methodology, assumptions, and inputs used to determine the flow rate.

#### SCE&G Response:

V.C. Summer initially aligns the Safety Injection System for recirculation with the RHR Pumps and Charging Pumps delivering flow to the Reactor Coolant System cold legs. These flows are presented on Table 16 of the Supplemental Response (4290 gpm for Train A and 4196 gpm for Train B). At approximately 8 hours following switchover from injection from the RWST to Cold Leg Recirculation from the sump, the system is realigned for simultaneous Hot Leg and Cold Leg recirculation. Two system alignments are possible. The preferred alignment included in the Emergency Operating Procedures is for the Charging pumps to deliver flow to the hot legs and the RHR Pumps to remain aligned to the cold legs. The calculated flows for this alignment are 4148 gpm (Train A) and 4134 gpm (Train B) assuming only one RHR Pump and one Charging Pump are operating). These flows are slightly less than those presented in Table 16 of the Supplemental Response for Cold Leg recirculation. The alternative alignment is for the RHR Pumps to deliver to the Reactor Coolant System hot legs and the Charging Pump to deliver to the cold leas. This alignment is not specifically proceduralized, but is allowable under engineering guidance during post-LOCA long term cooling. The RHR Pumps are only provided with two 6 inch hot leg injection lines (as opposed to three 6 inch cold leg injection lines). The RHR flows were not specifically calculated for this alternate alignment; however, with the

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#### NRC RAI #18 (Cont.)

discharge header resistance significantly higher (only 2 injection lines instead of 3), the pump flow will be lower. In all cases, the Cold Leg recirculation flow rates presented in Table 16 of the Supplemental Response are bounding.

#### NRC RAI #19

The 2004 Edition of the American Society of Mechanical Engineers (ASME) Code is not currently endorsed in the Title 10 of the *Code of Federal Regulations* (10 CFR). Provide justification and/or re-evaluation for discrepancies, if any, between the applicable portions of the 2004 Edition of the ASME Code which were used in the analysis and the respective Code Editions which are currently endorsed by the NRC in 10CFR50.55a.

#### SCE&G Response:

10CFR50.55a currently endorses the 2004 Edition of the ASME Code. The analysis used portions of the ASME Code, Section III, Subsection NF (Class 3), 2004 edition with 2005 addenda. For the portions of Subsection NF used in the analysis, there are no discrepancies between the 2004 edition and the 2005 addenda.

#### NRC RAI #20

The licensee's submittal stated that current VCSNS LOCA dose calculations are required to assume the passive failure of a high-head safety injection (HHSI) pump seal at 24 hours after the event with isolation of the leak in 30 minutes. To eliminate the need for assuming a pump seal failure, Section 3p of the licensee's supplemental response stated that the licensee would be preparing an Alternate Source Term (AST) dose analysis and would be submitting an AST license amendment. The licensee stated that if it could avoid the assumption of a HHSI pump seal failure at 24 hours, there would be no need to replace the pump's carbon/graphite disaster bushing. A March 18, 2008 letter from the South Carolina Electric and Gas Company to the NRC, confirmed the licensee's commitment to submit the AST amendment, and the licensee's letter dated December 10, 2008, indicated that this submittal would be made in a projected time frame of February, 2009. The licensee should either (1) obtain NRC approval of an AST amendment, or (2) satisfactorily address the radiological effects of failure of the high-head safety injection pump seal, potentially through replacement of that pump's carbon/graphite disaster bushing.

#### SCE&G Response:

SCE&G submitted the License Amendment Request for AST on February 17, 2009 in our letter RC-09-0004 (ADAMS Accession No. ML090720887).

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#### NRC RAI #21

The licensee stated that the debris loading expected during post-LOCA conditions may cause the high head safety injection [HHSI] pump seals to exceed the accepted 50 gallon per minute (gpm) leak rate and that the carbon/graphite disaster bushings in the pump seals may also not limit pump seal leakage to 50 gpm if the primary seal fails. The submittal stated that a more robust replacement pump seal assembly is not available.

- a. Confirm that the expected seal leakage does not diminish the pump(s) capacity below that required to accomplish the pumps design function.
- b. Confirm that the expected pump seal leakage is accounted for in the compartment flooding evaluation.

#### SCE&G Response to 21a:

Each of the six pumps circulating post-LOCA sump water is provided with two seals. The primary seal of each pump has been demonstrated to meet the 40-day mission time for V.C. Summer based on the methodologies contained in WCAP-16406-P. The second seal is a backup seal with carbon-graphite bushings. The backup seal is provided to limit seal leakage to 50 gpm if the primary seal were to fail. As covered in WCAP-16406-P, these bushings could not be demonstrated to meet a post-LOCA mission time. However, the backup seal is not relied upon unless there is a primary seal failure.

The licensing basis for post-LOCA recirculation is either one Active Failure or one Passive Failure. Assuming the Passive Failure is a pump primary seal, that pump may leak more than 50 gpm. With the failure of the primary seal, the operators would stop the pump once the leak was identified. The redundant pump, which is already running and is 100% capacity, would meet the analysis flows. Reduced performance of a pump with a failed seal is not a concern.

#### SCE&G Response to 21b:

The RHR pumps and Reactor Building Spray pumps are located on the 374 foot elevation of the Auxiliary Building. Each pump is within its own room with an 8.5 inch curb across the door way. The maximum calculated flood level on the Auxiliary Building 374 foot elevation is 9.4 inches. This is based on a Feedwater line rupture at a higher elevation that flows down to the 374 foot elevation. The flow rate of this rupture is over 10,000 gpm and bounds any potential leakage out a failed pump seal for both the RHR pump and Reactor Building spray pump.

The Charging pumps are located on the 388 foot elevation of the Auxiliary Building. Each Charging pump is in its own room with a 6 inch curb in the door way. A postulate pipe rupture within the Charging pump cubicle results in the maximum flood level of 6 inches. The flood level in the general floor area of the 388 foot elevation of the Auxiliary Building is 4.7 inches. This is based on 2862 ft<sup>3</sup> draining from a higher elevation. This represents a pipe rupture leak rate of over 700 gpm (2862 ft<sup>3</sup> x 7.48052 gal/ ft<sup>3</sup> / 30 minutes). This bounds any potential leakage out a failed pump seal for the Charging pump which has a run out flow of 688 gpm.

Note that a pipe rupture considered for flooding is not assumed to occur simultaneously with a LOCA and post-accident long term recirculation. The pipe rupture leakage rate is not added with a failed seal leakage rate.

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#### NRC RAI #21 (Cont.)

As noted in response to RAI #21a, the primary seals meet the 40-day mission time for V.C. Summer. Therefore, only one primary pump seal failure need be postulated based on the single failure criteria for evaluating flood levels.

#### NRC RAI #22

The licensee used coating abrasion data extracted from Westinghouse Commercial Atomic Power (WCAP)-16571-P, "Test of Pump and Valve Surfaces to Assess the Wear from Paint Chip Debris Laden Water," Rev. 0, to supplement erosion data in the erosion calculations. The NRC has not evaluated this WCAP. Submit data extracted from WCAP-16571-P pertinent to the wear evaluations, including information used to support the validity of the data.

#### SCE&G Response:

In addition to the following discussion, SCE&G will schedule a meeting with the NRC reviewer at the Westinghouse Rockville area office to provide direct access to WCAP-16571-P.

#### Background

In Generic Safety Issue GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance," the NRC required licensees to address the effects of ingesting debris into the Emergency Core Cooling (ECC) and Containment Spray (CS) systems following the postaccident realignment of those systems to recirculate coolant from the containment sump. The effects of debris on equipment and components downstream of the sump screen are referred to as "downstream effects" and the evaluation of those components is referred to as "downstream effects evaluations." Abrasive wear is the removal of material due to particles that move between two surfaces that are in close proximity and in relative motion. This type of wear affects certain components within pumps, such as wear rings, internal bearings, etc. On the other hand, erosive wear is the wear associated with particles striking a fixed surface. In general, the abrasive wear rate is greater than the erosive wear rate for a given concentration of debris. A method of evaluating downstream effects was described in WCAP-16406-P (Reference 22-1). Components exposed to debris can wear in two ways: pump running clearance wear by abrasion and valve, orifice and heat exchanger wear by erosion.

Abrasive and erosive wear models were described in Reference 22-1. The models were based on available data generated from early equipment testing of original equipment supplied to plants, and literature data based on slurry transport. Specifically, wear testing of components with entrained debris (Reference 22-1) included the following debris mix:

- 1. Abrasives: sand, concrete, and glass
- 2. Fibers
- 3. Protective coatings

No attempt was made in the tests to characterize the wear behavior by debris type. Thus, all of the debris types were treated as being equally abrasive.

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#### NRC RAI #22 (Cont.)

Debris generation and transport evaluations performed by and for licensees to address GSI-191 have shown that protective paint coatings debris is generally a major contributor to the debris source term that is passed through the containment sump screen. The concentration of paint coatings debris usually dominates the other debris mix or constituents and consequently contributes significantly to the wear of components using the Reference 22-1 model. While paint coatings debris is not thought to be as abrasive or erosive as sand, concrete or glass, there is minimal data available to Westinghouse to demonstrate the actual abrasive or erosive properties of paint coatings debris. To confirm our intuition, Westinghouse developed a test program to obtain abrasive and erosive wear data associated with protective paint coatings debris. The results of this test program are documented in WCAP-16571-P (Reference 22-2), and summarized below.

#### Summary of WCAP-16571-P

WCAP-16571-P documents testing performed on paint coatings to establish the wear characteristics of paint coatings. Below is the test summary:

- A test loop was constructed that circulated paint chip laden water in a closed pumped loop.
- A debris loading mix of inorganic zinc (IOZ) (≈ 11%), epoxy (≈ 80%), alkyd (≈ 8%) and acrylic (≈ 1%) paint coatings was used. The concentrations of 920 ppm and higher were tested. This debris loading also had an approximately even split between large and small particles, as defined by Reference 22-1. The debris mix is highly dominated by IOZ and epoxy, and has a low concentration of acrylic paint coatings (less than 0.5% of the total). A constant debris concentration was maintained for the tests.
- To accelerate the wear test, the test specimens were fabricated from pure aluminum of known hardness and stainless steel 300 series of known hardness to determine wear when exposed to debris laden fluid. The fixtures included simulated pump wear rings and a flat plate orifice plate.
- The duration of each test was approximately 24 hours.
- Wearing of the aluminum fixture was observed and could be measured, but minimal wearing was observed on the stainless steel fixture reflecting the fact that the hardness of pure aluminum is less than the hardness of the stainless steel 300 series. The amount of wear measured for the aluminum fixture was far less than would be predicted using the Reference 22-1 model, showing that the wear due to the softer paint coatings is less than other typical debris materials such as glass, concrete and fiber.
- Applying the methodology of Reference 22-1 on the measured wear, a paint coating specific model was developed. This is documented in Reference 22-2.

In WCAP-16571-P, it is shown that wear from paint coatings is not as erosive as sand, concrete or glass, which was the basis of the wear model in Reference 22-1. From the test data, a wear

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#### NRC RAI #22 (Cont.)

model was developed in Reference 22-2 for the erosive effects of paint coatings, which is patterned after the wear model in Reference 22-1. The resultant paint coatings wear model could then be used for the erosive effects of paint coatings in debris laden fluid, separately from the Reference 22-1 model, which is to be used for all other types of debris. By taking credit for the testing that was performed, the Reference 22-2 erosive wear model is an enhanced version of the Reference 22-1 wear model that takes into account the diminished erosive effects of paint coatings as compared to sand, concrete and glass. The Reference 22-2 erosive wear model utilized the same equation as Reference 22-1, except that the exponents on the concentration and hardness are adjusted to diminish the effects from those variables.

#### Applicability of WCAP-16571-P to V.C. Summer

In February of 2008, an evaluation (Reference 22-3) was performed for V.C. Summer to determine the erosive effects of debris laden fluid on valves in the ECC and CS systems. In this evaluation, it was determined that the critical valves are the ECC system injection line throttle valves, due to the fact that these valves are typically partially closed, causing high velocities through the close clearances of the valve internals. For the erosive wear models in References 22-1 and 22-2, velocity is a squared term, so high velocities through the valve would tend to increase the wear rate of the surfaces exposed to a debris laden fluid.

In the Reference 22-3 evaluation, the debris loading that is assumed to be introduced to the ECCS system and used for the calculations in the evaluation is highly dominated by paint coatings ( $\approx 85\%$  of total debris). For this reason, it was determined that it was appropriate to use the Reference 22-2 model to calculate the wear rate due to paint coatings, and use the Reference 22-1 model for the remainder of the debris loading ( $\approx 15\%$ ).

In reviewing References 22-1, 22-2 and 22-3, it was determined that the use of the Reference 22-2 wear rate model for paint coatings for the V.C. Summer downstream effects evaluations is justifiable for reasons outlined in Table 22-1.

Thus, the wear of the V.C. Summer downstream valves (Reference 22-3) was evaluated as follows:

$$W_{VCS} = W_{Coatings} + W_{Non-Coatings}$$

where,

 $W_{VCS} = V.C.$  Summer Total Valve Wear

 $W_{Coatings}$  = Wear due to Paint Coatings Debris (Reference 22-2 Model)

 $W_{Non-Coatings}$  = Wear due to Non-Paint Coatings Debris (Reference 22-1 Model)

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## NRC RAI #22 (Cont.)

Basis	Reference 22-1	Reference 22-2	Reference 22-3
Test Fixtures Used	Carbon Chrome Tungsten Carbide	Aluminum Stainless Steel	N/A
Duration of Each Test	≈ 6 hours	≈ 24 hours	N/A
Debris Mix (by weight)	65% abrasives (concrete and glass) 22% fibrous insulation 13% paint coatings	Only paint coatings 99.5% Epoxy/Inorganic Zinc (IOZ)/Alkyd 0.5% Acrylic More than 50% of debris sized as large particles (> 400 µm)	14.8% abrasives 0.1% fibrous insulation 85.1% paint coatings (Epoxy/IOZ/Alkyd) Approximately 80% of the paint coatings are small particles (< 100 μm)
Treatment of Debris	Abrasive effects of debris are weighted equally, regardless of debris type.	Only paint coatings were tested. Reference 22-1 wear model was used as a basis, and a paint coatings specific model was developed to account for the reduced wear effects of paint coatings, as compared to other types of debris.	Abrasive and fibrous debris were evaluated using the Reference 22-1 wear model, while paint coatings were evaluated using the Reference 22-2 wear model. This is applicable as debris mixes are very similar, and constituent sizes are smaller at V.C. Summer than was used in the Reference 22-2 testing.
Results of Testing	Carbon fixture wore excessively, no wear seen in chrome and tungsten carbide fixtures. Wear model seen in Reference 22-1 developed from this testing.	Wearing of Aluminum fixture seen, no wear seen in stainless steel fixture. The amount of wear measured for the aluminum fixture was far less than would be predicted using the Reference 22-1 model, showing that the wear due to the softer paint coatings is less than other materials such as glass, concrete and fiber. Wear model for paint coatings seen in Reference 22-2 developed from this testing.	N/A

## Table 22-1: Applicability of Reference 2 Wear Model

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#### NRC RAI #22 (Cont.)

#### Table 22-1: Applicability of Reference 2 Wear Model (Cont.)

Basis Reference 22-1		Reference 22-2	Reference 22-3
Regulatory Review	Approved by the NRC	Not reviewed, but Reference 22-2 wear model is based on approved Reference 22-1	N/A

#### **References for RAI #22**

- 22-1 WCAP-16406-P-A Revision 1, "Evaluation of Downstream Sump Debris Effects in Support GSI-191," March 2008.
- 22-2 WCAP-16571-P Revision 0, "Test of Pump and Valve Surface to Assess the Wear from Paint Chip Debris Laden Water For Wolf Creek & Callaway Nuclear Power Plants," July 2006 [Proprietary Class 2].
- 22-3 CN-CSA-05-104 Revision 2, "V.C. Summer (CGE) Sump Debris Downstream Effects Evaluation for ECCS Valves," February 2008.

#### NRC RAI #23

The NRC staff considers in-vessel downstream effects to not be fully addressed at VCSNS, as well as at other PWRs. The licensee's supplemental response refers to WCAP-16406-P which is not recognized by the NRC for addressing in-vessel downstream effects. Westinghouse has prepared WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid" to address in-vessel downstream effects. Further, the NRC staff has not issued a final safety evaluation (SE) for WCAP-16793-NP. Therefore, the licensee may demonstrate that in-vessel downstream effects issues are resolved for VCSNS by showing that the licensee's plant conditions are bounded by the final WCAP-16793-NP and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE. The licensee may alternatively resolve this item by demonstrating, without reference to WCAP-16793-NP or the staff SE, that in-vessel downstream effects have been addressed at VCSNS. In any event, the licensee should report how it has addressed the in-vessel downstream effects issue within 90 days of issuance of the final NRC staff SE on WCAP-16793-NP. The NRC staff is developing a Regulatory Issue Summary to inform the industry of the NRC staff's expectations and plans regarding resolution of this remaining aspect of Generic Safety Issue-191.

### SCE&G Response:

SCE&G is a part of the WOG program developing WCAP-16793-NP and has supplied debris loading to Westinghouse. SCE&G will demonstrate that in-vessel downstream effects issues are resolved for V.C. Summer by showing that V.C. Summer conditions are bounded by the final WCAP-16793-NP and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE. This response will be supplied within 90-days of the NRC SE on the WCAP-16793-NP.

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#### NRC RAI #24

Provide a detailed technical basis to support the conclusion that aluminum hydroxide is not expected to precipitate in the VCSNS sump water. This information should include the assumed post-LOCA temperature profile as a function of time. Indicate why the assumed temperature profile is the most limiting when considering the amount of dissolved aluminum in the sump water and the solubility of aluminum as a function of temperature at the assumed pH.

#### SCE&G Response:

While the SCE&G position remains that due to the low concentrations of corrosion products plant specific head loss testing should not be required, SCE&G agrees to perform a single chemical effects head loss test. This test will be carried out at the AECL facilities consistent with previously approved chemical effects tests by AECL. SCE&G will communicate with the NRC prior to testing including the proposed test protocol. The NRC may witness the test (or portions thereof) at their discretion.

Due to the similarity of the topics, a single set of References is provided for RAI #24, #25 and #26. These are provided following RAI #26.

Aluminum hydroxide (Al(OH)<sub>3</sub>) may exist in an amorphous form or as one of three crystalline forms: gibbsite, bayerite, or nordstrandite<sup>1</sup>. Various forms of AlOOH (boehmite, diaspore, or pseudoboehmite) could also precipitate, but gibbsite is thermodynamically most stable and other metastable phases can be changed to gibbsite through aging. The precipitation of these aluminum crystalline phases depends on their solubility in solution.

The solubility of gibbsite in non-borated water as a function of temperature at various pH values (Figure 24-1) was calculated from thermodynamic data reported by Wesolowski [6] [1992]. The solubility of gibbsite under these conditions is a weak function of temperature, decreasing by a factor of about 10 as the temperature is decreased from 100°C to 25°C at pH 10. However, the solubility of gibbsite is a very strong function of pH. For example, at 50°C, the solubility drops by a factor of ~300 when the pH is lowered from 10 to 6.5.

The temperature and pH dependencies of the solubilities of bayerite, diaspore and boehmite [Benezeth et al., 2001[7]; Apps et al., 1988[8]] are similar to that of gibbsite although bayerite has the highest solubility relative to the other three aluminum phases at the same pH (Figure 24-2). The solubilities of all of these compounds in non-borated water are very low; for example, at pH 7 and below 100°C, the solubilities of all four compounds are less than 0.1 mg/L below.

The solubility of amorphous aluminum hydroxide is much higher than that of the crystalline forms. Park et al. [9] [2006] reported a  $K_{sp}$  value<sup>2</sup> of  $8.0 \times 10^{-13}$  for the amorphous phase at 25°C; this value is approximately 400 times larger than the solubility of gibbsite at the same temperature, which is consistent with the high measured aluminum concentrations in ICET Test 1.

<sup>&</sup>lt;sup>1</sup> There is a fourth, rare polymorph, doyleite, that has a slightly different structure than the other three forms, but is not considered important in this context.

<sup>&</sup>lt;sup>2</sup> This value was taken from Van Straten and de Bruyn [10] [1984].

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#### NRC RAI #24 (Cont.)

The amphoteric property of aluminum hydroxide makes it dissolve readily in strong acids and bases. Figure 24-3 shows the dissolved species of gibbsite as a function of pH at 50°C. In acidic solutions, the dominant species of aluminum hydroxides is  $AI^{3+}$ . Over the pH range 4 to 9, a small change in pH towards the neutral point results in rapid and voluminous precipitation of colloidal aluminum hydroxide, which readily forms a gel containing considerable excess water and variable amounts of anions. The gel composition and properties depends largely on the method of preparation and can crystallize on aging. Above pH 9, the dominant aluminum species in solution is hydrated aluminum ion,  $AI(OH)_4^-$  (Figure 24-3).





#### Precipitation of Aluminum Hydroxide

The precipitation of aluminum hydroxide phases from supersaturated aluminate solutions has been studied by a number of groups (e.g., Van Straten and De Bruyn [10] [1984; Vermeulen [11] [1975]). Wesolowski [6] [1992] noted that approach to equilibrium from supersaturated aluminum solutions can be very slow (15–90 days); the formation of a metastable surface or bulk phase with a higher solubility than gibbsite was suggested.

<sup>&</sup>lt;sup>3</sup> The thick solid curve is the total solubility of gibbsite.

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#### NRC RAI #24 (Cont.)

Van Straten and De Bruyn [10] [1984] reported that when a suspension of aluminum hydroxide in water is aged at a pH of 7 or higher, it undergoes a two-step aging process: amorphous aluminum hydroxide transforms into poorly ordered boehmite (pseuoboehmite), which in turn transforms into bayerite, the stable polymorph. It has also been shown that supersaturated aluminate solutions form the most-soluble phase first, become saturated with that phase, and subsequently form the next soluble phase. This process follows the Ostwald rule of stages<sup>4</sup>. For example, in a solution supersaturated with respect to amorphous  $Al(OH)_3$ , pseudoboehmite, and bayerite (phases in order of decreasing solubility), amorphous  $AI(OH)_3$  will form first, then pseudoboehmite, and finally bayerite. Upon aging of the precipitate, amorphous Al(OH)<sub>3</sub> will convert first to pseudoboehmite, which will subsequently convert to bayerite. In experiments in which solutions of aluminate ions were titrated with acids at various rates, they found that the formation of a crystalline phase was favored by very low titration rates, with amorphous phases being favored at high titration rates. They also noted that an amorphous phase was formed immediately once a critical value of the supersaturation was reached and if the titration speed was quite rapid. The degree of supersaturation in these tests was (pAI – pOH  $\leq$  –1.9). Based on this conclusion, the supersaturated aluminum concentration required for precipitation should be greater than 2.1 mg/kg at pH 7 and 25°C, which is 100 times higher than the solubility of crystalline aluminum hydroxides (Figure 24-2).

Anions present during aluminum hydroxide precipitation can be absorbed by the aluminum hydroxide gel and may stabilize or destabilize the colloid. Studies have shown that the crystallization of gibbsite from amorphous aluminum hydroxide can be greatly inhibited by the presence of sulfate, silicic acid, and citric acid [Klasky et al., 2006 [12]]. It has been reported that nitrate has a rather weak effect, and perchlorate has no effect at all [Klasky et al., 2006 [12]].

There is significant data in the literature to indicate a strong interaction between boron and aluminum, which can lead to a significant increase in the solubilities of both gibbsite and boehmite (up to factors of 6) [Klasky et al., 2006 [12]]. One study of the adsorption of boron onto aluminum hydroxide surfaces found that the boron present in the aluminum hydroxide get was held predominantly on the surface as a specifically absorbed ion. Aging studies showed that the adsorption of boron onto the aluminum surface precluded crystallization. Kinetic experiments using pressure-jump-relaxation have also shown that boron adsorbs as an innersphere complex on aluminum oxide via a ligand exchange of borate with surface hydroxyl groups [Toner and Sparks, 1995 [13]]. The pzc for the AI(OH)<sub>3</sub> free of any specifically adsorbed anions was 9.72, whereas for the boron-containing gel, the the point-of-zero-charge<sup>5</sup> (pzc) was found to be 7.57-8.14. As a result, the presence of boron may significantly change the flocculation behavior of the aluminum hydroxide or oxyhydroxide. For tests carried out in the pH range 7.5-10.0, close to the pzc of Al(OH)<sub>3</sub>, the behaviour of the precipitate will be a strong function of pH, and the adsorption of borate ion could promote flocculation. Klasky et al. [12] recommended that equilibrium calculations for the ICET test conditions consider the aluminumborate complex in order to properly assess the effects of the presence of borate ion in the test solution on aluminum solubility.

<sup>&</sup>lt;sup>4</sup> The Ostwald rule of stages predicts that the thermodynamically least stable phase should form first, followed by the more thermodynamically stable phases.

<sup>&</sup>lt;sup>5</sup> pH at which a colloid particle surface has no net charge.

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#### NRC RAI #24 (Cont.)

While boron was identified as a constituent of some of the precipitates, it was unclear whether the boron was present as part of an aluminum-boron compound, or adsorbed on the surface of an aluminum hydroxide or oxyhydroxide. If the latter is the case, then the presence of boron may have significantly changed the flocculation behavior of the aluminum hydroxide or oxyhydroxide, and the surface chemistry of the precipitates must be considered. For tests carried out near the pzc, the behavior of the precipitate will be a strong function of pH, and the adsorption of borate ion could promote or prevent flocculation.

Most of the studies of aluminum hydroxide precipitation carried out under (PWR) post-LOCA sump water conditions have shown that the solubility of aluminum in these solutions is higher than the reported solubilities of the crystalline phases. Aluminum concentrations in solution under simulated PWR sump water chemistry conditions can be as much as three magnitude higher than the solubility of crystalline phases. This is probably due to the slow precipitation kinetics and the presence of dissolved boron species or other impurities in the solutions. The resulting supersaturated aluminum solutions are most likely to precipitate amorphous phases under PWR sump water chemistry conditions.

Table 24-1 summarizes most of the available AI solubility data under PWR post-LOCA sump water conditions, as a function of solution pH. Graph 24-4 has been divided into a "Precipitation" and a "No Precipitation" region based on the data. The data strongly suggest that, at a given pH, precipitation does not occur at AI concentrations in the "No Precipitation" zone.

Source	[B] (mg/L)	Temperature (°C)	рН	Solubility (mg/L)
CR-6915 pg 74	2800	60	9.3	126
CR-6915 pg 74	2800	60	8.7	80
ICET 1	3120	60	10	380
ICET 5 (max)	2860	60	8.5	54
ICET 5 (min)	2860	60	8.5	34
CR-6913 C5	2800	60	10	260
CR-6913 C5	2800	60	9.8	115
CR-6913 C5	2800	60	9.5	60
CR-6913 pg 63	2800	60	9.6	53
CR-6913 pg 63	2800	60	9.6	35
CR-6913 pg 63	2800	60	9.6	49
Feb 15 2007	4500	38	8.4	50
AECL	2800	25	7	20
WCAP-16785	2500	60	8.14	98.4

#### Table 24-1

#### Summary of Relevant AI Solubility Date Under PWR Post-LOCA Sump Water Conditions

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#### NRC RAI #24 (Cont.)

The initial Argonne National Laboratory (ANL) head loss testing of aluminum hydroxide precipitates were performed with surrogates proposed by industry or by forming precipitates insitu using aluminum nitrate, Al(NO<sub>3</sub>)<sub>3</sub>, as the source of dissolved Al. In a post-LOCA environment, however, the precipitates would be formed in-situ with the source of the Al being dissolution of AI by corrosion of AI metal. In this respect, sodium aluminate is a much more representative aluminum source in alkaline solutions, as the aluminum ions released by Nitrate ions would not likely be present at concentrations corrosion would hydrolyse. comparable to those obtained when AI(NO<sub>3</sub>)<sub>3</sub> is the source of dissolved AI. Recently, ANL performed a series of head loss tests in which the source of AI being corrosion from AI alloy plates Bahn et al., 2008d [14]. Tests were performed using Alloy 1100 and Alloy 6061. The objective of these tests was to compare the head loss resulting from precipitates formed from aluminum coupon corrosion with the head loss resulting from the use of precipitates prepared using the methodology presented in WCAP-16530-NP [Lane et al., 2006 [15]] or precipitates formed *in-situ* as a result of chemical injection.

Post-test examination of the glass fiber bed and bench top test results showed that Fe-Cu enriched intermetallic<sup>6</sup> particles were released by corrosion of the alloys and captured in the bed during the loop test. Differences in head loss behavior associated with the intermetallic particles were attributed to differences in the sizes of the intermetallic particles in Alloy 6061 and Alloy 1100. The Al corrosion vertical head loss loop tests in which the source of aluminum was the corrosion of Alloy 6061 and Alloy 1100 Al plates suggested that the solubility of aluminum in these tests was lower than that measured in tests where the source of aluminum was chemical addition. It was suggested that this was due to heterogeneous nucleation of Al hydroxide on intermetallic particles and/or on the surfaces of pre-existing Al hydroxide precipitates. It was concluded that the potential for corrosion of an Al alloy to result in increased head loss may be dependent on its microstructure, i.e., the size distribution and number density of intermetallic particles, as well as on the Al release rate.

The solubilities were obtained from Figure 24-4, which summarizes the available data on Al solubility in borated water presented by Bahn et al. [2008d [14]]. This map of precipitation space is similar to the one developed by Guzonas [16], but the data are represented as pH + p[Al], allowing the two variables, pH and Al concentration, to be plotted against temperature in a single graph. In the figure, a filled symbol indicates Al hydroxide precipitation was observed at that condition and an open symbol indicates Al hydroxide precipitation was not observed. The following data are included:

- Data from ANL's long-term Al solubility bench top test data [Bahn et al., 2008a [17]];
- Some room temperature data points from the previous ANL report [Park et al., 2006 [9] ];
- The stable Al concentrations observed in ICET-1 and 5 [Dallman et al., 2005a; Dallman et al., 2005b [18]];
- Solubility test data by Westinghouse at 140 and 200°F;
- ANL bench top test data in sodium tetraborate solution [2008b [19] ];
- The previous ANL head loss test data associated with AI hydroxide precipitates [Park et al., 2006 [9]; Bahn et al. 2008c [20] ] including the two AI plate tests described in the report [Bahn et al., 2008d [14] ] are designated as diamond symbols.

<sup>&</sup>lt;sup>6</sup> The intermetallic particles are primarily (FeSiAl) ternary compounds ranging in diameter from a few tenths of a micrometer to 10 μm.

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## NRC RAI #24 (Cont.)

The observed decrease of pH + p[AI] as a function of temperature in Figure 24-4 is a consequence of the dominant equilibrium:

$$AI(OH)_{4}^{-} = AI(OH)_{3}(s) + OH^{-}.$$
 (1)

The equilibrium constant of the reaction can be expressed as

$$K_{14} = \frac{[OH^-]}{[Al(OH)_4^-]}.$$
 (2)

Since  $AI(OH)_4^-$  is the dominant dissolved aluminum species in alkaline solution, the overall aluminum concentration is equal to  $[AI(OH)_4^-]$ . Therefore,

$$pH + p[AI] = logK_{14} + pK_w,$$
 (3)

and pH + p[AI] represents the sum of  $logK_{14}$  and pK<sub>w</sub>.

Recently, Bahn et al. (2008) reported bounding estimates of aluminum solubility in alkaline environments containing boron [36]. Their most conservative curve, which bounds all the available data, is reproduced in Figure 24-5, along with the predicted aluminum concentrations for the three V.C. Summer cases examined. At pH 8.5, the predicted aluminum concentrations in the V.C. Summer sump are a factor of 7 to 10 lower than the most conservative solubility estimate, and no precipitation is expected. At pH 7.5, the predicted aluminum concentration lies just below the most conservative solubility estimate. As both the calculated aluminum concentration and the solubility limit are considered conservative, precipitation is unlikely.

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### NRC RAI #24 (Cont.)





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## NRC RAI #24 (Cont.)



Figure 24-5 Solubility limit at 136.8 F based on the bounding estimates of aluminum solubility in alkaline environments containing boron presented by Bahn et al. (2008). The three V.C. Summer cases have been added.

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#### NRC RAI #25

Please provide a table showing, for each of the VCSNS plant-specific solubility cases evaluated, the following plant parameters: pH, temperature, amount of dissolved aluminum, and the assumed aluminum solubility.

#### SCE&G Response:

Table 25-1 lists the pH, temperature, submerged surface area, dissolved aluminum concentration and the solubility of aluminum inferred from the relevant literature data (borated alkaline water).

 Table 25-1

 Calculated AI concentrations in V.C. Summer post-LOCA sump water after 40 days.

		рН	Ten	np (F) <sup>*</sup>	Submerged	Dissolved	Assumed	
	0 ~ 2 h	2 h ~ 40 d	0 h	40 d	areas (ft <sup>2</sup> )	[Al] (mg/kg)	Solubility <sup>™</sup> (mg Al /kg)	
0 1	40.5		100	400 7		(119, 19)		
Case 1	10.5	8.5	120	136.7	417.6	10.0	127	
Case 2	10.5	8.5	120	136.7	212	5.1	127	
Case 3	10.5	7.5	120	136.7	417.6	6.27	12.7	
Temperature evolution is shown in Figure 25-1.								
"Solubility	<sup><math>^{\circ}</math> Solubility of amorphous Al(OH)<sub>3</sub> inferred from Figure 25-2 at Day 40.</sup>							

The submerged area for Case 1 and 3 is includes 6.3  $\text{ft}^2$  on aluminum know to be submerged, 219.5  $\text{ft}^2$  of aluminum without a specified location within the Reactor Building and 191.8  $\text{ft}^2$  of operating margin for future application. Case 2 covers the more realistic scenario where the aluminum without a specific location and the operating margin are reduced by one half. This is reasonable since the submerged level is 8 ft above the floor while the Reactor Building extends over 180 ft above the floor level.
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# NRC RAI #25 (Cont.)



Figure 25-1 Post-LOCA temperature evolution of V.C. Summer sump



Figure 25-2 pH + p[AI] as a function of temperature for amorphous aluminum hydroxide in borated alkaline water The calculated AI concentrations for the three V.C. Summer cases are also plotted on the graph.

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#### NRC RAI #26

To account for plant-specific chemical effects, licensees have used a number of approaches including: adding pre-mixed chemical precipitate to integrated head-loss tests; inducing precipitation in the head-loss test loop; or performing longer term tests in simulated post-LOCA environments. For those licensees using pre-mixed chemical precipitate, i.e., the WCAP-16530-NP methodology, the NRC staff has accepted the assumption of three specific precipitates based on the predicted amount and properties of these precipitates bounding other precipitates that could form following a LOCA. Given that the VCSNS analysis assumes no impact from chemical effects based solely on the assumption that aluminum hydroxide is not expected to form, provide the technical basis that shows why precipitates other than aluminum hydroxide could not form in a post-LOCA environment and affect head-loss across the sump strainer.

# SCE&G Response:

In a sodium hydroxide plant, two precipitates have typically been considered to have the potential to form in the post-LOCA sump water: aluminum hydroxide (or oxyhydroxide) and some type (usually sodium) aluminosilicate. Table 26-1 summarizes the major precipitates identified in the ICET tests; no aluminosilicate species were reported. This fact was recognized by the group that carried out the thermodynamic modeling [Jain et al., 2006 [21]]; they later repeated their modeling with the formation of aluminosilicates suppressed, as discussed below. Table 26-2 lists the precipitates formed by the cooling of various simulated sump water solutions in the Westinghouse Owners Group (WOG) single tests [Lane, 2006 [22]]. They reported the formation of aluminosilicates in three tests in which fiberglass was the starting material and the pH was 12. This is perhaps not surprising as the starting material, fiberglass, is itself an aluminosilicate; cooling a solution of its high temperature dissolution products might be expected to reprecipitate an aluminosilicate.

There was little corrosion of any of the other alloys included in the ICET tests, and it can therefore be concluded that for sodium hydroxide plants there is little likelihood that precipitates involving these metals (e.g., iron, zinc) will form.

Summary of Chemical Phases Identified during ICET Tests 1, 4, and 5 (non-TSP tests).						
Test ID	Deposit	Formula				
	tincalonite	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> 5H <sub>2</sub> O				
1	borax	$Na_2B_4O_5(OH)_4\cdot 8H_2O$				
	unknown	Compound containing AI, B, Na, CO <sub>3</sub> <sup>2-</sup>				
	unknown	Compound containing Na, B, Al				
	tobermorite	Ca <sub>2.25</sub> (Si <sub>3</sub> O <sub>7.5</sub> (OH) <sub>1.5</sub> )(H <sub>2</sub> O)				
4	calcite	CaCO <sub>3</sub>				
		N				
		·				
5	unknown	Compounds containing O, Na, Al, C, Ca Mg				
		and Si				

Table 26-1

# NRC RAI #26 (Cont.)

# Table 26-2 Precipitates Formed by the Cooling of Various Simulated Sump Water Solutions in the PWOG Single Effects Tests.

Type of Test and Conditions	Precipitate (as identified by SEM)
Precipitation from cooling, AI at pH 4	Hydrated AIOOH
Precipitation from cooling, AI at pH 8	Hydrated AIOOH
Precipitation from cooling, AI at pH 12	Hydrated AIOOH
Precipitation from cooling, other fibreglass,	NaAlSi <sub>3</sub> O <sub>8</sub> with minor calcium
рН 12	aluminum silicate
Precipitation from cooling, concrete, pH 4	Calcium aluminum silicate – Al rich
Precipitation from cooling, mineral wool, pH 4	Hydrated AlOOH
Precipitation from cooling, FiberFrax at pH 4	Hydrated AIOOH
Precipitation from cooling, FiberFrax at pH 12	NaAlSi₃O <sub>8</sub>
Precipitation from cooling, galvanized steel,	ZnSiO₄ with Ca and AI impurities
pH 12	
Mixture of TSP and cal-sil	Calcium phosphate and a silicate
Mixture of TSP and powdered concrete	Calcium phosphate with AlOOH
pH 12, 265 fibreglass with high calcium from	Sodium calcium aluminum silicate
pH 4 cal-sil	

Attempts have been made to use thermodynamic modeling [e.g., Jain et al., 2005 [23]] to predict the possible chemical species that could precipitate in the post-LOCA sump water. For example, the results of Jain et al. suggested that sodium aluminosilicate with the composition of the naturally occurring mineral analbite, NaAlSi<sub>3</sub>O<sub>8</sub> would be one of the dominant precipitating phases. However, NaAlSi<sub>3</sub>O<sub>8</sub> was not detected in the ICET tests (Table 26-1), although it was observed in the PWOG single effects testing (Table 26-2). It was noted that, while these silicates are the thermodynamically stable phases, their formation is kinetically slow.

As an example of a typical thermodynamic prediction, we can consider the potential formation of fully disordered<sup>7</sup> albite, NaAlSi<sub>3</sub>O<sub>5</sub>. Under the chemistry conditions expected in V.C. Summer post-LOCA sump water (a weak alkaline solution), the dissolved aluminum and silicon are present as  $Al(OH)_4^-$  and  $Si(OH)_4^0$ :

The thermodynamically calculated equilibrium constant for equation (1) for fully disordered albite,  $NaAlSi_3O_5$  can be expressed as [Arnorsson and Stefansson, 1999 [24]]:

$$\log K = -97.275 + \frac{306.065}{T^2} - \frac{3313.51}{T} - 28.622 \times 10^{-6} T^2 + 35.851 \times \log T$$

Where,

$$K = [Na^+][Al(OH)_4^-][H_4SiO_4^-]^3$$
,

<sup>&</sup>lt;sup>7</sup> The disordered form is expected to be less stable than the ordered form.

# NRC RAI #26 (Cont.)

and  $[Na^+]$ ,  $Al(OH)_4^-$  and  $H_4SiO_4$  are the equilibrium concentrations. At 60°C, the calculated equilibrium constant from equation (1) is K=1.11×10<sup>-20</sup> or log (K) = -19.96. Table 24-1 lists the values of the logarithm of the concentration product, log (Q) for the ICET tests.

From Table , the logarithm of log (Q) in the ICET tests are between -10 and -14, which are greater than log (K). Thermodynamically, NaAlSi<sub>3</sub>O<sub>4</sub> should precipitate from these solutions, however, none of the tests observed the precipitation of sodium aluminosilicates including NaAlSi<sub>3</sub>O<sub>4</sub> at 60°C and 25°C, probably due to kinetic factors.

Concentr	ations of Na , Ally	$O_{\Pi_{4}}$ and $S_{I}(O_{\Pi_{4}})$	and log (Q) values in	om the ICET Te	SIS
Test ID	[Na <sup>⁺</sup> ]	[Al(OH)₄] (mol/L)	[Si(OH)4°]	Log (Q)	]
	(mol/L)		(mol/L)		
Test 1	0.2391	1.41×10 <sup>-2</sup>	3.03×10 <sup>-4</sup>	-13.03	]
Test 2	0.0391	2.04×10 <sup>-4</sup>	3.21×10 <sup>-3</sup>	-12.58	7
Test 3	0.0870	3.70×10 <sup>-6</sup>	3.57×10 <sup>-3</sup>	-13.83	]
Test 4	0.5000	2.04×10 <sup>-4</sup>	6.43×10 <sup>-3</sup>	-10.57	1
Test 5	0.0609	2.00×10 <sup>-3</sup>	4.29×10 <sup>-4</sup>	-14.02	1

Table 26-3
Concentrations of Na <sup>+</sup> , Al(OH) <sub>4</sub> <sup>-</sup> and Si(OH) <sub>4</sub> <sup>o</sup> and log (Q) values from the ICET Tests.

To clarify the apparent contradiction between experimental results and modeling results, AECL reviewed the published solubility and kinetics data on the formation of some relevant aluminosilicates. These data have been used to assess the likelihood that aluminosilicates will precipitate under post-LOCA sump water chemistry conditions.

#### **Thermodynamic Considerations**

When metallic aluminum and aluminum oxide or other salts dissolve in alkaline solutions, aluminum hydroxide can be produced. The amphoteric property of aluminum hydroxide makes it dissolve readily in strong acids and bases as shown in Figure 26-1. In the absence of any species that can form complexes with aluminum, the dominant aluminum species is  $AI(OH)_3$  between pH 7 and 9, while above pH 9, the dominant aluminum species in solution is hydrated aluminum ion,  $AI(OH)_4$ , with a regular tetrahedron structure when the concentration of aluminum is well below 0.1 mol/L [Arson, 1982 [25]].

As silicates or silica dissolve in water, various silicon species can be present depending on the pH of the solutions:

$$H_4SiO_4 = H_3SiO_4^- + H^+$$
(1)

$$H_3 SiO_4^- = H_2 SiO_4^{2-} + H^+$$
 (2)

$$H_2SiO_4^{2-} = HSiO_4^{3-} + H^+$$
 (3)

$$HSiO_4^{3-} = SiO_4^{4-} + H^+$$
 (4)

$$2H_4SiO_4 = H_6Si_2O_7 + H_2O$$
 (5)

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$$H_2O + 2SiO_4^{4-} = Si_2O_7^{6-} + 2OH^{-}$$
 (6)

Over the pH range 6.8 to 9.3 at  $25^{\circ}$ C, the dissolved silicon species are dominantly H<sub>4</sub>SiO<sub>4</sub> [Wilkin and Barnes, 1998 [26]]. Like Al(OH)<sub>4</sub>, the basic structure of the silicon species is tetrahedral.



Figure 26-1 Solubility of  $Al(OH)_3$  as a function of pH [Wefers and Bell, 1972 [27]].

When aluminum and silicon species are both present in aqueous solution, polymerization of aluminum and silicon similar to the polymerization of silicon species shown in Equations (5) and (6) can occur to form various aluminosilicates. Depending on the Al/Si ratio and the pH of the solution, aluminosilicates such as feldspars, nepheline and zeolites can be produced, in which the molar ratio of Al/Si ranges from 0 to 1. The molar ratio of Al/Si in aluminosilicates usually follows Löewenstein's law [Löewenstein, 1954 [28]], which states that an AlQ<sub>4</sub><sup>5-</sup> tetrahedron cannot be connected with another AlQ<sub>4</sub><sup>5-</sup> tetrahedron by a common oxygen atom. Hence, the maximum Al/Si ratio in aluminosilicates is 1:1, and the silicon and aluminum tetrahedra alternate to form an ordered framework.

The solubilities of aluminosilicates depend on various factors including material structures, pH, temperature, Si/AI ratio and ionic strength. In alkaline solutions, a high pH generally increases the solubility of aluminosilicates; in acidic solutions, increasing acid concentration destroys the framework of aluminosilicates and increases the solubility. Figure 26-2 shows the solubility of nepheline (NaAlSiO<sub>4</sub>) glass at 25°C as a function of pH. Near neutral pH, nepheline has the lowest solubility; this behavior is also observed from the solubility data for jadeite and albite glasses [Hamilton, 2001 [29]]. The effect of temperature on the solubility of aluminosilicates appears to be not well understood. Both positive and negative temperature coefficients of solubility have been reported, even for same type of material (Figure 26-3).

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Figure 26-2 Solubility of nepheline glass as a function of pH at 25°C.



Figure 26-3 Solubility of amorphous sodium aluminosilicate NaAlSiO₄ in 3 M NaOH as a function of temperatures. Squares are from Mensah et al. [2004] [30]; Circles are from Ejaz and Jones [1999] [31].

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# NRC RAI #26 (Cont.)

#### Kinetics of Aluminosilicate Precipitation

The post-LOCA sump water in a PWR is not an equilibrium system; the physical and chemical conditions change over the strainer mission time. Therefore, predictions based on equilibrium thermodynamics are unlikely to give accurate predictions concerning the formation of precipitates due to chemical effects. Instead, precipitate formation will be dominated by processes such as supersaturation, heterogeneous nucleation, colloid stabilization, and gel formation, leading to the formation of amorphous or poorly crystalline phases [Torres, 2006 [32]]. These phases are far more soluble than the thermodynamically most stable phases for the specified conditions. Typically, the nucleating phase possesses the lowest interfacial free energy of all candidate phases, with recrystallization to form more stable phases taking place over timescales longer than the period of coolant recirculation. These mechanisms must be taken into account when attempting to understand the behavior of chemical species in post LOCA sump water.

The crystalline aluminosilicates generally have very low solubilities in water, while the solubilities of the corresponding amorphous materials are much higher. For example, the solubility of amorphous sodium aluminosilicate is about six times that of crystalline zeolite A in 3 M NaOH solutions at 25°C [Mensah et al., 2004 [30]] although both have same chemical formula, NaAlSiO<sub>4</sub>. The solubility data for amorphous phases are important in understanding and predicting the formation of crystalline aluminosilicates and zeolites because amorphous phases usually form first, and these gradually transform to crystalline phases.

The mixing of alkaline aluminate and silicate solutions at particular concentrations typically results in the formation of aluminosilicate gels, which, upon heating in contact with the supernatant solution, are converted to aluminosilicates or zeolites. Gelation or precipitation may be delayed for long periods depending on the Al and Si concentration, pH, temperature and the nature of the cation. Generally, the chosen synthesis conditions are far away from the equilibrium state, and supersaturated Al and Si solutions are commonly used to speed up the nucleation during the preparation of aluminosilicates.

The relation between supersaturation ratio and induction time  $t_{ind}$ , i.e., time elapsed between mixing the aluminate and silicate solutions and the first visible sign (if any) of gel or precipitation formation, can be expressed empirically by the equation:

$$\log(t_{ind}) = A + \frac{B}{T^{3}(\log(S)^{2}}$$
(8)

where A and B are dimensionless empirical constants; T is absolute temperature; S is supersaturation ratio, defined as

$$S = \frac{[A1]}{[A1]_{eq}} \tag{9}$$

or

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$$S = \frac{[Si]}{[Si]_{eq}}$$
(10)

where [Al] and [Si] are the total concentrations of aluminum and silicon species in solution, respectively, and [Al]<sub>eq</sub> and [Si]<sub>eq</sub> are the total concentrations of aluminum and silicon species at the equilibrium state, respectively. It has been found that increasing the temperature and supersaturation ratio decreases the induction time for aluminosilicate formation.

The effect of pH appears to have two opposite effects on the precipitation of sodium aluminosilicate. Thermodynamically, lowering the pH decreases the solubility and increases the supersaturation ratio. On the other hand, kinetic experiments show that sodium aluminosilicate solutions with relatively low [AI] and or [Si] concentrations (0.05 mol/kg) and low alkalinity (2 M) exhibited an extreme longevity with respect to precipitation [North et al., 2001 [33]]. This is one of the reasons that high alkaline concentrations are generally used to shorten the crystallization time of aluminosilicates [Ejaz and Jones, 1999 [31]]. In the Integrated Chemical Effects Tests (ICET), the low alkaline concentrations (pH < 12) probably make sodium aluminosilicates difficult to precipitate.

Mensah et al. [2004] [30] measured the solubility of amorphous sodium aluminosilicate and crystalline zeolite at different aluminum concentrations. They found that increasing the aluminum concentration decreases the solubility of aluminosilicates.



Figure 26-4 Solubility of amorphous sodium aluminium silicate (NaAlSiO<sub>4</sub>) as a function of aluminium concentration at 30 and  $65^{\circ}$ C. The base solution contains 4.0 M of NaOH, 1.0 M NaNO<sub>3</sub> and 1.0 M NaNO<sub>2</sub> [Mensah et al. 2004].

Park and Englezos [2001] [34] measured the concentrations of AI and Si in various equilibrium states and constructed a useful solubility map to predict the precipitation conditions for sodium

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aluminosilicates (Figure 26-5). It can be seen that the concentration of aluminum decreases with increasing concentration of silicon in the solution, and vice versa.

It should be noted that the pH ([OH] = 0.89 M) in Figure 26-5 is greater than that of the ICET tests; a high pH increases the solubility of aluminosilicates. However, the dependence of the solubility of aluminosilicates on pH is weak at low hydroxide concentration ([OH] < 1 M) [Gasteiger et al., 1992 [35]; Mensah et al. 2004 [30]].

Preliminary modeling, carried out before the first ICET results were available, used input values from peer-reviewed literature (corrosion/dissolution rates) and the ICET test plan (surfaces areas, water composition) [Jain et al., 2005 [23]]. It was assumed that the system was in thermodynamic equilibrium; no kinetic information was included. The most oversaturated phase was allowed to precipitate. The reactions were limited to those materials used in the ICET tests and excluded the uptake of  $CO_2$  from air. At pH 10, various amounts of silicate species were predicted to form over time; the species predicted included  $CaSiO_3$ ,  $Ca_2Mg_5Si_8O_{22}(OH)_2$ ,  $ZnSiO_4$ ,  $SiO_2$ ,  $NaAlSi_3O_8$ ,  $Fe_3SiO_4O_{10}(OH)_2$ ,  $Ca_3FeSiO_3O_{12}$ , and  $ZnFe_3O_4$ . However, silicate phases were not observed to form in the ICET tests. It was noted that, while these silicates are the thermodynamically stable phases, their formation is kinetically slow. Aluminum hydroxide was also not detected in the ICET tests, only aluminum oxyhydroxides. Hence the simulations were repeated with the formation of silicates and aluminum hydroxide suppressed. When the revised simulations were run for ICET Test 1 [Jain et al., 2006 [21], reasonable predictions of the Al and Ca concentrations in solution were obtained for the first 720 h, after which the model overpredicted the concentrations of Al and Ca.

The concentrations of selected elements measured in the ICET carried out by Los Alamos Laboratory at the University of New Mexico are listed in Table 26-4 for the three tests applicable to sodium hydroxide used at V.C. Summer. Based on Figure 26-5 and the data in Table 26-4, it is expected that there should have been no sodium aluminosilicate precipitation in these tests, as observed.

Concentration of Selected Elements in Water Samples taken from the ICET Tests.											
Toot		Maximum concentration in water samples									
	pН	(mg/L)									
טו		AI	Fe	Ni	Cu	Zn	Mg	Si	Ca	Na	Р
Test 1	10	380	Nr	nr	1.2	1.8	nr	8.5	15	5500	nr
	(no TSP)										
Test 4	10	bd	bd	nr	0.3	bd	bd	180	50	11500	nr
	(no TSP)	`(5.5)				(0.3)					
Test 5	8.5	54	bd	nr	0.9	0.8	1	12	34	1400	nr
	(borax)										
- below detection											

Using the calculated aluminum concentration of V.C. Summer (about 2 to 10 mg Al/kg) and Figure 26-5, a silicon concentration greater than 0.1 mol/kg or 2800 mg/kg would be required for sodium aluminosilicate to precipitate. Such a high silicon concentration is unlikely in the

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V.C. Summer sump water since the dissolved silicon concentration resulting from dissolution of the various types of debris in alkaline solution is typically below 200 mg Si/kg H<sub>2</sub>O. Hence, the precipitation of sodium aluminum silicates is unlikely to occur in the V.C. Summer post-LOCA sump water.



Figure 26-5 Precipitation zones for sodium aluminosilicates at 25°C and 0.89 M hydroxide [Park and Englezos, 2001 [34]].

#### Precipitation of Carbonates under V.C. Summer Water Chemistry Conditions

In general, many metal ions  $M^{2+}$  and  $M^{3+}$  can react with  $CO_3^{2-}$  to forms carbonate precipitates,  $M(II)CO_3$  or  $M(III)_2(CO_3)_3$ , such as  $CaCO_3$  and  $Gd_2(CO_3)_3$ . However, the precipitations of carbonates under V.C. summer sump water chemistry condition (pH 7-10) are not issues because of following reasons:

- (1) The solubility of  $CO_2$  in water is low, e.g.,  $6.64 \times 10^{-6}$  mol/L at  $50^{\circ}C$ . As the temperature increases, the solubility of carbon dioxide decreases. For example, the solubility of  $CO_2$  in water at  $50^{\circ}C$  is about half of that at  $25^{\circ}C$  while at  $125^{\circ}C$  the solubility of  $CO_2$  is only 25% of the value at  $25^{\circ}C$ . The evaporation of large amounts of water can form a thick layer of steam to further prevent the dissolution of  $CO_2$  from atmosphere. It is expected that the concentration of the dissolved  $CO_2$  in V.C. Summer water is much lower than the solubility of  $CO_2$  at similar temperature.
- (2) Under V.C. Summer sump water chemistry, bicarbonate ion  $(HCO_3^{-1})$ , not carbonate ion,  $CO_3^{-2-}$ , is the major dissolved carbon species in weakly alkaline solution (Figure 26-6). For

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example, more than 70% of the dissolved inorganic carbon species are present as bicarbonate at pH 10, while below pH 9, almost all of the dissolved inorganic carbon is bicarbonate.



Figure 26-6 Inorganic carbon species distribution as a function of pH at 298 K.

(3) Al<sub>3</sub>(CO<sub>3</sub>)<sub>2</sub> and Fe<sub>2</sub>(CO<sub>3</sub>)<sub>3</sub>, if present in water, are rapidly hydrolyzed to form the hydroxides (Al(OH)<sub>3</sub> or Fe(OH)<sub>3</sub>) due to their much lower solubility.

 $AI_2(CO_3)_3(s) + H_2O \rightarrow AI(OH)_3 \downarrow + HCO_3^-$ 

 $Fe_2(CO_3)_3$  (s) +  $H_2O \rightarrow Fe(OH)_3 \downarrow$  +  $HCO_3^-$ .

(4) The possibility of the precipitation of other carbonates such as Mg<sup>2+</sup> and Ca<sup>2+</sup> carbonates was considered. It was concluded that these precipitates are not an issue for V.C. Summer, based on the following calculations:

Using pH =  $7.0 (25^{\circ}C)$  as an example, we have the following:

Solubility of CO<sub>2</sub> is 6.65×10<sup>-6</sup> at 50°C

K<sub>sp</sub>(CaCO<sub>3</sub>) =3.8 ×10<sup>-9</sup> (38°C)

 $K_{sp}(MgCO_3) = 2.09 \times 10^{-5} (50^{\circ}C).$ 

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The use of the K<sub>sp</sub> for CaCO<sub>3</sub> at 38.8°C (only available data) instead of 50°C should not affect the conclusion because the temperature change, and hence the K<sub>sp</sub> change, in going from 38.8 to 50°C is not large. All K<sub>sp</sub> values are from Martel [1964].

Based on the distribution in Figure 26-6, the calculated carbonate concentration at pH 7 is:

 $[CO_3^{2-}] = 1.31 \times 10^{-8} M.$ 

The required minimum [Ca<sup>2+</sup>] for CaCO<sub>3</sub> precipitation is:

$$[Ca^{2^+}] = K_{sp}/[CO_3^{2^-}] = 3.8 \times 10^{-9}/1.31 \times 10^{-8} = 0.29 \text{ M}$$

The required minimum [Mg<sup>2+</sup>] for MgCO<sub>3</sub> precipitation is:

$$[Mg^{2^+}] = K_{sp}/[CO_3^{2^-}] = 2.09 \times 10^{-5}/1.31 \times 10^{-8} = 1.59 \times 10^3 M.$$

Similar calculations can be carried out at pH 7.5 and 8.5. The pH values of the three V.C. Summer cases examined are reported in Table 26-5.

Minimum Mg <sup>2+</sup> and Ca <sup>2+</sup> concentrations for precipitation of MgCO <sub>3</sub> and CaCO <sub>3</sub> .					
рН	[CO <sub>3</sub> <sup>2-</sup> ] (M)	[Mg <sup>2+</sup> ]	[Ca <sup>2+</sup> ]		
7	1.31×10 <sup>-8</sup>	1.59×10 <sup>3</sup>	0.289		
7.5	1.31×10 <sup>-7</sup>	1.59×10 <sup>2</sup>	0.0289		
8.5	1.31×10 <sup>-5</sup>	1.59	2.89×10 <sup>-4</sup>		

Table 26-5

At pH 7.5, it is not possible for the [Ca<sup>2+</sup>] and [Mg<sup>2+</sup>] in the V.C. Summer sump to reach the required values, and precipitations of CaCO<sub>3</sub> and MgCO<sub>3</sub> is not expected. For pH 8.5, the precipitation of MgCO<sub>3</sub> is impossible because the dissolved magnesium concentration in the V.C. Summer sump water cannot reach the required value. However, the dissolved calcium concentration required for precipitation at pH 8.5 is only 2.89×10<sup>-4</sup> mol/kg or 16 mg/kg. Particulate CaCO<sub>3</sub> precipitation was observed in one ICET; however, the precipitated calcite was from the cal-sil samples used in the test. Typically, for precipitation of calcium carbonate to occur, an empirical law requires that the supersaturation degree is greater than 10, i.e., the concentration of Ca<sup>2+</sup> should be greater than 160 mg/kg. Based on the materials used in V.C. Summer, such a high concentration of calcium is unlikely. Hence, the precipitation of calcium carbonate at V.C. Summer is unlikely to happen.

The analysis completed for V.C. Summer confirms that chemical precipitants are not expected to contribute to strainer head loss under post-LOCA conditions. Based on the analysis, the need for plant specific chemical effects head loss testing is not supported.

# Reference List for Chemical Effects RAI #24, #25 and #26

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- [2] US NRC, V.C. Summer, Request for Additional Information, Supplemental Response Dated 2/29/2008 to Generic Letter (GL) 2004-02.
- [3] AECL Proposal No. GNP-700844-006, "NRC Requests for Additional Information (RAI) on Supplemental Response Dated 2/29/2008 to Generic Letter (GL) 2004-02", 2009 April.
- [4] Fisher, N.J., Cheng, Q., Haque, Z., "Large-Scale Testing for Replacement Passive-Design Sump Strainers – Reflective Metal Insulation Blockage and Thin Bed Tests", AECL Test Report V.C. Summer-34325-TR-001 Rev. 1, 2007 November.
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# LIST OF COMMITMENTS

The following table identifies those actions committed to by VCSNS in the Response to Request for Additional Information for Generic Letter 2004-02. Any other statements in this submittal are provided for information purposes and are not considered regulatory commitments. Please direct any questions regarding these commitments to Mr. Bruce L. Thompson, Manager Nuclear Licensing at VCSNS, (803) 931-5042.

	REGULATORY COMMITMENT	DUE DATE
1.	VCSNS will perform comparison testing between Marinite and Tempmat to verify fiber loading and submit the tests results to the NRC.	December 31, 2010
2.	VCSNS will meet with the NRC Staff at Westinghouse to review and discuss WCAP-16571-P, "Test of Pump and Valve Surface to Assess the Wear from Paint Chip Debris Laden Water for Wolf Creek & Callaway Nuclear Power Plants", July 2006.	Schedule to be arranged based on NRC, VCSNS and Westinghouse personnel availability.
3.	VCSNS will perform plant specific chemical effects head loss testing and submit the results to the NRC.	December 31, 2010